Initial Problem Scoping in K-2 Classrooms (Fundamental)

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(Fundamental)

The use of engineering design as "the glue" to integrate science, mathematics, and computational thinking standards-based content is becoming more prevalent in educating K-12 students [1]–[2]. Engineering design provides students with contexts that facilitate learning and connections across disciplines [2], but also provides opportunities for students to engage in realistic problems and deepen conceptual understanding of science and mathematics concepts [3]–[5]. Furthermore, engaging students in engineering design promotes problem solving skills and an appreciation for how problems can have more than one answer and how multiple ideas and approaches can be applied to the same problem [6].

In a simplistic view of engineering design, engineers iterate between understanding the problem and developing a solution to the problem. The need to deeply understand the problem as part of the process of developing solutions is called problem scoping. Problem scoping affects the way a problem is investigated, analyzed, and eventually solved; therefore, understanding how a problem is approached is an extremely important aspect in understanding how the solutions are developed [7]–[8]. However, it has been suggested that younger students commonly rush through these beginning steps on their way to building and testing design solutions [9]. This is not only different from the ways in which experts conceptualize and engage with engineering problems but suggests that beginning designers are not recognizing the importance of understanding the problem before designing [7]. With the emphasis on engineering design within the Next Generation Science Standards [10], engineering design is becoming more common in K-12 classroom and curricula. Therefore, as more K-12 students are engaging in engineering design it is important to deepen our understanding of how students are approaching and engaging with engineering problems.

There is some research regarding pre-college problem scoping techniques; however, there is a gap in knowledge with respect to primary students. The purpose of this research is to explore problem scoping in the early stages of integrated science, technology, engineering, mathematics, and computational thinking (STEM+C) curricular units. The hope is to shed light on the developmental appropriateness of problem scoping for students in early elementary. Our research question is: What evidence exists to demonstrate K-2 students can engage in meaningful problem scoping while participating in introductory problem scoping activities from a STEM+C integration curricula?

Literature Review

While there are many different models and representations of the engineering design process, there are some core commonalities across different models: activities related to understanding the problem, activities related to developing solutions, and processes for revision and improvement. Researchers describe design as ill-defined, open-ended, and context dependent (e.g., [11], [12]). This can make design complex as there are no known right answers and the boundaries of the task are not immediately clear, but this also allows the designer freedom to explore opportunities and make decisions about how to define and constrain the problem. This process of determining what the essence of the problem is and what the boundaries are is called problem scoping.

Our understanding of problem scoping – what it entails, why it is important, and what the process looks like – is largely grounded in empirical studies of adults engaged in design. Over the past 40 years, researchers across the globe have been studying the design process and practices of practicing engineers and other design professionals. Over the past 30 years, researchers have also examined the design processes of undergraduates, as emerging design professionals. While there is now a substantial body of literature characterizing design as practiced by adults, the literature on children's design processes and practices is much more limited. While we believe that the design processes of children will be different from the design processes of adults, we also believe that understanding what design looks like as practiced by adults can help us to understand how children engage in design. Therefore, in this section we summarize key findings from studies of practitioners' and undergraduates' problem scoping behavior, and then discuss the existing research on problem scoping as practiced by children.

Research from Atman and her colleagues provide insights into why problem scoping is important for design educators to consider. "Problem scoping and information gathering are aspects of design activity that involve identifying criteria, constraints, and requirements; framing the problem goals or essential issues; gathering information; and, stating assumptions about information gathered" [7; pp. 361]. In a series of studies involving undergraduate engineering students and practicing professionals (e.g., [7], [13]), Atman and her colleagues asked study participants to "think aloud" while attending to a variety of engineering design tasks. In one set of studies, participants were asked to spend up to three hours designing a playground for a fictitious neighborhood [7], [13]. As part of the administration of the study, the study administrator was able to share more information with study participants upon request. For example, study participants could ask if anyone had surveyed neighborhood residents regarding the type of play equipment that the children might enjoy, or if there were regulations for the amount of space required between a fence and a play structure. In comparing the data collected from college freshmen, graduating seniors, and practicing professionals, Atman and her colleagues found that the practitioners spent significantly more time on problem scoping in comparison to the students, and the seniors spent more time than the freshmen. They also found that scores of the quality of participants' solutions were correlated with the amount of time spent on problem scoping. Jain and Sobek's study of student design processes and clients' satisfaction with the final project products yielded similar findings: students who spent more effort on problem scoping (i.e., gathering and synthesizing information to better understand a problem or design idea) tended to score higher in terms of client satisfaction [14]. These findings suggest both the importance of problem scoping and the need for some focus on problem scoping in undergraduate education.

