Chapter 3
Developing a Researchable Question: Open Inquiry in a School Garden

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Abstract Learning how to ask questions about the natural world is a central enterprise of science. Yet typical instruction seldom provides students with the opportunity to develop and investigate their own scientific questions. School garden ecosystems offer a rich setting for students to investigate their own questions. In this study, middle school students participate in a 15 week after school science program situated in their school's garden. After engaging in teacher led empirical garden investigations, students are asked to develop scientific questions of their own to investigate. In this design experiment, we examine how students' scientific questions emerge and the roles that phenomena, tools and consultations play in the development and refinement of students' researchable questions. Findings suggest that instructional scaffolds played different roles for different students as they generated and refined their research questions.

Keywords Inquiry · School garden · Scientific questions · Design experiment · Instructional design · Open inquiry · Researchable questions

3.1 Introduction

Scientific questions are central to the enterprise of science. Questions motivate scientists to investigate the world and construct new understandings about how the world works. As such, recognition of the importance of the disciplinary practice of asking scientific questions is reflected in the vision for science education outlined by the K-12 Framework for Science Education (NRC 2012) and the Next Generation

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Science Standards (NGSS Lead States 2013). Asking questions is one of the central scientific practices advanced by these new reforms as an authentic practice of science. Despite the fundamental role questioning plays in scientific practice, students are seldom provided opportunities to generate their own questions for investigation (Chinn and Malhotra 2002; Germann et al. 1996; Van Booven 2015).

The design of science curriculum and instruction dictates the role students play in scientific inquiry. For example, if the scientific question and the methods for investigating the question are provided to students, little is left as problematic for students to resolve themselves. Schwab (1962) proposed a three-level taxonomy to characterize the varying degrees of *openness* of inquiry: (1) the first level is the simplest in which the problem is defined for the student as well as the methods for solving the problem; (2) the second level in which problems are posed for the student but the methods are left undefined; and (3) the third level in which both the problem and the method are to be determined by the student. In the first two levels, the problem or research question is well-defined by the curriculum or the instructor. In the third level, the problem is ill-defined or ill-structured, requiring students to determine the "problem space" (Newell and Simon 1972) requiring a framing of the problem and research question.

Open inquiry refers to inquiry settings in which students develop and pursue their own research questions. Several open inquiry studies have compared student experiences in open-inquiry contexts with settings where the instructor determined the research question. Krystyniak and Heikkinen (2007) found that students who engage in open inquiry are more self-reliant and participation was more evenly distributed amongst students. Moreover, Berg et al. (2003) found that students in the open-inquiry context were better able to describe and evaluate what they had done in the experiment, suggest potential revisions to the experiment, and come up with new ideas. In a comparison of high school biology students, Sadeh and Zion (2009) found that students in the open-inquiry setting exhibited more characteristics of what they referred to as *dynamic inquiry*. The open inquiry students in their study tended to have a greater awareness of change during inquiry as well as deeper procedural understanding.

3.2 Instructional Models for Open Inquiry

It is possible for students to engage in open inquiry with the support of carefully designed instruction. According to Zion and Mendelovici (2012) open inquiry "simulates and reflects the type of research and experimental work that is performed by scientists, thus demanding higher order thinking capabilities (i.e., questioning, designing an experimental array, critical and logical thinking, reflection)" (p. 384). Open-inquiry research studies have employed a variety of instructional models and scaffolds to support students' inquiry. The models have different constraints around questions, different degrees of teacher-directed inquiry prior to the open-inquiry opportunity, and different instructional scaffolds that support students as they pursue their own inquiry projects.

The conceptual scope of open inquiry tasks can be broadly defined, such as “find out and report about the relationships between biotic and abiotic features” of the schoolyard (Roth and Bowen 1993, p. 171) Alternatively, the scope of students’ research questions can be strategically focused on a particular conceptual terrain such as pond dynamics (Lehrer and Schauble 2008) or cricket behavior (Metz 2004). In open-inquiry research, the instructional design typically involves a series of teacher directed activities or whole class investigations that build towards open-inquiry (Keys 1998; Metz 2004). As students begin their own investigations, instructional models support students by including scaffolds such as question heuristics and a menu of research methods (Metz 2004), regular research consultations (Lehrer and Schauble 2008), time management tools (Eilam 2002), and data collection equipment (Roth and Bowen 1993).

During open inquiry, van Uum, Verhoeff, and Peeters (2017) noted that scaffolding enables teachers to balance support and transfer responsibility to students for their own learning. Hard scaffolds consist of documents with explanations and/or exercises focusing on difficult parts of the inquiry process. Soft scaffolds include explicit references to and additional explanations of the hard scaffolds. Combining hard scaffolds with additional soft scaffolding promoted students’ scientific understanding and contributed to a shared guidance of the inquiry process by the teacher and students. Thus, effective design of open inquiry instruction can leverage these scaffolds to support student investigations. Furthermore, developing students’ skills to pose and respond to questions and actively engage in inquiry behaviors, enables students to problem solve and critically engage with learning and society. Additionally, implementing a community of inquiry within an inquiry science curriculum develops students’ questioning and science inquiry behaviors and allows teachers to foster students’ inquiry skills (Nichols et al. 2017).

