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Clinical Interviews Shed Light on Relationships Between Next Generation Science Standards Dimensions in Upper Elementary Students

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CLINICAL INTERVIEWS SHED LIGHT ON RELATIONSHIPS BETWEEN NEXT GENERATION SCIENCE STANDARDS DIMENSIONS IN UPPER ELEMENTARY STUDENTS

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The Next Generation Science Standards (NGSS) call for the use of classroom discourse and investigation into the relationships between their dimensions of science education. This study investigated how upper elementary students use the dimensions when responding to interview questions involving real world data. Results indicate a strong relationship between these responses and the demonstration of the scientific practice of *constructing explanations and designing solutions*. To support this practice, students primarily drew upon the scientific concepts of *cause and effect: mechanisms and explanation* and *systems and system models*. When these concepts were utilized at or above grade level, as determined by the NGSS progression matrices, they routinely resulted in a scientific explanation or solution that was also at or above grade level. Additionally, when students used multiple scientific concepts when giving a response, they repeatedly demonstrated scientific explanations or solutions at or above grade level. This research reinforces the importance placed on the relationship between crosscutting concepts and science and engineering practices found in the NGSS. This work has been accomplished with support by National Science Foundation Grant #1316660.

CLINICAL INTERVIEWS SHED LIGHT ON RELATIONSHIPS BETWEEN NEXT GENERATION SCIENCE STANDARDS DIMENSIONS IN UPPER ELEMENTARY STUDENTS

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S. T. M.

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CHAPTER I

THE PROBLEM AND ITS BACKGROUND

Statement of the Problem

The new *Framework for K-12 Science Education* (henceforth referred to as the *Framework*) provides a research driven, comprehensive foundation of scientific and engineering concepts and practices to aid educators in their practice. How do upper elementary students use these practices and draw upon scientific concepts when discussing real world data? With what degree of complexity do students use these practices and concepts when engaged in scientific discourse around real world data? What interaction exists between the practices and concepts? These questions are the foci of this manuscript.

Study Rationale

A review of the *Framework* and the resulting Next Generation Science Standards (NGSS) reveals two important themes that guide this investigation. First, the *Framework* suggests that science education is most successful when three dimensions of science (science and engineering practices [SEPs], crosscutting concepts [CCCs], and disciplinary core ideas [DCIs]) are taught simultaneously. These dimensions support, inform, and rely on each other to build student understanding of science. For example, the idea of combining atoms to form new substances (DCI) can be deeply understood through the practice of developing and using a model (SEP) to visualize the concept of patterns (CCC) in the repeating atoms. Second, the grade level progressions outlined for the crosscutting concepts and science and engineering practices are, “sketches … based on the committee’s judgment,” due to a lack of research evidence available (Schweingruber, Keller, & Quinn, 2012).

The *Framework* and NGSS set forth a research agenda to help expand the best practices of science education for years to come. Much of the current research related to this new framework for science education is centered on the SEPs, and primarily those of explanations and argumentation. Investigations have been conducted into the impact of assessment framing on argumentation (Berland & Hammer, 2012) and the interplay between explanations and argumentation in student talk (Falk & Brodsky, 2014; Reiser, Berland, & Kenyon, 2012). Studies have researched scientific inquiry in the science classroom by examining explanations (Ruiz-Primo, Li, Tsai, & Schneider, 2010) and even addressed the interwoven nature of the SEPs of *explanation* and *argumentation* (Berland & McNeill, 2012). These studies, however, do not investigate the relationships between practices and concepts. More needs to be done in this area to study the *Framework*’s assertion that science education is at its best when multiple dimensions are taught simultaneously.

The *Framework* points out that the grade level progressions that they put forth require more research. This current lack of research leads to statements such as Bybee’s (2011), “in elementary grades, these practices entail … mastering oral and written presentations” (p. 13). Is this an attainable goal for elementary students? Research is needed that investigates the experiences that students at all levels are having under this new framework of science education in order to establish attainable progression goals.

In this study, I intend to investigate answers students provide to interview questions regarding problems using real world data. In doing so, I will focus on two major areas; (1) how students engage in the SEP constructing explanations and designing solutions, and (2) the interaction between the SEP and CCCs when doing so. In both areas, progression matrices outlined in the NGSS will be used to analyze the student discussions. This research intends to contribute to the growing body of research on student ability levels through their use of the CCCs and SEPs.

Significance

As a result of this study, insights will be gained into how preexisting student knowledge of the CCCs, identified through the grade band indicators developed by the NGSS, relates to the construction of scientific explanations and solutions in upper elementary students. The NGSS provide a grade level progression matrix for educators regarding the CCCs and SEPs. This study will explore the how upper elementary students demonstrate knowledge of CCCs and the practice of explanation with regard to this matrix. Exploration of student ability levels along the progression matrices provided by the NGSS will add to the growing body of knowledge regarding what students should know and be able to do with that knowledge in the upper elementary grades. This knowledge is beneficial to the education research community, practicing educators as they begin adopting the NGSS, as well as teacher preparatory programs interested in laying a solid foundation in the *Framework* for pre-service teachers.

Theoretical Framework

This study uses the *Framework* and the resulting NGSS as a foundation to explore how students connect crosscutting concept knowledge and the construction of scientific explanations and solutions. The committees who have guided the future of our science education system readily admit that the research on progressions through the CCCs and SEPs is lacking (Schweingruber et al., 2012). Thus, they have called for additional research regarding where students should hypothetically lie on a continuum of scientific understanding as they grow and mature.

Research Questions

1. Using the NGSS matrices, at what level of sophistication (determined by grade band indicators) are upper elementary students engaging in the science and engineering practices and crosscutting concepts when talking about real world data?
2. When responding to questions involving real world data, in what way do students use crosscutting concepts when designing and articulating explanations and solutions?

Assumptions and Limitations

The transcripts that will be used during this research were obtained through researcher-directed interviews designed by Dr. May Jadallah to investigate the reasoning skills of upper elementary students. As such, the questions asked by the original researcher were not designed to address the desires of the current investigation, nor was there an opportunity for the researcher to probe students in areas that were directly related to the current investigation. As Welzel and Roth (1998) point out, this presents inherent problems in establishing a baseline of knowledge. Their work establishes that interviews are intricate processes whereby interviewees begin at a low level of complexity and only progresses to their maximum level of complexity through scaffolding by interviewers.

Due to this, it is possible that the resulting level of complexity demonstrated by the participants in this study reflect a lower level than would have been possible with a different interview focus.

CHAPTER II

REVIEW OF RELATED LITERATURE

The *Framework* and NGSS

In July of 2011, the National Research Council (NRC) released *A Framework for K-12 Science Education* after a multi-year development process. Since its release, the science education community (teachers, researchers, teacher educators, curriculum designers, etc…) has been engaged in studying the *Framework* and putting its recommendations into practice. What follows is an examination of the *Framework*, NGSS, and scholarly research surrounding elementary science education.

A New Standard

The development of the *Framework* was spurred by two distinct influences. First, it capitalized on the development of the Common Core State Standards for mathematics and English/Language Arts (Schweingruber et al., 2012) and their adoption by a majority of states across the United States. This movement makes states more likely to adopt a new set of national science education standards that support Common Core goals. Second, there was recognition that the existing national science education standards created in 1996 could be improved. In addition to advances in science, years of new research into science teaching and learning had been completed. The *Framework* builds on the extensive research into science education that preceded it, by emphasizing the dual goals of understanding the ideas of science and engaging in the practices of science.

Additionally, the *Framework* encourages concepts, idea, and practices to be practices over multiple years of school, focusing on increasing complexity at each successive grade level. The *Framework* provides specific guidelines which allow students opportunities to experience the process of science by engaging in both scientific *and* engineering education (Schweingruber et al., 2012), an area that previously received little attention.

Recommendations

The *Framework* recommends three dimensions around which K-12 science education curricula should be built. These are (1) a set of seven crosscutting concepts (CCCs), (2) a set of eight science and engineering practices (SEPs), and (3) a range of disciplinary core ideas (DCIs) that span wide areas of science and engineering. The authors recognize that these three dimensions cannot be independent of each other during the learning process. Instead, the *Framework* insists that instruction must include all three in order to be most effective. To this end, the committee also included their insights into how to implement and integrate the *Framework* into curricula, which resulted in the *Next Generation Science Standards* (NGSS).