While problem scoping is often associated with the beginning of a design process, problem scoping can occur throughout the design process. Several researchers have described design as a process where designer's problem space (i.e., set of ideas about and understanding of the problem) and solution space (i.e., the set of possible solutions and details about the possible solutions) co-evolve [15]–[16]. As the designer begins to develop an understanding of the problem, the designer begins to consider possible solutions, but in considering possible solutions, the designer realizes new features of the problem or realizes they need to learn more about the problem. Similarly, in studies of patterns of iterative design behaviors, Adams and her colleagues [17] observed problem scoping to occur throughout the design process.

Adams is an example of one researcher working to translate the research that has been conducted on adults' design behavior to pre-college population. Crismond and Adams [9] developed a matrix that maps key features of studies of adults' design behavior to a framework that articulates areas for scholarship of design teaching and learning. The elements within the framework also represent skills that educators might address in their design instruction. The first "Strategy" or aspect of engineering design that Crismond and Adams present in their matrix is problem scoping. Based on a synthesis of the research literature, Crismond and Adams suggest that learners initially will treat design tasks as well-defined and straightforward and not realize a need to further explore the problem. They suggest that it is important for K-16 design education to focus on helping beginning designers learn how to define criteria and constraints and facilitate a process where learners delay making design decisions until they have had time to explore and understand critical elements of the challenge.

Many models of engineering design for pre-college learners are consistent with Crismond and Adams' recommendations. In the Next Generation Science Standards, "Defining and delimiting engineering problems" is one of three core components of the design process. For grades K-2, children should be able to "Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool." This is based on the 2012 National Research Council report that suggests that by the end of grade 2, children should understand that "a situation that people want to change or create can be approached as a problem to be solved through engineering. Such problems may have many acceptable solutions. Asking questions, making observations, and gathering information are helpful in thinking about problems. Before beginning to design a solution, it is important to clearly understand the problem" [18; pp.205]. Similarly, the model of the engineering design process that is used in the Engineering is Elementary curriculum, includes problem scoping as one of five major components of design. In this curriculum, initially developed in 2003, problem scoping is presented as "Ask" and described as "ASK: What is the problem? How have others approached it? What are your constraints?" WGBH's Design Squad similarly emphasizes the importance of understanding the engineering problem in their model of engineering design [19].

Crismond and Adams [9] suggest that younger children might be especially prone to skipping problem scoping activities, immediately attempting to solve the design problem. While prior research has documented this to be true for college freshmen (e.g., [7], [20]), little research has investigated the actual problem scoping behavior of children. One study, conducted with young children in a science center, suggests that perhaps younger children are interested in engaging in problem scoping behavior (rather than skipping past it). Svarovsky and her colleagues [21] investigated the design behavior of 4-6 year-old children as they attended to design tasks with a parent. In their analysis of the design behavior of the parent-child dyads, they found that the pairs engaged in problem scoping more frequently than any of the other design activities (i.e., in 30% of the coded segments). They defined problem scoping as "understand the boundaries of the problem" (p. 6) and operationalized this to look for instances of participants identifying constraints or clarifying design goals.

In another study, Watkins and her colleagues [8] offer rich insights into the problem scoping behavior exhibited by fourth graders engaged in design as part of a classroom activity. Watkins and her colleagues analyzed video-recordings of the fourth graders' conversations and design work using a framework based on Donald Schön's theory of Reflective Practice [22] and Valkenburg and Dorst's [23] application of Schon's work in their study of practicing professionals. They argue for the importance of looking at three features of students' problem scoping: naming, setting the context, and reflecting. They describe naming as the process of identifying criteria and constraints as well as information that is gleaned through a process of "navigating the different perspectives of the players involved in the problem" [8; pp. 46]. Setting the context is described as a process where the student designer considers how different problem requirements might interact with each other, a process of balancing and prioritizing aspects of the problem, and a process of "developing a coherent sense of the problem context" [8; pp. 46]. Finally, they describe reflecting as a process of "explicitly acknowledging and evaluating the problem space" [8; pp. 46] and the decisions the designer has made about what to prioritize and consider. This framework allowed Watkins and her colleagues to relate the problem scoping behavior of the fourth graders to empirical studies of experts' design behavior. Like Svarovsky's study, Watkins and her colleagues found evidence that children can engage in problem scoping behavior that goes beyond what Crismond and Adams' hypothesized in their paper.

This study builds on this prior research, specifically in the age range between Svarovsky's study and Watkins. We build on the frameworks for examining problem scoping that were developed by these teams of researchers, but also modify Watkins et al.'s discussion of naming, setting the context, and reflecting to better fit the age of our participants and their instructional context.

Methods

This study explores if evidence exists to show that K-2 students can engage in meaningful problem scoping while participating in introductory problem scoping activities from a STEM+C integration curricula.

Participants

Using purposeful sampling, data from six different classrooms out of 17 were selected to be analyzed. These six classrooms (two kindergarten, two first grade, and two second grade) were identified based on how well the educator followed the curriculum and the amount of interactions (students to teacher and student to student) captured. All of the teachers participated in a summer professional development focused on integrated STEM, computational thinking, and the implementation of these curriculum. It is important to note that the use of a purposeful sampling technique involves the identification and selection of representative examples (Patton, 2002) from a larger data set that involved 17 K-2^{nd} grade classrooms and many hours of classroom video that was recorded over several days during the full implementation of these curriculum units.