3.3 Motivating Questions for Scientific Inquiry

Ernst Mayr (1997) wrote about the motivation behind scientific inquiry and noted that “in most cases, scientists are largely motivated by the simple desire for a better understanding of puzzling phenomena in our world” (p. 40). When confronted with ‘puzzling phenomena’ scientists seek to explain how the world works by designing investigations to test their hypotheses. Simon (2001) observes that curiosity motivates both scientists and children, as “idle or purposeful, curiosity is the motor that interests children in science; it is also the principle motor that energizes and steers the education of professional scientists and the conduct of their professional work” (p. 5). It is important to recognize the role of curiosity in driving and sustaining scientific inquiry with children, as they are curious about the world around them and, given the opportunity, they ask many questions.

Scardamalia and Bereiter (1992) analyzed the types of questions posed by students and distinguished between 'basic' questions and 'wonderment' questions. *Basic questions* pertain to factual, orienting information that one might find in a textbook, while *wonderment questions* reflect curiosity, puzzlement, skepticism, or a knowledge-based speculation. It is the latter that drives the enterprise of science. Chin, Brown, and Bruce (2002) found that wonderment questions were more likely to arise in classroom science contexts when students were engaged in open-inquiry tasks compared to engagement in more structured inquiry. Additionally, students' interests in topics for investigation may simply come from passing thoughts, fleeting concerns, phobias, obsessions, or fascination with media-related characters (Katz and Chard 1998). Students' interests may not be of high educational value or amenable to empirical investigation. For example, Chin and Kayalvizhi (2002) found that when sixth graders generated questions for investigations, very few of these questions (11.7%) could be answered through classroom investigations. The authors classified questions as 'investigable' if they 'allow pupils to generate and collect original data, analyze and interpret their findings based on these data and finally, make a conclusion that answers the investigative question posed, on the basis of available first-hand evidence' (p. 274). 'Non-investigable' questions were classified as questions involving basic information, complex information or philosophical or religious questions. If students are to develop 'investigable' or 'researchable' questions, they need assistance in transforming their interests into a question that can be investigated empirically.

Singh, Shaikh, and Haydock (2019) indicate that even with very little teacher guidance, students can engage in questioning and thereby ask each other a surprising number of investigable science questions. Their questioning can be authentic, and both explicit and implicit. The reality is that in most science classrooms, students do not receive adequate opportunities to develop and pursue their own research questions, a process characteristic of authentic scientific inquiry. Thus, through the context of a school garden science class, the authors explore the origin of students' interests and strategies for cultivating and refining their interests into research questions.

3.4 School Gardens as a Strategic Context for Open Inquiry

School gardens are increasingly common features of schoolyards (Blair 2009; Desmond et al. 2004) and are strategic settings for open inquiry research for several reasons. First, the school garden is a complex ecology and the scientific concepts at play include big ideas from many key disciplines such as botany, zoology, and soil science. The school garden phenomenology can be leveraged to teach big ideas such as nutrient cycling, biodiversity, soil ecology, artificial selection or plant growth and development. These ideas, among many others, comprise the conceptual terrain that undergirds the school garden ecology. This conceptual terrain is sufficiently complex to support a wide range of student research questions. The school garden ecology is a web of intertwined biotic and abiotic relationships that can be explored through open inquiry. While constraining inquiry within the boundaries of the school garden context and its associated conceptual terrain begins to focus inquiry on questions of educational value, additional instructional scaffolds can further foreground important aspects of the conceptual terrain.

Second, school gardens ecologies are also rich in phenomenology that can stimulate students' curiosity and interest. Experiencing phenomena first-hand stimulates students' curiosity which can, in turn, motivate inquiry (Simon 2001) and working in school gardens induces many student questions (Rahm 2002). Metz (2011) makes a convincing case for the importance of immersing students directly in phenomena in order to build domain knowledge, which is critical for more sophisticated scientific reasoning. The rich phenomenology of school gardens is a unique space for students to get a 'feel for the organism' by affording them a direct experience with the subtleties and complexities of a real ecosystem. It is strategic to capitalize on the school garden as a unique accessible space with rich phenomenology.

A third affordance is the compelling environmental and societal motivators associated with school gardens. Many school gardens aim to reflect sustainable agricultural practices such as compost piles, diversified crops, and non-chemical pest management strategies, reflective of a larger movement towards urban agriculture and sustainable farming (Stone 2009). In contrast to industrial methods of agriculture such as monoculture and chemical inputs, school gardens are diversified food systems that produce fruits and vegetables for consumption. The emphasis on growing food teaches students how healthy food can be grown while caring for the environment. Science in school gardens, and inquiry in particular, can be motivated by these same societal and environmental concerns: How can we grow food in sustainable ways? How does an ecology that supports food production function? How can we best conserve water and soil fertility while producing healthy vegetables? It is in this context of authentic, practical, societal concerns that students' questions can be encouraged and supported (Fusco 2001).

Finally, open inquiry science instruction in school gardens can draw from the scientific discipline of agroecology, the study of ecologies that produce food (Altieri 1989; Francis et al. 2003; Gliessman 2007). As Lehrer (2009) argues, it is important for science learning to be grounded in the practices of particular scientific domains. Different scientific domains have particular ways of conducting investigations with tools and data representations that are particular to that discipline. Agroecologists study ways in which ecological principles can be applied to sustainable food production. Agroecology is oriented around problem-solving, including research into the effectiveness of ecological methods for improving soil fertility, controlling pests, conserving water and managing food systems in concert with the economic, social and cultural well-being of local communities (Francis et al. 2003; Gliessman 2007). With agroecology as a disciplinary referent, inquiry in school gardens can be grounded in authentic scientific practices.