Crosscutting concepts. There are a core set of concepts that pervade all disciplines of science. In addition to laying out a broad set of ideas that pervade all areas of science, these concepts outline a common vocabulary that should be spoken and referenced by educators, regardless of scientific discipline. For example, students as young as kindergarten should hear the term *cause and effect* instead of more colloquial phrases such as, “this makes this happen”. The importance of science literacy has been formally identified and discussed for decades, beginning in 1958 with the Rockefeller Brothers Fund report on education in America and continuing up through the NSTA’s

Science Anchors Project in 2010 (NGSS Lead States, 2013). The *Framework* seeks to raise the role of these dimensions, which it terms *crosscutting concepts* (CCCs).

The committee suggests that the CCCs be incorporated into every learning opportunity and referenced with a common vocabulary throughout a child's K-12 education. This common language across scientific disciplines, of which engineering is included, helps students recognize the core concepts in different contexts (Schweingruber et al., 2012). It reinforces the idea that their science courses really do build on one another even if the specific discipline they study from year to year changes. For example, teachers can discuss the concept of *structure and function* in a biology course one year (cell size), a chemistry course the following year (molecular bonding), and an engineering course the next (structural stability).

The crosscutting concepts are an important focus in the development of the NGSS. As they were incorporated into the standards, the NGSS team gained insights into the complexity of the crosscutting concepts and how they potentially influence student learning in science. Many of these understandings were already hinted at in the *Framework* (crosscutting concepts should advance in complexity across grade levels, be repeated in many different scientific contexts, include engineering at all stages, provide a common vocabulary), but some were expanded upon in the NGSS. For example, the NGSS explicitly state that, "the crosscutting concepts can help students better understand core ideas… [and] … science and engineering practices" (NGSS Lead States, 2013). The crosscutting concepts provide the tools and foundation necessary to tackle complex phenomena that students are introduced to for the first time. Similarly, as students engage in the practices of science and engineering, they potentially draw upon or build their understanding of one or more of the crosscutting concepts. They use the example of students analyzing and interpreting data (the third science and engineering practice) by looking for patterns through observations (the first of the crosscutting concepts). A classic example of this interaction between analyzing data and observing patterns can be found in the wolf/moose population interaction problem. Students are given a graph showing population numbers of wolves and moose in a given area over the course of many years. Through observing the pattern of population increase and decrease between the two populations over time, students are challenged to interpret the data and predict what would happen if one of the populations experienced a larger than normal fluctuation in its size. Their interpretation of the data largely relies on their ability to recognize the pattern that is presented to them. A firm foundation in developmentally appropriate crosscutting concepts helps students as they tackle new ideas in science and engineering and engage in more sophisticated science and engineering practices.

Science and engineering practices. Concepts are not the only principles of science that cross multiple disciplines. The way in which science is conducted is also common among different areas of science and engineering. These *ways* of conducting science are referred to by the *Framework* as *science and engineering practices*. The term *practices* is used by the committee to draw a distinction these principles and science *skills* that have been referenced in previous works guiding science education (Rutherford & Ahlgren, 1990). The *Framework* suggests that *practices*, “stress that engaging in scientific inquiry requires coordination both of knowledge and skill simultaneously” (Schweingruber et al., 2012, p. 31).

As it did with the crosscutting concepts, the NGSS lays out guiding principles that were developed after insights were gained in working with the practices. Most of these mirror the principles for the crosscutting concepts, but the NGSS committee does emphasize a new idea for the practices: “Engagement in practices is language intensive, and requires students to participate in classroom science discourse” (NGSS Lead States, 2013).

Explanations. One practice in particular, *constructing explanations and designing solutions*, deserves special attention in this review. Due to the nature of data collection (researcher-facilitated interview) and the questions given to students, this SEP will likely be demonstrated frequently. There is no singular consensus on what defines a scientific explanation, but commonalities do exist in previous research. In their work on building a stronger concept of scientific explanation, Bratten and Windschitl (2011) note that, “many philosophers of science broadly conceptualize scientific explanations as attempts to move beyond descriptions of observable natural phenomena into theoretical accounts of how phenomena unfold the way they do” (p. 641). This common foundation, however, does give rise to many different interpretations. One of these philosophical definitions is the *causal* model of explanation first put forth by Salmon (1978). This model differs from the others (covering law, statistical-probabilistic, pragmatic, and unification) in that it focuses on finding and shedding light upon the causes for phenomena (Braaten & Windschitl, 2011). When played out in the classroom, student explanations often take the form of verbal discourse. Notably, however, Ruiz-Primo, Li, Tsai, and Schneider (2010) purposefully based their research into scientific explanations around written responses instead of classroom discourse. They cite many studies which promote the benefits of written over oral responses. Their study indicated students have difficulty providing quality scientific explanations (defined as providing claim, evidence and reasoning) and suggests that "teachers themselves are not fully aware of the importance of constructing explanations in science instruction" (Ruiz-Primo et al., 2010).

Falk and Brodsky (2014) further describe an *exploratory argumentation* method, whereby students are presented with a fascinating but accessible scientific phenomenon to investigate. Students are asked to pose as many explanations as possible that address the what, how, and why of the phenomenon. If the situation calls for it, students can also be asked how they might gather evidence to support certain explanations. This method attempts to locate and substantiate the underlying causes for a scientific phenomenon, and thereby emphasizes the causal model of scientific explanation.

The ideas of Falk and Brodsky, like many others (Berland & McNeill, 2012; Berland & Hammer, 2012; Falk & Brodsky, 2014; Osborne & Patterson, 2011) do not draw a definitive distinction between the practices of explanation and argumentation. This reflects a particular viewpoint held by the science education research community on the definition of an explanation which is *explanation as justification*. This method is currently seen as one of the more popular methods of teaching scientific explanation for educators because it combines explanations with evidence-gathering and reasoning, hallmarks of the SEP of *engaging in argument from evidence*. This is contrasted by the two other uses of explanation in science education; *explanation as explication* (where students are only defining terms and situations through recall) and *explanation as simple causation* (students focus on the cause-effect relationship in an event) (Falk & Brodsky, 2014). The *Framework* asserts that science and engineering practices should be "used iteratively and in combination" (Schweingruber et al., 2012, p. 31) with one another. Thus, the SEP of *constructing explanations and designing solutions* should not be engaged in without incorporating other SEPs and CCCs when possible. This would seem to align the *Framework* with the *explanation as justification* (due to its inclusion of evidence-gathering and reasoning) and *explanation as simple causation* (due to the inclusion of the CCC of cause-and-effect) models of scientific explanations.

The *Framework* uses other terminology that can be viewed as falling in line with certain philosophical viewpoints on scientific explanations as well. It states that, "scientific explanations are accounts that link scientific theory with specific observations or phenomena" (Schweingruber et al., 2012), and expects students to be able to, "construct their own explanations of phenomena using their knowledge of accepted scientific theory", "use primary or secondary scientific evidence…to support or refute an explanatory account of a phenomenon", and "offer causal explanations" (p. 69). The author's statements can be seen to situate the *Framework* between the philosophical models of unification, where the emphasis is on using major scientific theories to support explanation, and the aforementioned casual explanation.

Future Research

The *Framework* outlines a set of six core questions that drive a research agenda for the science education in the coming years:

> (1) What are the typical preconceptions that students hold about the practices, crosscutting concepts, and core ideas at the outset? (2) What is the expected progression of understanding, and what are the predictable points of difficulty that must be overcome? (3) What instructional interventions (e.g., curriculum

> materials, teaching practices, simulations or other technology tools, instructional activities) can move students along a path from their initial understanding to the desired outcome? (4) What general and discipline-specific norms and instructional practices best engage and support student learning? (5) How can students of both genders and of all cultural backgrounds, languages, and abilities become engaged in the instructional activities needed to move toward more sophisticated understanding? (6) How can the individual student's understanding and progress be monitored? (Schweingruber et al., 2012).