The STEM+C curriculum was taught by the six teachers in classrooms with an average of 23 students. The classrooms are located within five public schools across three districts in the Midwest. Table 1 provides a profile of each school in the study.

Table 1: School Profiles

School	Asian	Black	Hispanic	Multiracial	White	Free/ Reduced price meals
1	7.5%	5.4%	4.1%	5.4%	77.8%	7.3%
2	0.0%	2.4%	2.2%	7.0%	88.3%	57.1%
3, 4	1.2%	16.5%	38.5%	7.3%	36.1%	73.4%
5	9.3%	6.7%	14.4%	5.4%	63.7%	31.6%
6	8.9%	6.1%	15.5%	5.1%	64.0%	41.6%

Context

This study involved three units from an integrated literacy and STEM+C curricula, called PictureSTEM (see http://picturestem.org for complete downloads of the units studied), developed for use in K-2 classrooms. Educators were asked to teach the unit that was assigned to their grade level (see Table 2 for unit overviews). The units consisted of an introductory lesson and six pairs of literacy and STEM+C integration lessons. Five main components set this curriculum apart from other commonly-implemented engineering lessons: 1) engineering design as the interdisciplinary glue, 2) engineering design to provide opportunities for student participation in problem scoping as well as solution development, 3) realistic engineering contexts to promote student engagement, 4) high-quality literature to facilitate meaningful connections, and 5) instruction of specific STEM+C content within an integrated approach.

Table 2: Unit Overviews

Grade/Unit	Unit Overview
Kindergarten, *Designing Paper Baskets*	Max and Lola want to give people who visit their rock collection a basket to collect their own rocks; however, they will not be able to make enough for everyone. In this unit, students explore patterns and investigate the strength and properties of paper before applying them to design a paper basket.
First Grade, *Designing Hamster Habitats*	Perri's Pet Palace wants to offer its customers a new pet habitat that meets all of the basic needs of a hamster. In this unit, students learn about animals' basic needs and how a habitat provides for these needs and explored characteristics of two- and three-dimensional shapes before designing a hamster habitat and exercise trail.
Second Grade, *Designing Toy Box Organizers*	Talia's Toy Box Company has received complaints from parents about how messy toy boxes can get and how hard it is for their children to find their toys without dumping out all of the toys. In this unit, students investigate standard units of measure and sort objects according to their physical properties before applying them to design a toy box organizer.

Problem Scoping in the Curricula

In the introductory lesson, educators shared a series of letters (two in kindergarten and first grade and three in second grade) with students. Kindergarten, first, and second grade students used the information from the letters to: 1) identify the client, the client's need, and why the client had that particular need, 2) ask the client questions about the problem, 3) brainstorm possible solutions, and 4) identify requirements of the solution (criteria and constraints). Second graders also helped the client define what makes a good solution and created tests to determine if the solution was successful (possessed the characteristics they identified). The information related to the problem, criteria, and constraints was recorded on large chart paper during the introduction lesson, and students revisited it throughout the unit to connect what they were learning to the problem and make updates to what they wrote as their understanding of the problem grew.

Data Collection and Analysis

Classrooms were videotaped during the implementation of the curricula. A video camera was stationed in the back of the classroom during whole class instruction, and it was repositioned to focus on a single group of students when the class worked in small groups. Researchers also used Livescribe pens that recorded audio as researchers noted their observations. For this exploratory study, only the data from the introductory lessons were analyzed. The collected video and audio data were transcribed. Two researchers independently coded the data using *a priori* coding based on the framework stated by Watkins et al. [8] and described in the literature review section of this paper. The results were classified according to their relevance with our research question, and organized in three categories: naming, setting the context, and reflecting. All names of participants used in this paper are pseudonyms. For readability, quotes from teachers and students have been minorly edited to remove extraneous words such as "um" and "like" when they do not add to the understanding of what the participants are communicating.

Limitations to the Study

This research study is designed to consider only the introductory problem scoping that happens in the kindergarten through second grade classrooms included in this study. Because of the scope of this study, there are aspects of problem scoping that happen beyond the introduction to the problem that are not included in this analysis. In addition, much of the interaction between students and teachers in the introductory lesson is related to the students answering comprehension and inference questions based on what they learned through the email interactions from the client. Due to this, during the introductory lesson for each grade level, much of the student talk is related to answering direct questions from teachers. Therefore, at this point in the curriculum, it is difficult to ascertain how much of the engineering problem the students truly understand. This means that our results and discussion are related to the types of formative information a teacher might glean while teaching the curricula. Furthermore, due to the small number of classrooms included in this case study and the fact that all classrooms were working on curricula created with similar structure for the introductory problem scoping lesson, the claims made are not generalizable but rather potential indicators of what might be expected at these grade levels in similar situations.