Thus, school gardens can provide meaningful learning experiences for students. Yet, factors that are important for such success are sufficient budget, parental involvement, and support from community, school administrators, and teachers

(Burt et al. 2018a). Research demonstrates that school gardening is a promising pedagogical strategy for promoting students' healthy physical, psychosocial, and dietary behaviors as well as their achievement (Burt et al. 2018b; Kuru et al. 2020). They are also considered a positive way of teaching young children environmental and agricultural practices while improving social cohesion between them.

From a pedagogical perspective, several conditions are required to ensure good learning outcomes. These factors entail developing a subject-integrated school garden curriculum and teaching practices that include experiential learning and hands-on activities as teaching methods, making the subject content less abstract, stimulating the students' senses, and increasing the feeling of meaningfulness. Still, it is important to further explore the contribution of gardens to the development of students' critical minds and whether its impact is a long-term progress (Roscioli et al. 2020).

3.5 The Study

3.5.1 Rationale and Research Questions

This study examines the development of students' research questions in the context of students' own investigations. Specifically, this study tracks the emergence of students' interests and how instruction functions to transform those interests into researchable questions. In particular, the authors examined two research questions:

1. In an open inquiry setting, how stable are students' research interests?
2. How does instruction function to support the emergence and development of students' research questions?

3.5.2 Methodology

This study uses a design experiment approach (Cobb et al. 2003) to investigate how students develop research questions in a particular instructional context. Design experiments "entail both 'engineering' particular forms of learning and systematically studying those forms of learning within the context defined by the means of supporting them" (p. 9). This study analyzes both the research questions that students develop *and* the specific instructional context in which these questions are generated and refined. Since self-regulated student inquiry in school gardens is uncommon, an after-school garden science class was designed to support these inquiry practices.

3.5.3 Instructional Design: After-School Garden Science Class

The following set of principles guide the instructional design. For each principle, an elaboration on the rationale and a brief description are presented to address how the principle is reflected in the instructional design for the garden science class.

1. *Situate scientific inquiry in a context motivated by compelling social and/or environmental concerns.* When inquiry has a larger goal, it adds meaning and purpose to the endeavor. Situating inquiry in the school garden context connects inquiry to a social goal of producing healthy food while minimizing environmental harm. The garden science class is framed in terms of the value of understanding the garden ecology for sustainably growing food. This framing provides both social and environmental motivations for students to conduct scientific research in the garden.
2. *Privilege student interest as motivator for self-regulated inquiry.* Learning and motivation are deeply connected. In self-regulated inquiry, students' interests function to motivate them as they pursue inquiry projects. In the garden class, students were expected to generate a research question of personal interest to them. Student interest was a central criteria for determining which question to pursue.
3. *Immerse students in phenomenology to activate student interest and build domain knowledge.* Direct experience with natural phenomena can stimulate curiosity that drives inquiry (Simon 2001), and puzzling phenomena can lead to questions (Mayr 1997). Students are immersed in the school garden phenomenology immediately. The whole class research also facilitates their exposure to different features of the school garden.
4. *Anchor inquiry in the authentic practices of a scientific domain.* Scientific inquiry with students can begin to approximate authentic practices of real scientists by enlisting particular scientific disciplines as referents (Lehrer 2009). In this curriculum, the scientific field of agroecology was used as a domain referent. Students use agroecological research methods and instrumentation to conduct their inquiry projects.
5. *Develop student competence in quantitative methodology as a source of academic and scientific rigor.* While math and science may be commonly taught as separate subjects in schools, mathematics and science are deeply intertwined. Mathematics is a language used by science to record data that is then modeled and analyzed to uncover patterns, correlations, or comparisons. By incorporating the collection of quantitative data as evidence in service of students' investigations, mathematics is applied for a purpose. This makes the investigation an opportunity for students to practice and apply math skills as part of scientific inquiry.

3.5.4 Setting and Participants

The research site for this study was a large, public middle school in an urban school district in a mid-size city in a western state. The school has a well-established school garden as well as a kitchen for teaching students how to cook. The school garden is approximately one acre in size with 40–50 garden beds, fruit trees, a chicken coop, a greenhouse, and a small pond. The school garden is maintained by a staff of garden educators who teach gardening classes to students at the school. Classes come to the garden weekly to engage in gardening tasks (e.g., planting, harvesting, cultivating, etc.) for 6–8-week rotations. Each class at the school attends 1–2 rotations each school year. Students also attend rotations in the kitchen where they learn how to cook with the produce from the garden. While science is not an explicit focus of the garden classes, teachers make connections between the science curriculum and the students' experiences in the garden. Students do not engage in scientific inquiry during the regular garden class. However, students do build content knowledge about the garden ecology through working in the garden and through informal lessons by the garden educators.

The school has an ethnically diverse student body (7.8% Asian, 16.1% Hispanic, 23.2% African American, 34.7% Caucasian and 17% multiple/no response), with 40% economically disadvantaged. Participation in the garden science class was entirely voluntary. The class was advertised as part of the catalog of after school classes offered at the school. Brief recruiting presentations were also given to each sixth and seventh grade science classrooms to encourage students to register for the class. Five sixth graders and two seventh graders (4 girls and 3 boys) participated in the study. Four students were Caucasian, two students were African American, and one student was an English language learner from South Asia. All names used in this chapter are pseudonyms.