The first two are focused on student preconceptions and their progression of understanding. The third addresses the student's experience as they progress through their learning path. The fourth core question points out the importance of classroom learning communities and the norms that teachers and students establish in science classrooms. Scientific discourse, which the committee claims is, "relatively rare in science classrooms at present" (Schweingruber et al., 2012), receives special attention in the classroom learning community. Finally, questions five and six address assessing instructional activities and student understanding, but each in their own way. Five tackles the gender and socioeconomic gap that exists in current science education, which six looks at how the individual student transverses his/her path through science education. Taken as a whole, these questions inform the *Framework's* key areas of research, which includes "how the full set of practices interact with understanding of the core ideas and crosscutting concepts" (Schweingruber et al., 2012). The current investigation looks to take up this charge by exploring the interaction between the SEPs and CCCs through classroom discourse.

NGSS Progressions

The *Framework* became the foundation on which new national science standards were built. The resulting NGSS were developed in partnership with twenty-six states, and have presently been adopted by eleven states. The NGSS underwent a review process by the NRC and were determined to be “consistent with the content and structure of the *Framework*” which informed them (NGSS Lead States, 2013). The NGSS adapt the concept of progressions that was originally outlined in the *Framework*. Simple tables were created (Crosscutting Concepts Matrix and Practices Matrix, referenced in Appendices B and C respectively) to help teachers quickly identify what their students should be investigating in their grade level. The *Framework* did not provide specifics of where students should be along the continuum at the end of a grade band. The NGSS expand on the progression discussion from the *Framework* and add suggested endpoints for each concept by grade band. However, the *Framework* committee is quick to point out that, “the progressions…should be treated as hypotheses that require further empirical investigation” (Schweingruber et al., 2012). The progression descriptions for the crosscutting concepts outlined by the *Framework* are representative, and should not be seen as absolute. Thus, students may experience a CCC in a more complex or simple way than the progression outlines due to factors such as personal experiences and conceptual development (Duschl, 2012). This is in contrast to learning trajectories, central to the mathematics Common Core state standards, which aim to provide research informed and validated routes to learning concepts (Confrey, Maloney, Nguyen, Mojica, & Myers, 2009).

CHAPTER III

RESEARCH METHODOLOGY

Statement of the Problem

When fourth grade students are not exposed to formal instruction based on the NGSS, what interactions exists between their use of the CCCs when generating scientific explanations and solutions to problems when interacting with real world data? Specifically, with what level of complexity do these students use the SEPs and CCCs when engaged in a clinical interview involving real world data, and are there relationships between the levels of complexity in one area and the other?

Research Design Procedures

This study will be a qualitative exploration of upper elementary student responses to questions about environmental-urban data and will be open to any insights that can be found. The analytical approach that I will take be phenomenological, as I will be exploring the experience that students have with the NGSS as they discuss a problem using real world data (Lapan, 2003). It is important to note that the interview itself was not conducted in a strictly phenomenological manner. There was no bracketing interview conducted, and the purpose of the interview was focused on spatial reasoning skills rather than purely the nature of the experience (Lapan, 2003). Therefore, it is the analysis of the textual data resulting from the interviews that will be conducted with a phenomenological mindset.

Design

This research uses data that has been collected during the pilot phase of another research study (National Science Foundation Grant #1316660). That study explores how interpreting and analyzing digital maps using Geographic Information Systems (GIS) impacts the spatial reasoning skills of upper elementary students. During the pilot study, a research assistant became the lead teacher in a fourth grade classroom for ten days. During the science and social studies time allotted to the students, the assistant taught how to use GIS to interpret and analyze digital maps.

Participants

Participants consisted of about sixty fourth grade students from a rural elementary school in central Illinois. They came from three different fourth grade classrooms at the same school. School demographics show that 96% of students are identified as White. Low-income and students with disabilities rates are both identified as 9%, and 0% of the population are identified as English-learners (Illinois State Board of Education, 2014).

Data Collection

Eight student groups were created between the three classrooms that participated in the study. Not all students who participated in the GIS study participated in the group interview process. Four group interviews were analyzed, with each group containing two students. In each instance, one member of the group was female and the other male. Each group engaged in a researcher-facilitated clinical interview and was audio-recorded. Discussions lasted approximately twelve minutes. Students were presented with real world data comparing the public transportation and non-vehicular habits of Japanese and American citizens. Following the introduction of the data, students were asked the following question, “Do you think it is good for us to use cars to get around or should we travel more using bikes, buses, and trains like Japan?” Additional prompts were prepared and used throughout the discussion to promote critical analysis of the topic (see Appendix A). These prompts and the researcher-facilitated interview process presented students the opportunity to use various SEPs including *analyzing and interpreting data*, *constructing explanations and designing solutions*, *engaging in argument from evidence*, and *obtaining, evaluating, and communicating information*. Additionally, the CCCs of *cause and effect: mechanisms and explanations*, *scale, proportion, and quantity*, *systems and system models*, and *stability and change* have been identified as potential areas that students may reference.

Researcher-facilitated interview. The method of researcher-facilitated interview used in this study addresses the assessment concerns outlined by the *Framework* and the NGSS. In his synthesis of the CCCs, Duschl (2012) says that an assessment of a concept should, “…contain many of the social and conceptual characteristics of what it means to ‘do’ science; e.g., talk and arguments, modeling and representations” (p. 37). These conversations allow students to think through explanations and solutions through discussions, critique, and argumentation; something that is difficult to obtain had data been collected through written responses.

Additionally, this method is notably different from analysis that is concerned more with student to student discussion. In this study, the discourse analyzed will primarily involve the interviewer and the interviewee, though small amounts of group talk among students is expected.

Methods

The resulting audio discussions were transcribed. The transcripts were analyzed and coded. The process of transcript analysis consists of first breaking down the interviews into units of coding, characterized as "the most basic segment … of the raw data … that can be assessed in a meaningful way" (Boyatzis, 1998). Next, it was determined if those units of coding displayed evidence of one or more SEP or expressed a knowledge or application of one or more CCC. Finally, those responses that have been coded were further categorized by assigning them to the most closely aligned NGSS grade band progression level (see Appendices B & C).

Recent methodologies used to investigate scientific discourse include Machamer, Darden, and Craver's (MDC) framework (Russ, Scherr, Hammer, & Mikeska, 2008) and the use of Toulmin's Argument Pattern (TAP) (Erduran, Simon, & Osborne, 2004). In each case, student responses were analyzed with different theoretical frameworks in mind; mechanistic reasoning and TAP respectively.

The MDC framework described the reasoning skills of first grade students engaged in scientific discussion by drawing parallels to how professional scientists search for mechanisms to account for real world problems. Russ et al. (2008) modified the MDC framework to create a coding scheme that could be applied to the classroom discourse of elementary students to analyze the depth of their mechanistic thinking. Their results demonstrate that students of a very young age have the foundational reasoning skills that are present in professional scientists, but that those skills are used sporadically (Russ et al., 2008).

In contrast, the application of TAP to scientific discourse by Erduran, Simon, and Osborne (2004) is a reworking of an established framework for analyzing argumentation. This TAP influence can also be seen in widely published science education literature in the form of the *claim, evidence and reasoning* method (McNeill & Krajcik, 2011). This has contributed to the *explanation as justification* characterization of scientific explanations that pervades the current science education landscape. The Erduran et al. (2004) study identifies five levels of increasingly more sophisticated indicators of quality argumentation. Student discourse is coded based on these indicators and the resulting data can be used, Erduran et al. states, in, “tracing improvements in argumentation over time” (p. 931). This method can be useful in identifying a baseline of argumentation ability with students.

The discourse analysis method used in this research draws influence from these studies, but has been modified to address the research questions outlined. Similar to the TAP method, I will adapt an established model, the NGSS matrices, to code the present data. I will consider both the sophistication, as with the TAP model, and the frequency of student discourse involving specific CCCs and SEPs, as with the MDC framework. This will provide insight into a baseline of student knowledge and ability.

CHAPTER IV

ANALYSIS OF THE DATA

Coding

Units of coding were established for each interview prior to coding and consisted of connected responses from individual students. Often, this would mean that two unique student responses would be combined into one unit of coding. In the following example, Student 1 (S1) finished his thought after an interjection by Student 2 (S2). The two statements from S1 are regarded as one unit of coding.

> S1: Ummm, for us it might be a little, like, car fact…
>
> S2: Challenging since we're not used to it.
>
> S1: Yeah, and car factories might go down since there would be less so that would be kinda hard for those people to find different jobs.