Results and Discussion

In order to better understand how primary students are approaching, engaging with, and understanding engineering problems, this study examined K-2 students' talk during participation in introductory problem scoping activities. The results of this study are organized based on the framework put forth by Watkins et al. [8] that provided the scaffolding of naming, setting the context, and reflecting as important aspects of problem scoping. The results will be presented using this framework.

Problem scoping: Naming

The first aspect of problem scoping that will be presented are those results related to naming. Naming is the most basic level of problem scoping in which students are identifying key aspects of the design problem such as constraints, criteria or client. Watkins et al. [8; pp. 46] define naming as, "identifying the different constraints, criteria, and pieces of information in a problem that span across different categories and arise from navigating the different perspectives of the players involved in the problem." Within our data, patterns related to naming emerged as part of three larger categories, or dimensions, that are identified as who, what, and why. When looking across the data, we saw that students in each grade level had differing levels of success with ideas associated with the naming aspect of problem scoping. Across the different dimensions of naming, the second grade students were able to identify who, what, and why, whereas the first graders and kindergarten students needed help with identifying the what and why aspects of the problem. To help illustrate these findings, we will describe the patterns and present classroom examples related to three aspects of naming which include the "who - who are the actors within the problem space", "what - what is the problem", and "why - why does the problem need to be solved."

Naming: Who are the actors within the problem space

As noted in the methods section, the introductory lesson for all three grade levels includes a series of letters that introduces students to the problem, client, client's needs, and why the client has that particular need. After reading the first letter, students in all three grades could identify the client. However, in order to get insight into students' understanding of the client, teachers often prompted students by asking, "Who is the client?", "Who needs our help?", or "Who wrote the letter?" As an example, in the first grade curriculum, the teacher and students were sitting on their class discussion rug during this exchange:

teacher:	Who needs our help? We call them the client. Who needs our help? Who are we going to be working with?
several students:	Perri.
teacher:	The fancy word for that is client.

This excerpt is representative of a common way that teachers were observed using the letter to help set up the problem by having students identify who needed their help, allowing students to answer, and providing a bit of vocabulary at the same time (e.g., client). This approach of using the letter to help identify the "who" was successful in terms of a method for helping students to identify the client, or who they were solving the problem for, across all three grade levels.

While students in all three grade levels had no trouble identifying their client, the direct understanding of the end user was not as clear to students. There was evidence of all three grade levels discussing the needs of their end user, but it was rarely named as such. For example, in the kindergarten classrooms, students had discussions with their teacher about what someone collecting rocks would need, but it was generally in the form of discussing possibilities for their client (Max) and not for the end user (kids at the nature center). Another example of where the students needed some additional prompting to move past the idea of just having the client and to consider the end user(s), could be seen in this second grade example where the teacher is facilitating a classroom discussion around the letters and client.

teacher:	Let's think back to Talia's email. Who is the person who uses the Travel With Me toybox? Rachel?
Rachel:	Kids.
teacher:	Right, kids. Who else might be affected by the Travel With Me toybox? Ariel?
Ariel:	Parents.
teacher.	Parents. So, the kids and the parents.

In both of these examples, the teacher needed to ask questions to help students revisit the letter and distinguish who was asking for help (the client) from who would be using the product. From our data, when looking at helping students to develop an understanding of who are the actors within the problem space, primary students were more readily able to identify the client but needed help from the teacher to tease out who the end user for their designs would be and that this person can be different from the client.

Naming: What is the problem and its requirements?

The second dimension of naming that arose from patterns in the data was related to the "what" or what is the problem that students are being asked to solve in this curricular unit. Analysis of this data revealed differences related to how students across the three grades engaged with this aspect of naming. Students in second grade could identify "what" without help from the teacher; however, students in first grade and kindergarten were given a few leading questions (scaffolding) to identify what the problem was that needed to be solved. The teacher scaffolding that led to success for the younger students was commonly seen through a series of teacher questions in which the students were prompted with specific and guiding questions, such as "what does the client need help with" or "what is our problem." A representative example of a teacher guiding students to the identification of the "what" aspect of naming within the engineering problem from our data can be seen in this first grade classroom. After reading the first letter, the teacher encouraged students to piece together the client's request from the letter.

teacher: Lily, what does Perri need us to do?

Lily: Help us...help her with...hamster habitats.

teacher: What does she want us to do to that hamster habitat?

Lily: Expand it.

teacher: What does expand mean? That's a big juicy word. What does that mean?

Lily: Make it bigger.

teacher: Make it bigger, so they need a bigger hamster habitat.

This transcript shows that Lily initially provides very general ideas regarding the problem. The letter focuses on hamster habitats, but the client's problem is more specific. The teacher helps to guide the student by asking, "What does she want us to do to that hamster habitat?" This brings the focus to the specific solution request from the client, which helps to focus the student's initial thoughts about the problem.