3.5.5 Procedures for Conducting the Study

The garden science class convened for two hours after school, one day a week over the course of 15 weeks. For the first seven weeks of the program, the students engaged in a series of teacher-directed research projects that investigated characteristics of different soils. The investigations focused on developing an understanding of the biological, chemical, and physical properties of healthy soil. In particular, the investigations highlighted the connections between compost, organic matter, biological activity, and soil health.

One of the authors was the instructor and researcher, determined the research questions and led the design of the investigations. An example of a question pursued as a class: *How does the biological activity of the soil in the garden beds compare to the biological activity of the garden soil by the trees and soil outside of the garden?* Students played a central role in each investigation by making predictions, selecting sampling locations, collecting samples, analyzing data, and drawing conclusions. Students were exposed to different methodological techniques, such as worm counts, decomposition papers, nitrate tests and invertebrate traps (Gliessman 2007; Miles and Brown 2003). While participating in the group inquiry projects, the students recorded their emerging thoughts about what interested them in the garden. They documented potential research questions or research interests that were not formulated on a regular basis in their science journals. These are categorized as *emerging interests*.

During weeks 8 and 9, each student participated in a 20–45-minute research consultation. The goal of the consultation was to help students transform their interests into a researchable question. During the consultation, each student reflected on their initial research questions from the pre-interview and the emerging questions taken from their notebooks or interests they stated during class. Each initial question from their pre-interview and each question or interest from their notebooks was presented one at a time to the student. The student reflected on each question as an object of thought and stated whether they were interested/not interested in the idea. Students discarded ideas that no longer interested them and kept those of interest in front of them. They shared their current thinking about potential research directions.

Collectively, the class helped each student develop, specify, and refine their interests. Students helped each other to evaluate their interests in relation to class-generated criteria of what makes a good research question (Table 3.1). Through successive rounds of reflection on students' prior ideas and feedback from the class and instructor, the students gradually refined their interests into a single researchable question.

In the second half of the garden class, students conducted an investigation driven by their research question. Students designed a research plan, collected data and analyzed their results. The inquiry projects spanned 4–5 weeks, with students working each week on their projects. Since students were at different stages at different times, they often helped each other collect data for their respective research projects.

Students used desktop publishing computer software to create individual research posters explaining their investigations, and including the following sections: Title, Introduction, Research Question, Hypothesis, Methods, Results, Conclusions, Limitations, Implications, and Future Research. Due to the time-consuming nature

Table 3.1 Criteria for good research questions

Criteria	Description
Interesting	A question of real interest to the student
Genuine	A question that the student does not already know the answer to
First-Hand	A question that can be answered through first-hand research in the garden
Doable	A question that can be investigated given the time and resources available
Important	A question that is important for understanding how the school garden works and has implication for how to grow food
Original	A question that is different from the questions that others are asking

Informed by Chin and Kayalvizhi (2002)

of the poster creation, most students had to spend additional time outside of the garden class to complete their posters. Students' electronic posters were then printed on large (3′ × 5′) poster-size paper and hung using wooden dowels. During the last session of the garden science class, the students hosted a *Garden Science Research Poster Conference.* The students' classroom teachers, families and the school garden staff were invited to attend. Students took turns presenting their research and conference attendees took the opportunity to examine the posters individually and engage with the students about their research.

3.5.6 Data Sources and Analyses

This study draws on several data sources for analysis including semi-structured interviews, students' science notebooks, video tapes of garden class, and researcher/instructor field notes. Semi-structured interviews were conducted with each student prior to the beginning of the garden science class (pre-interview) and at the end of the garden science class (post-interview).

During the pre-interview, students were asked to generate three questions that they might want to investigate during the garden science class. Each student generated three potential research questions (referred to in the analysis as the "initial" questions or interests.) The pre-interview also included questions about the students' garden content knowledge and epistemological beliefs about science, however those questions are not part of the analysis presented in this paper. Post-interviews focused on how students developed their research question and how useful different features of the instruction were for supporting the development of their question. These reflections were used to corroborate findings from the instructional analysis. The audio recordings of the interviews were transcribed and analyzed.

During the course of the class, students were also asked to record emerging research interests and questions in their science notebooks on a weekly basis. Students also used their notebooks to record information relating to their investigations. During the subsequent consultations, ideas from their notebooks (and initial interests from their pre-interview) were shown to the students on sentence strips for the students to consider and reflect upon.

The final source of data for this analysis is a video record of the instruction. The video record was largely restricted to the use of a single camera. While whole class discussion related to the teacher-directed investigations and the student-centered consultation are captured by the video, the video record does not include every comment or exchange during the course of the garden science class. In particular, the video is only a partial record of exchanges that occurred while students were collecting data separately in the garden or as they worked on their individual investigations. Video records of the consultation were transcribed. Students' treatment of their initial and emerging interests was interpreted based on the transcript and visual placement of the sentence strips from the video record. The transcript was used for analysis of the consultation dialogue.

In addition to researcher field notes, the aforementioned data sources constitute the database which the analysis in this study is based. For analyses that involved all students in the study, particular sections of the interviews or transcripts were analyzed across all students. For the case study analyses, data relevant to each case study student formed the basis of the findings.