Once the units of coding were established, a first round of coding was undertaken by the researcher. This first pass was conducted to establish the presence of CCCs and SEPs in the responses provided by the students. Each interview was analyzed, one unit of coding at a time, through the lens of one CCC or SEP at a time. If a unit of coding displayed the characteristics inherent in the CCC or SEP (see "Description" in Table 1), an "x" was placed in its corresponding CCC or SEP Excel spreadsheet cell. Once one dimension was coded for its presence in each interview, the next dimension was coded. An individual response could, and often was, coded as displaying multiple dimensions.

Copies of the original interview transcripts were created, and a second round of identical coding was done at a minimum of one week after the initial coding session for reliability analysis. Examples of units of coding from the interviews along with their associated NGSS dimensions can be found in Table 1.

Table 1

Examples of Coded Interview Statements and Their Associated NGSS Dimensions

Dimension	Description*	Example Statement
C1: Patterns	When students identify patterns (natural or man-made) and use them to identify, describe, interpret, or answer questions.	Or make 'em realize like what like, what it's doing to the planet and see ummm you know your kids or whatever you're just going to have that too, it's just going to keep getting worse and worse.
C2: Cause and effect: Mechanisms an explanation	When students investigate and explain causal relationships and the mechanisms by which they are mediated.	It means that the exhaust fumes, they go up in the air and make the atmosphere thicker so it's harder to see the stars and stuff and it heats up our planet. And it also pollutes the air... so it's harder to breathe some of the time in really polluted areas.
C3: Scale, proportion, and quantity	When students recognize what is relevant about a phenomena at different measures of size, time, and energy and recognize how changes in scale, proportion, or quantity affect a system's structure or performance.	Maybe we could, ummm, like talk to our friends or our family and try to get them to stop using cars so much, because that a pretty big mass network because they talk to their family, they talk to their...word of mouth could get around pretty far. Some people might not listen, but it might help.
C4: Systems and system models	When students define a system under study, specify its boundaries, and make explicit models that exist within that system.	And plus, they think cars get you there faster, but once too many people think that, they don't.

(Table Continues)

Table 1
Continued

Dimension	Description*	Example Statement
C5: Energy and matter: Flows, cycles and conservation	When students track changes of energy and matter into, out of, and within systems to help understand the systems' possibilities and limitations.	Oh, more exercise. Better fit people instead of people that just sit in their car and push on their foot.
C6: Structure and function	When students recognize the way in which an object or living thing is shaped and its substructure impacts many of its properties and functions.	Yeah, and trains only have certain areas, there's only, there's way more roads than there is railroad tracks so you could get to the spot more easily.
C7: Stability and change	When students identify conditions of stability and determinants of rates of change or evolution of a natural or built system.	Or make 'em realize like what like, what it's doing to the planet and see ummm you know you're kids or whatever you're just going to have that too, it's just going to keep getting worse and worse.
P1: Asking questions (for science) and defining problems (for engineering)	Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations.	But what if there was lik…what if they had like a baby. What would they do with it?
P2: Developing and using models	Scientists use models to represent their current understanding of a system (or parts of a system) under study, to aid in the development of questions and explanations, and to communicate ideas to others.	Like when you go up into outer space, usually on Earth you go through pure oxygen so you get used to it so you don't go from umm, here to pure oxygen instantly so you gradually grow into it. … Like mountain climbers. They have to get used to the high level, and then come down, down, down, and then eventually they can go up to the top.

(Table Continues)

Table 1
Continued

Dimension	Description*	Example Statement
P3: Planning and carrying out investigations	The ability to design experimental or observational inquiries that are appropriate to answering the question being asked or testing a hypothesis that has been formed.	N/A
P4: Analyzing and interpreting data	Once collected, data must be presented in a form that can reveal patterns and relationships and that allows results to be communicated effectively to others.	they have more and if, like, are you…for the graph and everything they are trying to show how exactly how it would be put if uhh they were showing as you can see this one is more than this one because this goes sixty, this goes less than sixty and this is a little more less than that one so...
P5: Using mathematics and computational thinking	Mathematics enables the numerical representation of variables, the symbolic representation of relationships between physical entities, and the prediction of outcomes in science and engineering.	If like, people could use bikes like, if it's like, five miles away you could still use a bike, because that's not that long for usually a bike, 'cause you go a lot faster. Ummm, cars you usually can use cars as like ten or twenty miles, twenty thirty and higher and also like, but something around fives and in the uhhh between one and ten you could probably just ride your bike or walk.
P6: Constructing explanations (for science) and designing solutions (for engineering)	Scientific explanations aim to shed light on phenomena, predict future events, or make inference about past events. Designing solutions involves specifying constraints and criteria, producing/testing models, selecting among alternative designs, and refining design ideas.	It might be a little bit easier for them, and a little bit harder for them because they have, like sometimes they have to wait to get on the busses, and it could be a little bit easier for them because they have uh transportation where they can just get in and go instead of just sitting in traffic for a couple of hours.

(Table Continues)

Table 1
Continued

Dimension	Description*	Example Statement
P7: Engaging in argument from evidence	Students attempt to resolve questions between peers by identifying the weaknesses and limitations of scientific claims.	Mm sort of, like, it’s not necessarily like they’re making the pollution the on the bus is really making the pollution, but like they’re making the pollution because they’re riding on it, so the bus has a reason to drive so it’s making pollution so, but if the ummm people never rode on the bus then the bus wouldn’t rid…or drive and so people then wouldn’t so then the bus wouldn’t make pollution ‘cause it’s not driving.
P8: Obtaining, evaluating, and communicating information	Reading, interpreting, and producing scientific text are fundamental practices of science. The communication of scientific or engineering findings is also critical.	Like this also surprises me because in Japan, Chinese all over the other side of country they’re like eight years ahead of us before technology but yet they still choose not to use it and decide to walk.

*All descriptions adapted from the *Framework* (Schweingruber et al., 2012).

To establish which dimensions were demonstrated most frequently by students the following process was used. First, the researcher established the percent occurrence of each dimension (CCCs and SEPs were separated into two larger groups for this analysis) in each interview and each round of coding. For example, in interview 125208 the CCC of *systems and system models* (C4) constituted twenty-two percent of the coded responses for CCCs in the first round, and seventeen percent in the second round. These percentages were then averaged together to establish how frequently the dimension was being observed (see Table 2).

Table 2

Average Percent Occurrence of CCCs and SEPs Over Two Rounds of Coding

Interview	C1	C2	C3	C4	C5	C6	C7	P1	P2	P3	P4	P5	P6	P7	P8
125208	12	25	20	20	3	17	3	9	0	0	5	14	54	15	3
130818	9	32	21	20	5	10	3	2	0	0	7	25	50	7	10
520015	5	33	19	32	4	0	7	7	1	0	12	18	37	13	13
520014	0	42	14	38	2	1	3	0	1	0	12	19	55	5	7
Average	7	**33**	**19**	**28**	4	7	4	5	1	0	9	**19**	**49**	10	8

Note. C"x" = Crosscutting concepts 1-7. P"x" = Science and engineering practices 1-8. See Table 1.

The results of this analysis indicate *cause and effect: mechanism and explanation* (C2), *scale, proportion and quantity* (C3), and *systems and system models* (C4) to be the most common CCCs, and *constructing explanations and designing solutions* (P5) and *using mathematics and computational thinking* (P6) to be the most common SEPs demonstrated by students. Based on their averages of occurrence across all interviews and multiple coding sessions, these dimensions were chosen for a second level of coding.

The second level of coding attempted to establish the level of sophistication (established by grade band indicators in the NGSS matrices) at which these selected dimensions were exhibited. During this procedure, the researcher replaced the "x" for occurrence with a 1, 2, 3, or 4. These numbers represented the four grade bands identified in the NGSS matrices (1 = K-2, 2 = 3-5, 3 = 6-8, 4 = 9-12). To determine the level of sophistication, units of coding were analyzed against grade band indicators (see Appendix B). The same procedures established for the first level of coding were applied to the second level. Example statements from the interview transcripts matched with specific grade band indicators can be seen in Table 3.