The second grade students, on the other hand, also discuss the client's request after reading the first letter, but they are able to more independently identify details related to what problem they were solving. In this second grade example, the class is processing the first letter by discussing the client and clients' needs.

teacher: What do these kids need? Damian?

Damian: Get the toys organized so they're not in a mess.

As seen above, Damian was able to recognize and identify what was needed. Across all three units, class discussion after the first letter and before the second letter is conducted specifically to allow students to define the problem for themselves before it has been explicitly stated. Despite similarities in the approaches to and activities around problem scoping across the three curricular units, there are many ways in which second grade, first grade, and kindergarten students differ related to problem scoping, and this is one example of that difference. The kindergarten and first grade students generally had trouble articulating the problem whereas second grade students did not generally struggle.

A different but related issue is seen when the kindergarten and first grade students struggle to identify the requirements of the problem solution (criteria and constraints). One of the activities within all three units asks students to raise their hand when they hear any of the problem criteria or constraints during the reading of the second, more detailed client letter. Across all three grade levels, most students easily identify the more concrete criteria; however, the kindergarten and first grade students struggle to realize that the conceptual (or abstract) criteria were also requirements of the solution. In this excerpt, we see first grade students trying to identify the criteria and constraints.

teacher:	In her letter, Perri said there are several things she wants to make sure are true about the cage. I'm going to read you her letter one more time and when you hear something that Perri wants to make sure is true, I want you to raise your hand. [*Begins to read the second email from Perri*] "The exercise trail must connect to the two openings at the back of the cage."
most students:	[*raise hands*]
teacher:	"The hamster trail must be fun and exciting for the hamster."
all students:	[*do not raise hands*]
teacher:	We don't need to pay attention to that?
most students:	No. [*or shake their heads*]

The students in this example did not struggle with naming the criteria "connect to the two openings." However, the idea of being "fun and exciting for the hamster" is a more abstract idea – so the likely explanation of their not raising their hands is that the students did not recognize "fun and exciting for the hamster" as a requirement of the solution. This pattern continued for all of the criteria described in the letter with only a few students raising their hands for the other abstract criteria – i.e., "keep the hamster happy" and "keep the hamster healthy." Within the other 3 classrooms at the kindergarten and first grade levels, we saw similar results to the example above; while at the second grade level in both classrooms, the vast majority of students raised their hands or nodded their heads to identify all requirements regardless of their concrete or abstract nature.

Naming: Why does the problem need to be solved?

The final dimension of naming that will be discussed is the "why" of the problem, or why does the problem need to be solved. This dimension of naming requires identification of the reasons behind the problem and the client's motivation for requesting help from the students which is not as explicitly stated in the letters as the who or what dimensions of the problem. This is another area in which differences in problem scoping were seen across the grade levels. First grade and kindergarten students were seen struggling on the "why" of the problem, while second grade students were able to more readily identify why their client had those needs.

This difference is illustrated through the following examples that both came during a class discussion following the reading of the first client letter and was centered around "why" they were trying to solve the problem. The first example comes from a first grade classroom, and the second example comes from a second grade classroom.

teacher:	Why does she need bigger hamster cages? [*Waits for answers.*] Because she wants to make more money?
several students:	No.
teacher:	No, why did she say we need bigger hamster cages? Kyle?
Kyle:	Um, so more hamsters could fit.
teacher:	Okay, did she say, "I have so many hamsters I don't know what to do with them?"
most students:	No. [*or shakes of the head*]
teacher:	No, she wants the hamsters to be what? Sophia?
Sophia:	Happy and healthy.
teacher:	Happy and healthy. [*Writing*] Happy…
Sophia:	And grateful.
teacher:	healthy hamsters.

When trying to get to an understanding of "why" they are trying to solve the problem, the first grade students needed more guidance to figure out why the problem needed to be solved. The first email that the students received from their client described that Perri's customers were asking for changes to the cage in order for their hamsters to have "more room to run and explore to be happy and healthy." The first student answer was centered around his own thoughts, i.e., Kyle made the connection that expanding the habitat means more hamsters could fit. In order to help students go toward a more meaningful answer, the teacher redirected them by asking a question that would help the students think about whether or not Kyle's answer matched the problem space, i.e., "did she say 'I have so many hamsters I don't know what to do with them?'" This allowed the students to move forward with ideas that were related to the content of the email. The students in this classroom never really got to the point that Perri's customers were requesting the change in the hamster habitats, but they did identify that the hamsters needed to be "happy and healthy" once scaffolded by the teacher.

In the second grade example presented during discussion of the first letter, the students were quicker to jump to the idea that they were solving this problem of the messy toy box because they were helping the toy company meet the needs of the parents.

teacher:	What is Talia's problem?

Frederick:	She wants to deal with complaints from parents that kids have messy toyboxes.
teacher:	[Writing on a poster paper] She has "complaints from parents" that they have "messy toyboxes." Frederick, that was really good. Anything else? Yes, Duncan?
Duncan:	The only one [toybox] that they [parents and kids] get is the smallest one and the messiest one.
teacher:	Yes, it's the [sic] messy.