3.6 Findings and Discussion

The results and associated discussion are organized in two sections. The first section is an analysis of the stability of students' developing research interests. The second section examines how the central features of instruction functioned to support the development of individual student interests and research questions.

3.7 Part I: Continuity of Students' Research Interests

In an open inquiry context, students pursue research questions that are of interest to them. To foster the development of students' interests, it is important to understand how their interests originate and whether these interests are stable or if they change significantly over time. How do students' interests originate? How stable are students' interests and to what extent do they change over time?

As Mayr (1997) noted, scientists' interests are often motivated by 'puzzling phenomena' that they encounter. Students in this study had prior garden experience before beginning the garden science class. To what extent did they enter the class with 'puzzling phenomena' in mind? How attached were students to their initial research interests? To investigate these questions, the students' initial interests expressed during the pre-interview were compared with the final research questions that students decided to pursue. In comparing students' research questions with their initial interests, all of the students' eventual questions were different from their initial interests. There was not a single question that persisted from the pre-interview through the course of instruction. Of the 21 initial questions that students generated in the pre-interview, only four of them were even loosely related to the student's eventual question. For example, one of Edward's initial questions was "If we used different fertilizer that was man-made that had better plant growing stuff, but it wasn't as good for the earth what effects would it have?" Edward's eventual question was "How does the nitrate level change as you go deeper into the Earth?" These two questions are loosely related in the sense that both relate to soil health. However, the relationship between the two questions is indirect and one is not a refinement of the other.

Further analysis explicitly examined students' attachments to their initial and emerging interests. Students generated a total of 85 research interests through the seventh week of the garden science class. This includes initial interests from the

Table 3.2 Percentage of students' prior interests still of interest during consultation

	# of Interests (Initial and emergent)	% Interests maintained (Initial and emergent)	% Interests maintained (Initial)	% Interests maintained (Emergent)
Total	85	45%	18%	54%

pre-interview, emerging interests recorded in their science notebooks, and vocalized interests recorded in the researcher field notes. During the consultation in the eighth and ninth weeks, students classified each of their stated interests as either potentially "still of interest" or "no longer of interest." Table 3.2 shows the percentage of prior interests that were still of interest to students at the consultation. Collectively, students classified only 38 of these interests as potentially "still of interest." In other words, when it was time for students to evaluate their prior interests (both initial and emerging) they expressed continued interest in 45% of the questions and ideas.

Interestingly, further analysis shows that students only found 18% of their *initial* questions still interesting. Students no longer expressed interest in the vast majority (82%) of their initial, pre-interview research questions. In fact, in several cases, students completely disassociated themselves from their own pre-interview research question suggestions, denying that they had even asked those questions. Students maintained interest in 54% of the interests that emerged during instruction.

These findings indicate that students' interests changed during the course of instruction. Beyond vague similarities, the students' initial and eventual research questions were entirely different. Furthermore, students had weak attachment to their initial questions but greater attachment to the interests that emerged during instruction. Thus, instruction has the potential to foster the development and refinement of students' interests. Given that students may have weak attachments to initial ideas about research, it is important for instruction to allow for the emergence and development of more robust student interests.

3.8 Part II: Role of Focal Instructional Features for Supporting Student Interests

In this study, the instruction was designed to support open inquiry in an authentic, meaningful context. Additional analysis is needed to understand *how* the instruction functioned to support the emergence and refinement of students' research interests. It is important to analyze the specific trajectories of student interests and how these interests were influenced or not influenced by instruction in order to evaluate the utility of the instructional design. To investigate the interplay of interest and instruction, the analysis concentrates on the role of three focal instructional features of the garden science class: phenomenology, variables (with associated instrumentation), and consultation. The school garden phenomenology was emphasized from the start of the garden science class. Students engaged directly with the school garden phenomenology as the class conducted group research during the first half of the class. Throughout the instructional program, students worked directly with garden soils, plants, and organisms. This hands-on exposure to the garden ecology was designed to evoke student curiosity and to give them a “feel” for the garden phenomenology.

Instruction also emphasized the diversity of potential research variables that could be examined as part of an investigation. Explicit attention was given both to a range of measurable variables (e.g., worm counts, soil moisture levels, levels of soil compaction, plant height, decomposition rates, etc.) and the associated instrumentation to measure these variables. The measurable variables were emphasized during the whole group inquiry projects and as a menu of potential measures, which students could draw from as they developed their research focus.

The final focal instructional feature was the use of a consultation feedback format (Lehrer and Schauble 2008) during which each student reflected on their interests with the support, feedback, and suggestions of the class as whole. These focal instructional features form the basis of the subsequent analysis of the interaction between the instruction and the students’ emerging research interests.

To examine the ways that instruction functioned to support the emergence and development of students’ research questions, the analysis centers on case studies of three individual students in the study. Case study students were selected in a principled way (Yin 2003). Based on preliminary analysis of all of the students in the study, the case study students were selected based on the trajectory of their interests in relation to particular focal instructional features. For each focal instructional feature, one case study student was selected who was particularly influenced by that feature. Nina (pseudonym) was strongly influenced by the school garden phenomenology, while Laura was influenced by the variables and associated instrumentation, and the consultation played a critical role in the development of Alison’s research question.

In the following case study analyses, each of the three students’ research questions is considered in the context of the three focal instructional features. The case study analysis highlights the different roles that the focal instructional features play in the development of research interests and questions for these students.