Table 3

Examples of Coded Interview Statements by Grade Band with Cited NGSS Indicators

Dimension	Grade Band	Example Statement	NGSS Indicator Cited
C2: Cause and effect: Mechanisms and explanation	K-2	I think we should use bikes and busses ‘cause cars are kinda’ everywhere and they pollute the air.	Events have causes that generate observable patterns.
	3-5	I think we should use more walking and ummm ‘cause then it’s less pollution and everything to the Earth, then.	Cause and effect relationships are routinely identified, tested, and used to explain change.
	6-8	The pollution could hurt wildlife. Like, it could kill some animals because the pollution is bad for you.	Cause and effect relationships may be used to predict phenomena in natural or designed systems.
	9-12	We can make [bus stops] not on the most important roads since if the buses stops the cars will be waiting behind it. But maybe they’ll have some side roads of the important roads and then the bus can just pull up onto that road and start driving.	Systems can be designed to cause a desired effect.
C3: Scale, proportion, and quantity	K-2	Cars. Because they can go further and they can also go faster.	Relative scales allow objects and events to be compared and described (e.g., bigger and smaller; hatter and colder; faster and slower).
	3-5	Challenging since we’re not used to it… Like people in Japan have doing this for five hundred years probably.	Natural objects and/or observable phenomena exist from the very small to the immensely large or from very short to very long time periods.

(Table Continues)

Table 3
Continued

Dimension	Grade Band	Example Statement	NGSS Indicator Cited
C3: Scale, proportion, and quantity	6-8	But it is just showing by months, so maybe different months we have, so maybe this month, these ummm, sixty months is this amount, but next sixty months Japan is lower than us or more higher. So I think it could vary on the different ones.	The observed function of natural and designed systems may change with scale
	9-12	Maybe we could, ummm, like talk to our friends or our family and try to get them to stop using cars so much, because that a pretty big mass network because they talk to their family, they talk to their...word of mouth could get around pretty far. Some people might not listen, but it might help.	The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs **and** Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).
C4: Systems and system models	K-2	Yeah, like my house we cross across a train station so like if someone was coming to visit, they would have to get off at that and then walk down the side of the road and cross over in the road and then walk down into my subdivision, which would be hard. Or if you're going the other way into town. So that would be hard.	Objects and organisms can be described in terms of their parts.

(Table Continues)

Table 3
Continued

Dimension	Grade Band	Example Statement	NGSS Indicator Cited
C4: Systems and system models	3-5	And plus, busses they only go to one point and back and they can go to lots of different locations. And if we used all busses and bikes the streets wouldn't be so crowed so you could get to places faster.	A system can be described in terms of its components and their interactions.
	6-8	That's what I was thinking, like, the more you use gas like some gas can run out really quickly and some gas can't and it involves a lot of pollution but like biking walking it's good exercise for you and its, and it can be fun too if you're doing it with a friend or going to a friend's house.	Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.
	9-12	… Like when you go up into outer space, usually on Earth you go through pure oxygen so you get used to it so you don't go from umm, here to pure oxygen instantly so you gradually grow into it. Like, if you take all the cars out at once, it's like turning you instantly into oxygen, so you might have a bad reaction. Like mountain climbers. They have to get used to the high level, and then come down, down, down, and then eventually they can go up to the top.	Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

(Table Continues)

Table 3
Continued

Dimension	Grade Band	Example Statement	NGSS Indicator Cited
P5: Using mathematics and computational thinking	K-2	Like you want to go somewhere, and then you have, and then the nearest train station is like miles away.	Use counting and numbers to identify and describe patterns in the natural and designed world(s).
	3-5	But it is just showing by months, so maybe different months we have, so maybe this month, these ummm, sixty months is this amount, but next sixty months Japan is lower than us or more higher. So I think it could vary on the different ones.	Organize simple data sets to reveal patterns that suggest relationships
	6-8	A law...that says you can only, you can only, you can only have like one car per family, because my family has two cars.	Apply mathematical concepts and/or processes (such as ratio, rate, percent, basic operations, and simple algebra) to scientific and engineering questions and problems.
	9-12	N/A	N/A
P6: Constructing explanations (for science) and designing solutions (for engineering)	K-2	they have more and if, like, are you…for the graph and everything they are trying to show how exactly how it would be put if uhh they were showing as you can see this one is more than this one because this goes sixty, this goes less than sixty and this is a little more less than that one so...	Use information from observations (firsthand and from media) to construct an evidence-based account for natural phenomena.
	3-5	We could get like hooks and some places so streetcars don’t really make that much pollution and they also take some people places.	Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem.

(Table Continues)

Table 3
Continued

Dimension	Grade Band	Example Statement	NGSS Indicator Cited
	6-8	And not as many roads, so maybe more sidewalks which would have more plants around. And if there's more trees then more oxygen, so that would be kinda good. So that would be kinda good.	Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
	9-12	N/A	N/A

Reliability

In this study, reliability was established through a modified double coding system (Boyatzis, 1998) in which the researcher coded the interview transcripts twice. The second coding sessions were conducted at a minimum of one week after the initial sessions. To establish intrarater reliability, an analysis of percent agreement on presence was conducted. This method was chosen because the assumption in this analysis is that there is not an equal likelihood of observing presence and absence of each dimension (p. 155).

Two major themes emerged from this analysis; (a) increased presence of CCCs and SEPs led to more reliability and (b) the interview that was coded first showed the lowest reliability. The most reliable dimensions were *constructing explanations and designing solutions* (P6) followed closely by *cause and effect: mechanism and explanation* and *systems and system models* (C2). These dimensions also contained the highest number of coded units. This supports the notion that frequency of occurrence is of the utmost importance when establishing reliability (Boyatzis, 1998). The lowest levels of reliability came from two areas; those with very low coded units, and from the first interview that was coded. That interview, 125208, contained only one dimension that scored a reliability rate higher than 70% (see Table 4), which Boyatzis points to as the established acceptable rate for reliability (p. 156). Incidentally, that category was *constructing explanations and designing solutions* (P6), which had its highest number of coded units for the dimension in this interview.

Table 4

Intrarater Reliability: Percent Agreement on Presence

Interview	C2	C3	C4	P5	P6
125208	50	67	43	63	71
130818	83	75	71	57	79
520015	97	44	80	76	88
520014	85	55	87	43	80
Average	79	**60**	70	**60**	80

Note. C“x” = Crosscutting concepts 2-4. P“x” = Science and engineering practices 5-6. See Table 1.

These reliability results indicate that the dimensions of *scale, proportion and quantity* (C3) and *using mathematics and computational thinking* (P5) should be excluded from more in depth analysis due to not reaching the established 70% reliability rate. All further analysis does not include these two dimensions.

Crosscutting Concepts Analysis

The interview responses given by students displayed varying degrees of sophistication when coded using the NGSS progression matrices. For *cause and effect: mechanisms and explanations,* the most common grade band indicated was 6-8 (36%) followed by K-2 (29%), 3-5 (22%), and 9-12 (13%). In total, 71% of responses given were coded at or above grade level. Likewise, *systems and system models* responses demonstrated 6-8 grade indicators most frequently. Specifically, the majority (59%) of the total responses coded for *systems and system models* falling into the 6-8 grade band. Even more surprising, only 2%, or two total units, were coded below grade level (K-2).

Science and Engineering Practices Analysis

In contrast to the CCCs, the results show that students overwhelmingly demonstrated one particular SEP over the others; *constructing explanations and designing solutions*. In three of the four interviews, *constructing explanations and designing solutions* made up more than half of the units of coding. No 9-12 grade band indicators were coded for any of the SEPs, and the most frequent level coded was 3-5. This was particularly true for *constructing explanations and designing solutions*, with 64% of the responses coded at the 3-5 level. In total, students demonstrated their understanding of this SEP at or above grade level in 93% of their coded responses.

The SEP of *engaging in argument from evidence*, which was identified as a potential area of interest in this study, was demonstrated at its highest levels in groups 125208 and 520015 (only 15% and 13% respectively). In an effort to discover any relationships between these two interview sessions and their increased levels of *engaging in argument from evidence*, a simple gender analysis was run. The researcher determined the frequency at which a male or female students provided a response that was coded as *engaging in argument from evidence*, to determine if one gender was expressing the practice more often than another. The frequency of these units of coding was low, and it was determined that no significant relationship could be established (see Table 5).

Table 5

Percent of Responses Coded for Argumentation by Gender

Interview	Male	Female
125208	48	52
520015	60	40

Relationships Between Dimensions

In order to address the NGSS call for research involving the relationships between practices and concepts, three relationships between the CCCs and SEPs were explored. The first two looked at the relationship between the coded grade band level (sophistication) of a CCC and the resulting sophistication of *constructing explanations and designing solutions* for the same unit of coding. The third analysis investigated the relationship between the use of multiple CCCs and the level of sophistication demonstrated by the practice of *constructing explanations and designing solutions*.