It is interesting to note that in both this example and in the other second grade classroom, the students identified the problem as the fact that the parents had "complaints" or were "frustrated" [as seen in the other second grade classroom not presented above], rather than identifying the problem as that Talia needed something to keep the toyboxes from being messy which is more solution focused. Identifying the fact that one of the end users is complaining and that they are complaining about the messiness of the toyboxes shows that students are able to move beyond just identifying that they are designing for their client, Talia, to being able to identify reasons why the problem needs to be solved.

When looking at both of the earlier grades and the second grade classrooms, there was a clear difference in the ability of the students to recognize and pull out some of the reasons that the client is asking for their help. The kindergarten and first grade teachers provided space for the students to tell them why their respective clients needed the help of the class; however, in all 4 instances, teachers added quite a bit of scaffolding to help students get to reasons why the client needed a solution. On the other hand, both second grade classrooms had students providing reasons immediately without scaffolding.

Problem scoping: Setting the context

Setting the context is another aspect of problem scoping in which students work to develop a sense of the problem context, prioritize and examine interactions among problem requirements, and consider interactions among the criteria. This requires students to build on the identified aspects of the problem from the "naming" category ultimately creating a well-defined problem context. Within the K-2 study reported here, we found two distinct types of student talk in the introductory lessons that demonstrate versions of setting the context: relating the criteria to one another and summarizing the problem in their own words. These ideas were present in all three grade levels and in all six classrooms. One example of each has been provided here.

One way in which we saw students setting the context was through relating criteria to one another. In this excerpt from kindergarten, the teacher is leading the students through questions that allow them to identify and potentially provide additional details about the criteria and constraints of the problem. While many of the responses to the questions regarding what the baskets need to do are direct identification of the requirements from the email from the client, Gretchen adds detail beyond the criteria laid out.

teacher: What else does he want the baskets to do? Gretchen, what does he want the baskets to do?

Gretchen: He wants them to be strong enough to hold heavy rocks and make sure that they can hold wet rocks because usually, when you put water on paper, it gets really soft.

Gretchen's identification of the two criteria - hold wet rocks and be made out of paper - alone fall under naming; however, she also identified a cause and effect relationship between the wet rocks and the paper which potentially demonstrates her development of understanding of the problem context. While this is one example, we saw similar connections multiple times in all six classrooms that span all three grade levels.

Another way in which we saw students setting the context was summarizing the problem in their own words which demonstrated the beginning of the development of a coherent sense of the problem. The following two excerpts show a similar interchange in which one of the students in the class summarizes the problem that needs to be solved.

The first example is from a kindergarten classroom. In this excerpt, students have been interrupted by Kristen who holds her hand up and begins to talk about the solution rather than the problem. The teacher reminds Kristen that she has moved on to the solution, and that they need to focus on the problem. Then Alyssa chimes in with a succinct summary of one of the aspects of the problem at hand.

teacher: Yes?

Kristen: We could do like this, we could make a basket and then like a basket that looks like kind of a little… in a rock basket that has their picture so they know that it's theirs.

teacher: Well, you're getting into the plan stage, but I just want to know what their problem is. Yes?

Alyssa: They can't make a lot of baskets.

teacher: Right. That is a problem that they have.

Alyssa's response of "they [meaning Max and Lola] can't make a lot of baskets" is one of the primary reasons that these kindergarten students have been asked to develop a basket plan for Max and Lola.

The second example is from a second grade classroom. The teacher is probing the students about the problem they need to solve.

teacher: What is it that Talia needs?

Marvin: Help from us.

teacher: To do what? What is it she is wanting us to do?

Lily:	Think of a way to help kids find the toys easier.
Taylor:	And how to keep the Travel with Me toybox neat.

In this excerpt, we see the students building their problem definition as they listen to one another and add to their current ideas. Together, Marvin, Lily, and Taylor were able to articulate the overall need of the client through their own ways of thinking.

Both examples of students interacting with the teacher in these excerpts demonstrate that students at this age are able to refer back to the problem context, make sense of it, and summarize it in their own words. As one might expect, there are likely developmental differences represented by the data; the kindergarten example of reiterating the problem is less rich than the second grade example. However, the kindergarten students did provide evidence of richly describing interaction between criteria. While these examples and others from these classrooms show potential developmental differences, these examples also provide evidence that students are able to make the connections to the overall ideas in the engineering design problem.