3.8.1 *Case Study of Nina*

Nina is 12 years old, and an English language learner in the sixth grade. Over the course of the garden science class, Nina developed a strong interest in earthworms, an interest that she did not have before the class began as evidenced by a question from the post-interview (T = teacher/interviewer):

Teacher: Did you like worms before this class or did you always like worms or did you not like worms?

Nina: Not really, I thought worms were icky and scrawling [crawling] too much.

For her open inquiry investigation, Nina pursued the question, “How many worms are in all parts of the garden?” To investigate this question, Nina sampled soil from a garden bed, counted the worms and then estimated how many worms there might be in all of the garden beds in the garden. As part of her estimation process, she calculated the cubic feet of soil in one garden bed, counted the number of garden beds in the garden and used the worm count to estimate the total worms in the garden. Nina was very enthusiastic about her research. Given her initial lack of interest in worms, how did her interest emerge and transform into a researchable question? How did the three focal instructional features support Nina as she developed and refined her interests?

Different facets of the instructional design fostered Nina’s research interests. An analysis of Nina’s science journal shows a clear interest in worms developing in the third week of the garden class. During that third week, the group began research on earthworms in the garden, comparing worm counts in different parts of the garden (and outside of the garden) with different cultivation histories. None of Nina’s reported interests during the pre-interview or prior weeks related to worms. However, the worm phenomenology piqued her interest, evidenced by the emerging interests and questions in her journal. In the post-interview, Nina was asked about the extent to which the early group research and working in the garden was helpful to her as she developed her research interests:

Nina: It did help me because we worked about worms and I started to like worms that group research and then I started to do research about worms.

In the Week 7 instruction, students were introduced to a variety of measurable garden variables that could become part of their research question as needed. While these variables did elicit non-worm interests (as seen in interests she expressed in Week 7), Nina was ultimately undeterred in her commitment to researching worms.

Nina’s research consultation helped her to refine and consolidate her interest in worms. At the beginning of the consultation, Nina discarded her prior research ideas that did not pertain to worms. Her interest in worms was so robust that she had difficulty relinquishing any of the research questions that involved worms and even added one:

Teacher: I noticed that Nina discarded … that she’s not that interested in the fruit being buried under the ground, she’s not that interested any more in terms of the worms having brown things on them, and she’s not that interested in how long it takes for a leaf to decompose. Why are you not interested in these anymore?

Nina: I don’t know … I just don’t like them anymore.

Teacher: Why did you keep the ones that you kept?

Nina: Because I’m interested in worms and they are all about worms.

Teacher: Okay, so which of those interests you the most?

Nina: How do you know when worms get pregnant? How long worms are? The most I want to do … oh! I forgot something! How do you know if a worm is a boy or a girl?

A discussion ensued about how to tell if a worm was pregnant. While some students argued that this question was easily answerable on the Internet (and therefore not an appropriate question for empirical research), the class concluded that the circumference could be measured as a potential indicator of pregnancy. Students helped Nina frame research in terms of a comparison between the garden and her backyard at home and suggested the idea of calculating the average length. Nina attempted to combine her interests in worm counts and lengths:

> Nina: Can I put some of these together? I want to put these two together.
> Teacher: What kind of combined question would that be?
> Nina: I would say that when I estimate … when I found worms in one place, they were this long and when I found worms … when I estimated them in the whole garden they changed to a different sizes?

Her consultation continued until Nina decided to estimate the count and length of worms in the entire garden based on a sample count. Ultimately, in the process of conducting her investigation, Nina made estimations only based on the counts, rather than the counts and lengths.

Nina's case is one of intense curiosity and interest sparked by immersion in the school garden phenomenology. Her interests were robust and unwavering. The diversity of research variables minimally influenced her interests. The consultation primarily functioned to consolidate her questions and to help her select a research question that could accommodate her interests. It is also notable how she conceived of a linked set of questions as a potential inquiry trajectory for herself, when this aspect of science was not emphasized in the instruction.

3.8.2 Case Study of Laura

Laura is a high achieving seventh grade student who is 12 years old. She reported having had experience doing science inquiry projects at her prior school but had never conducted an investigation in the garden. Laura was quite independent throughout the class and very articulate about her thoughts and ideas.

Laura considered the whole class research to be helpful in exposing the research possibilities within the school garden. In the post-interview, she explained:

> I think it was good to have the group research first, because we didn't know that much about the garden and the possibilities in the garden and I think we thought there was a lot less than there actually was. So then when we did the group research, I don't think a lot of us would have thought about counting the invertebrates to see if it was healthy.

Laura eventually decided to pursue the research question: What is the average level of soil moisture in the soil with mulch and without mulch in the garden? How does it compare to soil moisture outside of the garden? Laura developed her eventual research question while listening to other students' research consultations. Laura was one of the last students to have her consultation, but she offered ideas and suggestions to other students during their consultation, as highlighted during her post-interview.

> Laura: As other people got people to talk about their research questions, I started getting ideas so then when I had a bunch of ideas I wrote them all down during the consultations and then I said some of them and people said, well that's not doable, so they helped me figure out which one would be the best one to do in our garden.

Teacher: So, you're saying that when you were listening to other people's consultations, even though it was their consultation, it was actually helping you, because you were thinking of ideas yourself?