CCC/SEP Grade Band Level Analysis

To explore this possible relationship, the units of coding were first filtered to only display those CCCs which were at or above grade level (established by a coding of 3-5, 6-8, or 9-12 on the NGSS progression matrices; see Appendix B). Next, the researcher determined the instances when a grade level or higher instance of the SEP *constructing explanations and designing solutions* was coded in the same unit of coding as a grade level or higher CCC. From this, it was established how often a grade level or higher instance of CCC corresponded with a grade level or higher expression of the SEP *constructing explanations and designing solutions*. Results indicate that in 89% of the instances where a CCC was expressed at or above grade level, and the SEP of *constructing explanations and designing solutions* was expressed in the same unit of coding, the SEP was at or above grade level (see Table 6). When an analysis was conducted to explore if demonstration of the practice was similarly related to the expression of *cause and effect: mechanisms and explanations* or *systems and system models*, a much weaker connection was found. In this scenario, the relationships was observed in less than 55% of instances (see Table 6).

Table 6

Relationships Between Dimensions

CE and ES	
Direction of Relationship	Each Coded at or Above Grade Level (%)
Concept to practice	89
Practice to concept	48
SSM and ES	
Direction of Relationship	Each Coded at or Above Grade Level (%)
Concept to practice	89
Practice to concept	53

Note. CE = Cause and effect: Mechanisms and explanations. SSM = Systems and system models. ES = Constructing explanations and designing solutions.

Multiple Concepts Impact Explanations

The last relationship investigated looked at how coding multiple CCCs for a unit of coding impacted the SEP of *constructing explanations and designing solutions*. The analysis first established each unit of coding where more than one CCC was expressed, no matter the coded grade band. It was then determined if the practice of *constructing explanations and designing solutions* was demonstrated for that unit of coding, and if it was coded at or above grade level. Finally, an overall percentage was found that demonstrated how often expression of multiple CCCs resulted in the demonstration of *constructing explanations and designing solutions* at or above grade level. In 88% of instances where multiple CCCs were expressed, *constructing explanations and designing solutions* was demonstrated at or above grade level.

CHAPTER V

DISCUSSION

This study aims to shed light on how students use CCCs and SEPs naturally and without prior intervention when discussing real world data. Specifically, where do their responses fall on the NGSS progression matrices, and does their use of CCCs impact their demonstrations of SEPs? The results of this study indicate that fourth grade students routinely demonstrate a grade level or higher competency in the SEP of *constructing explanations and designing solutions* and the CCCs of *cause and effect: mechanisms and explanation* and *systems and system models*. Additionally, there appears to be a relationship between this SEP and the CCCs studied. Finally, the use of multiple CCCs during a response, no matter their level of sophistication, was connected to the presence and sophistication of *constructing explanations and designing solutions*.

Trends in Crosscutting Concepts

Fourth grade students in this study consistently utilized their knowledge of *systems* and *cause and effect relationships* when discussing scenarios involving real world data. When verbally responding to questions about this data, students drew upon scientific concepts in three main areas; *cause and effect: mechanism and explanation*, *scale, proportion, and quantity,* and *systems and system models*. But due to low frequency and intrarater reliability, *scale, proportion, and quantity* was not included in more in-depth analyses.

Cause and Effect: Mechanisms and Explanations

The level of sophistication in student responses involving *cause and effect: mechanisms and explanations* spanned all grade level bands. One explanation for this trend may be the inconsistency in coding for a particular indicator; "Cause and effect relationships may be used to predict phenomena in natural or designed systems" (see Appendix B). This 6-8 grade indicator was coded often due to the presence of interview prompts such as, "how do you think life would be different in America if we used bikes, buses, and trains more than cars?" (see Appendix A). Responses to such prompts typically involved predictions, but were sometimes coded under a simpler indicator such as, "cause and effect relationships are routinely identified, tested, and used to explain change" (see Appendix B). The difference here is that one indicator implies that the student is using cause and effect relationships to predict possible phenomena and the other is simply explaining the possible change using cause and effect relationships. Interrater reliability analysis involving discussion among coders would help alleviate these coding inconsistencies. These inconsistencies primarily occurred within the 3-5 and 6-8 grade bands, and as such the majority of responses (71%) were still coded at or above grade level. It is notable that fourth grade students demonstrated 9-12 indicators many times throughout the interviews. These instances occurred when students displayed the indicator; "systems can be designed to cause a desired effect" (see Appendix B). Students often devised systems that could be implemented to decrease the environmental impact of certain forms of transportation.

Systems and System Models

Not only was *systems and system models* one of the most commonly expressed dimensions, it was also coded at a 6-8 grade level in the majority of instances (59%). In addition, this concept was coded at or above grade level in 98% of instances. A high frequency of such codes can be attributed to a particular indicator which states, “Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems” (see Appendix B). Students routinely identified relationships between different systems, as seen in the following excerpt connecting transportation, health, and finances (I1 represents the interviewer):

I1: How do you think life might be different in America if we used bikes and buses more and used cars less?

S1: Umm, there ummm would be less, ummm, people having to pay and everything, ummm, and not having to pay for insurance for their car and everything, so there would be less umm money there for them to pay.

S2: You would save a lot more money and get to buy a lot, really good houses and have a happy life with your family.

S1: And, ummm it would be exercise for you, so you could umm have you could get less money but the exercise at the same time. Ummm. I think it would be if we did the buses, then that would be the only thing that people were using so they would have to just pay the little amount for the buses, but not the huge amount for buying the car and ummm insurance, and everything that you have to get on to it instead of just going on the bus and paying that little bit.

These results indicate that fourth grade students may have the ability to think about systems in a more complex way than the NGSS progression matrices indicate.

Trends in Science and Engineering Practices

The most commonly demonstrated SEP in this study was *constructing explanations and designing solutions*. In three of the four interviews, more than half of all units of coding were attributed to this practice. This emphasis can easily be explained by examining the question prompts given by the interviewer. In nearly every question, students were asked to explain the data provided or come up with possible solutions to the implications of the data (see Appendix A). Two other SEPs warrant discussion as well. First, the second most coded SEP was *using mathematics and computational thinking*. Although it ranked second in presence coding, the frequency at which it was displayed was low enough that intrarater reliability results excluded it from further analysis. Second, *engaging in argument from evidence,* which was a SEP that is often referenced in research involving classroom discourse, was not coded for at significant levels. This is attributed to the indicators for *engaging in argument from evidence* relying on interaction among peers or the interviewer. The interview protocol used resulted in sessions that followed a question-response more so than question-debate format.

Constructing Explanations and Designing Solutions

In 64% of coded responses, students demonstrated *constructing explanations and designing solutions* at grade level (3-5). Typical indicators cited include, "constructing an explanation of observed relationships," and "use evidence (e.g. measurements, observations, patterns) to construct or support an explanation or design a solution to a problem" (see Appendix B). Higher than grade level indicators (6-8 or 9-12) were coded for 26% of the time. These responses included the verbal construction of a model or representation to provide an explanation or solution, or the application of specific scientific ideas or principles, while taking into account unanticipated effects (see Table 7).

Table 7

SEP Responses Above Grade Band Level

Coded Indicator (Grade Band)	Response
Construct an explanation using models or representations. (6-8)	We can make it not on the most important roads since if the buses stop the cars will be waiting behind it. But maybe they'll have some side roads of the important roads and then the bus can just pull up onto that road and start driving.
Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. (6-8)	And not as many roads, so maybe more sidewalks which would have more plants around. And if there's more trees then more oxygen, so that would be kinda good. So that would be kinda good.

Relationships Between Crosscutting Concepts and Constructing Explanations and Designing Solutions

One key area of future research outlined in the NGSS is to investigate "how the full set of practices interacts with understanding the … crosscutting concepts" (Schweingruber et al., 2012). The results of this study indicate that when these fourth grade students (a) drew upon CCCs at grade level or higher or (b) drew upon multiple CCCs regardless of the sophistication, *constructing explanations and designing solutions* was demonstrated at or above grade level. Interestingly, the opposite statements do not show strong relationships. When a response is coded for a practice at or above grade level, there was a corresponding CCC expressed less than 55% of the time. This seems to indicate that although drawing upon the CCCs investigated at grade level or above nearly always results in *constructing explanations and designing solutions* being demonstrated at a similar level (89% of the time), *constructing explanations and designing solutions* can also be demonstrated at or above grade level without the need of a similarly sophisticated expression the CCCs investigated. Possible reasons for this result include (a) *constructing explanations and designing solutions* being coded for more often than the CCCs investigated, (b) the practice drawing from CCCs that were not investigated for sophistication in this study, and (c) the practice being coded at or above grade level when more than one CCC was coded below grade level.