Problem scoping: Reflecting

Within problem scoping, Watkins et al. [8] define reflecting as, "explicitly *acknowledging* and *evaluating* the *problem space* and the decisions made about what to consider and prioritize" (p. 46). Their examples of this include fourth grade students displaying a sort of meta-awareness of the problem space and how some things they are considering may or may not be important. There were not any instances of self-guided reflecting in our data, which may be due to the fact that we are just considering the introduction lesson, but we did see teachers supporting students in reflecting upon the questions or decisions they were making. We expect that, especially at these younger ages, students will need some support in reflecting. The video recorded observations of the kindergarten and first grade lessons demonstrate how reflecting is mostly scaffolded by the teacher and enacted more so by the students in the second grade classroom. It is also important to note that the data for this study is only from an introductory lesson to the problem, and there is potential for growth in this area throughout the unit.

An example of reflecting from the kindergarten classroom comes about as the teacher is showing the students a poor example of a solution to the problem. In this case, the solution needs to be able to hold rocks to be transported. The solution is a paper basket with many holes. Below is a brief exchange the teacher has with her students.

teacher:	Would this be a good basket to give them to hold rocks?
several students:	No.
teacher:	Why not?
Kristen:	Because it has holes.
teacher:	Yeah. What would happen to the rocks?

John:	They would fall out.
Elizabeth:	If they're tiny.
teacher:	Yeah, if they were tiny. We never know what kind of rocks they'll be collecting.

In this example, the teacher helps the students reflect back to the problem and evaluate the potential solution based on what is important to consider for the problem space. She helped them connect why having holes would be bad in this case by asking the question, "What would happen to the rocks?" A student then responds, "They would fall out," and another adds, "If they're tiny." The teacher then reinforces why having holes and losing small rocks out of the basket would be a negative outcome as it relates back to the problem. From this example, we cannot conclude that the students would not have made those connections on their own, but instead that the teacher took this approach to support her students.

Within the first grade classroom, the teacher attempts to provide a little less support in the development of questions for their client; however, she finds herself redirecting the conversation back to what is important in the problem space. In this example, the teacher is asking students for questions they think would be important to ask to Perri before they begin designing an expanded version of a hamster habitat. In the exchange below, we see the teacher helping a student connect her response back to the problem space:

teacher:	Julie, what question do you have for Perri?
Julie:	Happy hamsters.
teacher:	Okay so that's not a question, what about happy hamsters? We need to know...
Julie:	They're happy because they have friends.
teacher:	Okay but are they happy right now?
Julie:	(shakes head no)
teacher:	Okay so we need know what...
Julie:	To do.
teacher:	Yeah, we need to know what to do. So maybe, what makes hamsters...
several students:	Happy.

In this example, a student responds by saying happy hamsters, but not in the form of a question. The student is correctly referencing the reason why customers want an expanded habitat – so that the customers' hamsters will be happy. The teacher then asks what we would need to know, and the student responds by suggesting having friends would make a hamster happy. The teacher then brings this idea of happy hamsters back to the task at hand of what do they still need to learn, what makes hamsters happy in this case. So while there is nothing wrong with the things the student was considering, she was not able to come up with a question for Perri that might help her to get at her ideas. Questions to Perri such as “How will we know if the hamsters are happy?” or “Will having friends make the hamster happy?” would have been a way to connect the student’s ideas to the problem space and also further their problem scoping. But the student didn’t really get to the point of asking the questions to the client, so this example shows the teacher demonstrating how to reflect back to the problem space.

In the same lesson in the same classroom, we see another similar example of a student bringing up something they would like to learn, but then struggle to connect it to the problem.

teacher:	What else do you want to ask her? Trevor?
Trevor:	Are hamsters baby hamsters or grown-up hamsters?
teacher:	Okay. Why would that be an important question? That’s a great question.
Trevor:	Uh, because hamsters, when they grow up, they kind of look the same.
teacher:	Okay, they kind of look the same, so we kind of need to know if they’re big hamsters or small hamsters.
Trevor:	To fit grown-ups.
teacher:	Knowing if they’re babies or grown-ups might help us figure out how we’re going to keep them happy and healthy or how we’re going to help her solve the problem. What else do we need to ask Perri, Carly?

Trevor offers up a question about the hamster’s size, which could certainly be connected to the problem. However, when asked why it’s an important question he says that when hamsters grow up they kind of look the same. His response does not immediately appear to be relevant to the problem space, so the teacher tries to connect it back to the problem by saying that they need to know if they are big or small hamsters. Then Trevor makes a comment about fitting grown-ups, which might be a comment about what size habitat a grown-up hamster may need as compared to a younger hamster; however, we do not learn more about his reasoning or what he was thinking about the problem as the teacher wraps up the exchange with a statement that connects everything back to the problem space. Certainly, summarizing and connecting back to the problem space is good practice by the teacher, but when thinking about how to help students to move to more self-guided reflection, there may have been an opportunity to support Trevor to get there on his own.

Continuing from the previous exchange, Carly responds to the teacher:

teacher:	What else do we need to ask Perri, Carly?
Carly:	Are the hamsters pregnant?
teacher:	Are they pregnant? Why would we need to know that?

Carly: Because we need to know how old they are.

teacher: Okay maybe age. Maybe if the hamsters were pregnant, we would have to make sure that the cage was also safe. Alright one or two more questions. Ian what do you want to know?