Laura: Yeah, so like Nina was talking about the worms and then I was thinking about the healthy soil and then I saw soil moisture on the table, and I thought, oh that would be cool.

When it was Laura's turn for a consultation, she dismissed all but one of her prior ideas. Instead, she shared her new idea about researching soil moisture. The question she reported was, "What is the average level of soil moisture in different parts of the garden and how does it compare to the triangle?" [The triangle refers to a non-cultivated section of dirt on the school grounds.] In her post-interview, Laura explained her new-found intrigue with soil moisture.

Teacher: Why soil moisture? Do you feel like you were interested in it because we hadn't done it in the class?

Laura: It seemed kind of unique, and it wasn't really like all the other ones, and the way that you would find the soil moisture, that was kind of cool, so I wanted to do that.

Laura was attracted to the uniqueness of the variable and the associated instrumentation that is used to measure soil moisture. Her consultation was relatively short since she had selected her question. Instead, the class helped Laura develop her research design, suggesting places to sample the soil including different locations for collecting data. These suggestions helped her incorporate the notion of testing garden beds with and without mulch.

Laura's research interests were ultimately influenced most by her intrigue with a particular garden variable and its associated instrumentation. As a class, we had not measured soil moisture, and yet it was an important variable that could be measured in the garden. Laura developed an interest around soil moisture and was able to develop her research question independently. While her own consultation was brief, she clearly benefited from participating in the consultations that preceded hers. Furthermore, because her question was more fully developed, the time spent on her consultation could be more efficiently spent helping her develop her research design.

3.8.3 Case Study of Allison

Allison is a 12-year-old student in sixth grade. She came into the garden science class with relatively sophisticated prior knowledge about the school garden ecology. She had many garden experiences at home and often made contributions to the class discussion that indicated her understanding. However, Allison's research interests were diverse, unfocused, and inconsistent.

In the pre-interview, Allison expressed interest in researching what might happen if a tropical plant was grown in the garden, what damage potato bugs can do and the role of ants in the garden. Her emerging interests during the whole class research did not reflect a persistent pattern of interest. Her interests generally wandered based on the weekly focus of the garden class.

Allison's research consultation was long and involved a lot vetting of different research question possibilities. The class offered suggestions to Allison with the goal of transforming her interests into a single researchable question. In some cases, the class compared Allison's ideas and potential research questions with the class criteria for what makes a good research question. Allison's peers considered her interest in potato bugs (expressed during her pre interview) as an idea that could be researched on the Internet and therefore not worth pursuing. Amidst the doubt expressed about the potato bug plan, Allison turned to one of the variables she had previously expressed interest in – soil compaction. Allison shared a sentence strip where she had written the following question: *How well can a plant grow when the soil is compact and/or no worms?*

Allison went on to describe a mixture of ideas related to soil compaction, water permeation and worms. While these ideas were all related, Allison struggled to clarify how these ideas may take the form of a research question. The instructor asked the group if they had any ideas for how Allison might simplify her research question.

Jeffrey (raises his hand): I have one! How about she just picks one variable so she could just do soil moisture instead of making it so complicated.

Laura: How about if you wanted to use more than one, for example you could say, does the number of earthworms in soil vary depending on the compaction of the soil.

Laura's suggestion stemmed from Allison's expressed interests while transforming those interests into a researchable question. These ideas were pursued further in the consultation.

Teacher: Can we take up what Laura just said? (To Laura) Can you repeat what you said?

Laura: Does the number of earthworms in soil vary depending on the compaction?

Teacher: (Holds up compaction and earthworm count variable cards). So, what would that mean? You would go look for …

Laura: Soil with like different compaction levels and then count the earthworms.

Teacher: So, Allison, do you hear what she is saying? She's suggesting that one idea … you don't have to go with this if you don't like it … but one idea to simplify all this … (points to the variables) because you've got so many ideas … is to take just these two variables (compaction and earthworm count) and say, is there a relationship between the level of compaction.

Teacher: Laura just gave a really interesting idea and I want to see if Allison wants to pursue that or not. Do you understand the idea? You take soil outside and you measure the compaction in different places and then you do an earthworm count and you see if there's a relationship, Allison, between the compaction of the soil and the amount of earthworms that are there … what do you think about that idea?

Allison: That sounds nice.

Rather than fully committing to the idea, Allison opted to think about it for a while and decide for herself. As the consultation ended and a new one began for a different student, I assured Allison that she had time to think about the idea to determine if it was an idea that she would like to pursue for her research. The following week, Allison still seemed reluctant to move forward. Instead, Allison returned to the variable cards that she had expressed interest in the previous week and reached for the compost temperature card.

Allison: (looks at variables) I could probably try compost temperature … I've always wondered how hot compost could get.
Teacher: Have you? It didn't show up in any of your questions …
Allison: Well, I didn't think about it until now. Then I just realized that compost can get *really* hot and like, well … what if it's hot enough to like… sort of like it makes it so warm that you can barely touch it…
Teacher: So, what would you ask, what would the question be?
Allison: How hot can compost get?
Teacher: Okay, so what would you do in order to test that question?
Allison: Stick a big ol' electric thermometer in like one of those compost piles out there and in the horse manure because that like is considered compost too.