Implications

Grade Level Indicators

This research indicates that upper elementary students have the ability to demonstrate certain scientific practices and utilize certain scientific concepts above their NGSS established grade bands. In the case of the two CCCs investigated (*cause and effect: mechanisms and explanations* and *systems and system models*), 6-8 grade indicators were coded more frequently than any other level. With regards to the SEPs analyzed, 6-8 grade indicators were coded for in more than a quarter of instances. The key factor behind these levels was the types of interview prompts used. This implies that proper questioning by an instructor is important when coaching students to their maximum cognitive potential.

Clinical Interview Prompt Bias

This study demonstrates how easily student responses are influenced by researcher constructed prompts. For example, had a question specifically asked for students to construct a representation or analogy to aid their explanation, more higher level indicators would likely have been coded for this practice. This serves as a caution to those who wish to use clinical interviews as a source of data for future studies in this area. Questions should be carefully constructed as to not unintentionally favor certain indicators tied to specific grade bands.

Classroom Pedagogy

Two main considerations for teachers emerge from this study. The first is that demonstration of *constructing explanations and designing solutions* is influenced by the sophistication of understanding of certain CCCs. Teachers should pay close attention to teaching the concepts of science throughout the school year, and add complexity to their instruction as they progress. Students who demonstrated a grade appropriate understanding of *systems and system models* and *cause and effect: mechanisms and explanations* consistently constructed scientific explanations or solutions with the same or higher level of sophistication. The second implication builds off of the first. Students in this study demonstrated grade appropriate explanations and solutions when drawing upon many different concepts, not just one in particular. Nearly every time students drew upon more than one concept, no matter the sophistication, during a response in which they gave a scientific explanation or solution, that practice was performed at or above grade level. These two points, when taken together, illustrate the importance of incorporating all of the CCCs into instruction as often and in as many scenarios as possible.

Professional Development and Teacher Preparation

Science education is at the cusp of transition, and adoption of the NGSS will require more than legislative mandates. Teachers, teacher education programs, and the students they serve need to believe in the proposed changes before quality implementation is reached. Research that demonstrates positive relationships between the dimensions provides teachers, new and veteran, with evidence for adopting the new system. When woven into professional development or new teacher preparatory programs, research into relationships between dimensions may influence how, when, and to what level of depth teachers adopt the NGSS.

Limitations

The main limitation with this study stems from the use of a coding scheme that was pre-determined and not specifically designed to code clinical interviews. This led to complicated choices on whether responses fit into certain grade band categories or not. In the following example, a response is coded as 9-12 for the concept of *systems and system models* due to the interpretation that the student is designing a system which will do a specific task (see Appendix B for indicator details).

I1: So what would be the solution to have more people use busses?

S1: Maybe we could, ummm, like talk to our friends or our family and try to get them to stop using cars so much, because that a pretty big mass network because they talk to their family, they talk to their...word of

> mouth could get around pretty far. Some people might not listen, but it might help.

This system design is occurring mentally, being delivered verbally, and is not being challenged or redesigned by peers. Whether this deserves to be coded as 9-12 is not entirely clear to the researcher. This limitation could be mitigated through future double coding and interrater reliability tests. Instead, intrarater reliability analyses were run. This choice removed the stage of analysis in which the observers discuss their coding rational and attempt to come to agreement on a common interpretation of the data. Although these discussions can often be frustrating, and even a counterproductive process (Boyatzis, 1998), establishing some framework for agreed upon coding could greatly improve future reliability of research in this area.

The choice of question prompts has a large impact not only on the NGSS dimensions that students exhibit, but also the sophistication (as outlined by the NGSS progression matrices) with which they respond. One example of this phenomenon can be found with the CCC of *cause and effect: mechanisms and explanations*. It was coded most frequently in the 6-8 grade band (36%), which corresponds with the first time that the progression matrix brings up the concept of making predictions using cause and effect relationships. As a result, any response coded for *cause and effect: mechanisms and explanations* that involved predictions was necessarily coded at a 6-8 grade level. The concern lies in the fact that many of the interview prompts in this study guided students to make predictions (see Appendix A). This unintentional bias can easily inflate the perceived sophistication of a dimension when conducting analysis of the interview responses. Care needs to be taken when creating question prompts for similar research to lower the potential indicator bias noted in this study.

Future Research

The current study's findings can be strengthened by future research in three distinct ways. First, the study would benefit from a larger and more diverse sample. If the same trends hold true, a larger sample size would potentially allow for reliable grade band level analysis for the other dimensions that this study found important (*using mathematics and computational thinking* and *scale, proportion, and quantity*). Second, interrater reliability analysis is the preferred method for obtaining reliable data in future studies of this nature. It is through this process that a consensus can be obtained about the grade band coding questions that were brought up in this study. Third, a similar study can be conducted with students from different age groups to reinforce the relationships found in this research. Though coding different grade band indicators is expected, similar relationship trends between dimensions are likely to be found. For example, does the expression of multiple CCCs still routinely result in grade level or higher scientific explanations and solutions with students in secondary school?

The limitations of this study present many opportunities for future research. Due to the emphasis placed on classroom discourse in the NGSS, future research should certainly include data from this form of student-student/student-researcher interaction. But if predetermined prompts are to be used, they should be designed with dimension indicator bias in mind. The creation of reliable, standardized interview prompts for such research would be beneficial to the field. This research found a relationship between certain CCCs and SEPs, and as such a series of standardized interview prompts may be necessary to obtain a more complete view of the interactions between all of the CCCs and SEPs.

Finally, it is essential that the science education community have research based learning trajectories for students. This study provides a small window into the natural abilities of fourth grade students to demonstrate certain scientific practices and reason with certain scientific concepts. Taken as they are, the results of this research indicate that fourth grade students can, for example, make predictions based on observed cause and effect relationships. This is a skill that the NGSS progression matrices only attribute to 6-8 grade students. Without research based evidence of what students are capable of doing at varying age levels, it will be difficult for the results of studies such as this one to argue for their validity.

Conclusion

Without specific intervention or emphasis, students in upper elementary grades can demonstrate certain scientific concepts and practices that make up the core of the NGSS. They can do so at or above their grade level consistently when engaging in scientific discourse around real world data. Students most often rely on their understanding of *systems and system models* and *cause and effect relationships* when providing scientific explanations or solutions. When they draw upon these concepts at a level determined by the NGSS to be grade level or higher, they routinely provide scientific explanations or solutions with a similar level of sophistication. Moreover, when students use their knowledge of more than one scientific concept in their explanation or solution, that explanation or solution is expressed at or above grade level nearly 90% of the time. This study suggests that knowledge of cause and effect relationships and/or systems and system models positively impacts upper elementary student's abilities to provide explanations and design solutions.

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APPENDIX A

GROUP COGNITIVE INTERVIEW PROTOCOL

Date:

Students' names:

- Read the basic prompt (page 2) with the students and ask the central question giving enough time for the children to respond.
- Depending on the children's response, use the prompts below.

Prompt Group IA: Students say cars

a) "Why do you think cars are a better way to travel?"
b) "Are there any ways in which cars are bad?"
c) "Are there any benefits to walking, biking, and using trains and busses instead?"
d) Have you changed your mind, do you still think that people should use cars to get around?

Prompt Group IB: Students say buses

a) "Why do you think things like bikes, buses, and trains are a better way to travel?"
b) "Are there any ways in which biking, buses, or trains are bad?"
c) "Are there any benefits to using cars instead?"
d) Have you changed your mind, do you still think that people should use bikes, buses, and trains?