Here we see Carly provide the question about whether or not the hamsters are pregnant, which she then connects to needing to know how old they are. This appears to be an extension of Trevor's idea, but again without a clear explanation connecting it back to the problem space. Again, we see the teacher connect it to a potential criteria of being safe (which was not alluded to in the client email). These sorts of exchanges were commonplace among the first grade classrooms as they were brainstorming questions to ask Perri.

Second grade students quickly came up with relevant questions that covered more of the problem space than the first graders in the similar part of the introductory lesson in their unit. The exchange below shows how the students immediately came up with relevant questions, which the teacher does not help relate to the problem space.

teacher: Do you have any questions for Talia about the Travel With Me toybox? What are your questions?

Rachel: How big or small it is.

teacher: Okay, how big or small is the toybox? Ariel?

Ariel: Can you just put compartments in it?

teacher: Okay, any other questions that you have for Talia? Logan?

Logan: How wide it is?

Fay: How tall is the box?

May: How many toys can it hold?

teacher: What else. Any other questions you have for Talia? Ariel?

Ariel: What is it made of?

teacher: That's a good question, what else?

However, when students provided questions that did not appear well connected to the problem space, the teacher asked the student to reflect on their question as below:

Reese: Does it have writing on the sides?

teacher: Okay. So while that is a good question, does having writing on the side, will that influence how you help them get organized?

Reese: [*Shakes head no*]

teacher: No, so is that a question that we need to include for Talia?

Reese: [*Shakes head no*]

teacher: Okay, May?

May: What color is it?

teacher: Okay, same thing, does the color of the box help us solve our problem?

May: [*Shakes head no*]

The above excerpt provides two examples of the teacher asking students if it was a question they need to include for Talia, and they both quickly agree with the teacher that it is not a question they need to ask. This could be because: (1) the students reflected on the answer compared to the problem space and agreed with the teacher, or (2) the students recognized that the teacher said nothing when the questions posed were "right" and now that the teacher is saying something that means the student question is "wrong." Furthermore, the teacher not allowing these "wrong" questions to be posed to Talia potentially limited the problem or solution space for the students. For example, had the students asked the question to Talia about the writing on the sides, perhaps the student designs may have included words on the side that helped with location of toys within the box. This teacher move potentially directed the students' ways of thinking in this exchange. While this cannot be directly inferred from this exchange, a caution is noted that teachers must be careful when they are directing students to "right" and "wrong" responses in these more open-ended settings.

These examples demonstrate how young students and their teachers approach reflecting, as defined by Watkins et al. [8], in the problem identification phase of an integrated STEM+C unit. While the teachers often scaffolded the reflecting through various prompts, we do see students able to evaluate their questions or ideas as they relate back to the problem at hand. We expect students will continue to develop this ability throughout the unit. However, we also see the need to be cautious of too much scaffolding as it has the potential to direct students down a path that was not intended and may not allow students to make their own connections to the problem space.

Conclusions and implications

This study provides initial evidence that K-2 students are able to participate in meaningful problem scoping during the introduction of an engineering design challenge. The results show that students do meaningfully participate in initial problem scoping with evidence at all three grade levels of engagement with naming, setting the context, and reflecting within the introduction to the problem. This is aligned with what we would expect given the pre-K study of Svarovsky [21] and the upper elementary study of Watkins et al. [8]. However, our data suggest that there is a difference in the scaffolding provided for students in the three grade levels to participate meaningfully in problem scoping during the early stages of the design process. The second grade students, on the whole, were able to meaningfully participate in naming, setting the context, and reflecting with little extra scaffolding from the teachers – we even saw that too much scaffolding at this level may have the unintended consequences of further limiting the problem or solution space or not allowing students to make connections on their own. The kindergarten and first grade students struggled more with certain aspects of problem scoping, particularly naming the reasons why they are being asked to solve a problem and reflecting on the problem space. While this pattern is not surprising from a developmental perspective, it may be that prior experience with engineering may also be related to why some second grade students have more meaningful problem scoping habits than younger students.

As we analyzed and organized the data and results from this study, we noticed that teachers generally had in mind where they wanted the students to end up during a discussion. Often, students provided responses that took the discussions in different directions than planned. Teachers struggled to elicit the full idea from the student opting to change the students' ideas to fit their intended direction. In some of the cases, the students seemed to be pursuing ideas that were not coherent or relevant, but in others, there were times the students needed help in fully articulating their idea. Strategies for implementing problem scoping that allows for ideas to develop within students at this age could help mitigate this issue.

This study focused solely on the introduction lesson to a 13-lesson STEM+C unit. Our next step is to use the findings from this study as the start to analyzing the student talk related to problem scoping in the later lessons. While we have provided evidence that problem scoping at K-2 can occur in a meaningful way, our goal will be to see if students' problem scoping habits develop as they dig more deeply into their design problem.

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