Ultimately, Allison decided to research the temperature of the compost. Her research questions were: *How hot does compost get? How does the compost temperature change from day to day?*

Even though Allison eventually decided on a research question that was not entertained during her consultation, the consultation still served an important function. Allison had diverse and wide-ranging interests, and the consultation functioned to help Allison explore and evaluate her different interests. Many of her interests were deemed impractical or too complex during the consultation, but it was still an important forum for her to share her diverse ideas and get feedback from others in the class.

Allison found numerous garden variables appealing and made attempts to construct a research question out of multiple variables. It is notable that of all the students, she was the only student who resumed interest in one of her initial questions from the pre-interview (potato bugs). However, Allison needed an extended consultation to arrive at an idea. The idea of researching the compost temperature seemingly appeared to arise randomly. While the compost temperature was listed as one of the potential garden variables, Allison contended that it had been a long term of interest of hers. It is possible that Allison's curiosity about compost temperatures was, in fact, a long-term interest. It is also possible that the garden variables ultimately triggered Allison's interest in compost temperature. Allison may have decided to pursue compost research after learning from the consultation experience about the types of questions that are amenable to empirical investigation.

3.9 Discussion

This study examined the generation and refinement of student research questions and the instructional features that supported their development. An analysis of students' initial, emergent and eventual research questions shows that students' research interests changed during the course of instruction. Students exhibited considerably weak commitments to their initial interests, yet they generally found their ultimate research questions to be both interesting and important. These findings offer an example of how open inquiry settings and scaffolding (van Uum et al. 2017) can offer students the opportunity to develop and pursue research questions (Chinn and Malhotra 2002; Germann et al. 1996; Van Booven 2015) that they find motivating and valuable. Students reported that they considered their questions to be not too easy and not too difficult.

An analysis of how the focal instructional features supported the emergence and refinement of students' research questions shows how the features can function differently for different students. While some students became captivated by particular topics, other students struggled to narrow their focus among a range of diverse interests.

For some students, exposure to the garden phenomenology induced the curiosity referred to by Simon (2001) and Rahm (2002). However, since the garden phenomenology was embedded in a whole group research context, it is hard to disentangle the role of the garden phenomenology from the role of the group research. Would Nina have been as captivated by the worms if she had discovered them outside of a research context? That question cannot be readily answered by the data from this study. However, it is clear that her exposure to the worm phenomenology did result in a robust, continued interest in worms, an organism that she previously disliked.

The consultation activity structure was adaptive to the particular needs of different students. Since the focus of each consultation was on the individual student and their interests, the group's feedback could attend to the specific issues that each student was facing. While certainly time-consuming, the consultation format is particularly powerful and arguably targeted the students' individual zone of proximal development. In Allison's case, the consultation activity structure was especially important as a space for her to evaluate each of her many ideas. In contrast, Nina's consultation functioned to consolidate closely related interests.

There is also evidence to suggest that the consultation is beneficial for the other students who are offering feedback to the focal student. Laura was an active contributor of ideas and suggestions during other students' consultations. Since Laura had essentially decided upon her research question by the time it was her turn, her consultation was able to advance her research design plans, more appropriately targeting her needs at the time.

The role of the garden variables and instrumentation in this study is less straightforward. The garden variables were sources of possibility and potential intrigue or interest (Lehrer 2009). But scientists measure variables in service of a question that they are pursuing. The measures are utilized as a way of operationalizing the research question or design, not necessarily objects of inquiry in and of themselves. However, in writing about expert problem solving in the context of scientific inquiry, Simon et al. (1981) explains that, in comparison to the *weak methods* used by novices, experts use *strong methods* as "powerful techniques that are carefully suited to the specific structure of the domain to which they are applied."

Experts approach scientific problems with a repertoire of particular methods and techniques that are well suited to that domain. Therefore, it is important for students to learn data collection methods that are specific to agroecological research *(strong methods)* if they are to conduct authentic inquiry in the school garden. To fully appreciate research possibilities in the school garden and to help operationalize their research questions, students need to be familiarized with relevant variables and techniques for measuring those variables. More research needs to be done to examine how to strategically introduce research instrumentation into open-inquiry settings so that they can both expose research possibilities and help to operationalize students' questions.

Another challenge facing open-inquiry research is how to design instruction that optimizes the parallel goals of student interest and the conceptual richness of the inquiry question (Roscioli et al. 2020). This study privileged students' interest as the top-level criteria for researchable questions. While the instruction did focus on explicit science ideas such as the ecology of soil, feeding relations and nutrient cycling, the conceptual terrain was only targeted to varying degrees by students' research questions. Future research should examine how to optimize student ownership and interest as well as strategically focus the inquiry on the important conceptual terrain of the target domain. This challenge is a matter of instructional design and may take many different forms or approaches.

This study is a unique existence proof that open inquiry in school gardens is possible under particular instructional conditions (Burt et al. 2018a, b; Kuru et al. 2020). Students developed and pursued their own research questions, an authentic process that is critical to scientific practice and yet rarely expected of students in science classrooms (Nichols et al. 2017). This study offers insight into questions of instructional design for scaffolding student question development in open-inquiry settings. Furthermore, for practitioners in urban agriculture, findings from this study offer insights into pedagogical approaches for developing students' skills to pose and respond to questions and actively engage in inquiry behaviors in non-formal settings. It also suggests one possible direction for the advancement of garden-based science education. Future research is needed to further evaluate the scaffolds that support open inquiry (van Uum et al. 2017) and how to integrate this instructional model into existing school garden programming and science instruction.

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