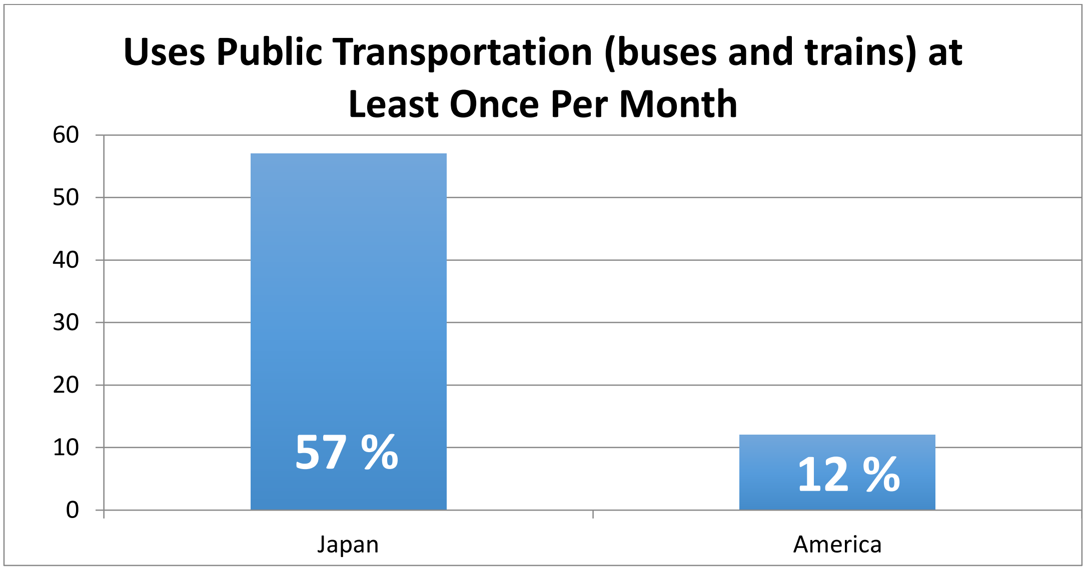
Prompt Group IC: Students say both

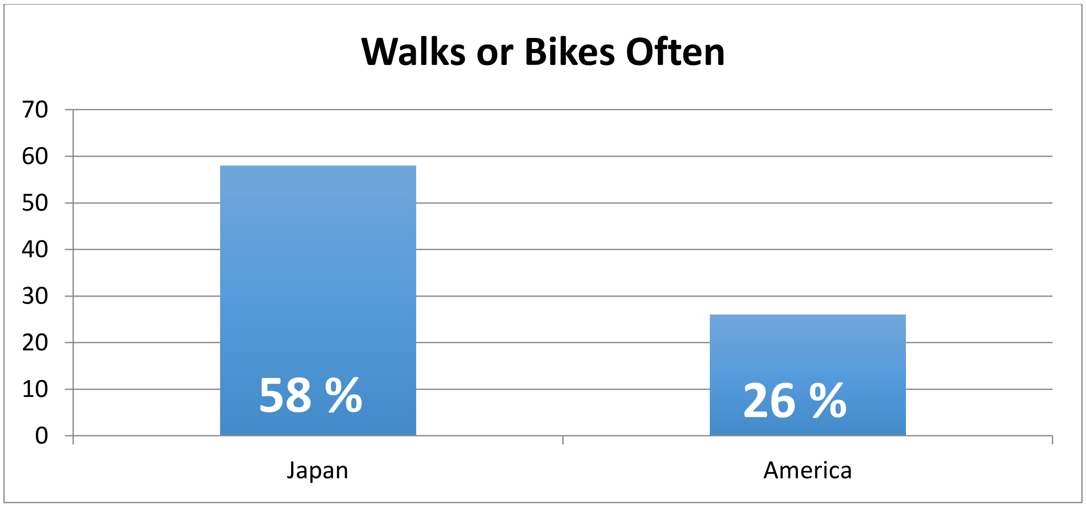
a) "What are the good things about cars? About bikes, buses, and trains
b) "What are the bad things about cars? About bikes buses, and trains?
c) "Have you changed your mind, do you still think that we should use both instead of depending completely on either of them?"

Prompt Group Two

a) How do you think life might be different in Japan because they use bikes, buses, and trains more than cars?
b) How do you think life would be different in America if we used bikes, buses, and trains more than cars?
c) What do you think we can do to start using cars less and bikes, buses, and trains more?
d) What are some specific things that you and your family can do to depend on cars less?

e) If we need to add additional bus stops to encourage people to take buses more often, where should we place the new bus stops?
f) Is there anything else you would like to say?


Uses Public Transportation (buses and trains) at Least Once Per Month


Walks or Bikes Often

In America people are more likely to use cars to travel than people in countries like Japan. People in America are also less likely to walk, bike, and take the bus or a train than people in countries like Japan.

Do you think it is good for us to use cars to get around or should we travel more using bikes, buses, and trains like Japan?

APPENDIX B

NGSS CROSSCUTTING CONCEPTS PROGRESSION MATRIX*

K-2 Crosscutting Statements	3-5 Crosscutting Statements	6-8 Crosscutting Statements	9-12 Crosscutting Statements
2. Cause and Effect: Mechanisms and Prediction – Events have causes, sometimes simple, sometimes multi-faceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.			
• Events have causes that generate observable patterns. • Simple tests can be designed to gather evidence to support or refute student ideas about causes.	• Cause and effect relationships are routinely identified, tested, and used to explain change. • Events that occur together with regularity might or might not be a cause and effect relationship.	• Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. • Cause and effect relationships may be used to predict phenomena in natural or designed systems. • Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.

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ALTERNATE ARRANGEMENT OF CROSSCUTTING CONCEPTS PROGRESSION MATRICES USED FOR THIS STUDY

Crosscutting Concept	K-2 Indicators	3-5 Indicators	6-8 Indicators	9-12 Indicators
Cause and Effect	• Events have causes that generate observable patterns. • Simple tests can be designed to gather evidence to support or refute student ideas about causes.	• Cause and effect relationships are routinely identified, tested, and used to explain change. • Events that occur together with regularity might or might not be a cause and effect relationship.	• Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. • Cause and effect relationships may be used to predict phenomena in natural or designed systems. • Phenomena may have more than one cause, and some cause and effect relationships in systems can only be described using probability.	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. • Systems can be designed to cause a desired effect. • Changes in systems may have various causes that may not have equal effects.
Systems and System Models	• Objects and organisms can be described in terms of their parts. • Systems in the natural and designed world have parts that work together.	• A system is a group of related parts that make up a whole and can carry out functions its individual parts cannot. • A system can be described in terms of its components and their interactions.	• Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. • Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. • Models are limited in that they only represent certain aspects of the system under study.	• Systems can be designed to do specific tasks. • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

Crosscutting Concept	K-2 Indicators	3-5 Indicators	6-8 Indicators	9-12 Indicators
Scale, Proportion, and Quantity	• Relative scales allow objects and events to be compared and described (e.g., bigger and smaller; hotter and colder; faster and slower). • Standard units are used to measure length.	• Natural objects and/or observable phenomena exist from the very small to the immensely large or from very short to very long time periods. • Standard units are used to measure and describe physical quantities such as weight, time, temperature, and volume.	• Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. • The observed function of natural and designed systems may change with scale. • Proportional relationships (e.g., speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes. • Scientific relationships can be represented through the use of algebraic expressions and equations. • Phenomena that can be observed at one scale may not be observable at another scale.	• The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. • Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. • Patterns observable at one scale may not be observable or exist at other scales. • Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. • Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

APPENDIX C

ALTERNATE ARRANGEMENT OF THE PRACTICES MATRIX*

Science and Engineering Practices	**K-2 Condensed Practices**	**3-5 Condensed Practices**	**6-8 Condensed Practices**	**9-12 Condensed Practices**
Constructing Explanations and Designing Solutions	*Using evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions.* • Used information from observations (firsthand and from media) to construct an evidence-based account for natural phenomena. • Use tools and/or materials to design and/or build a device that solves a specific problem or a solution to a specific problem. • Generate and/or compare multiple solutions to a problem.	*Using evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems.* • Construct an explanation of observed relationships. • Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem. • Identify the evidence that supports particular points in an explanation. • Apply scientific ideas to solve design problems. • Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.	*Constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.* • Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena. • Construct an explanation using models or representations. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	*Explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.* • Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

Science and Engineering Practices	K-2 Condensed Practices	3-5 Condensed Practices	6-8 Condensed Practices	9-12 Condensed Practices
Constructing Explanations and Designing Solutions			• Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. • Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion. • Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system. • Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. • Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and retesting.	• Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. • Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

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