Modeling Elementary Students' Ideas about Heredity: A Comparison of Curricular Interventions

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Abstract

Learning about heredity is important across the K–12 continuum. However, these ideas may be challenging for students. We examined third-grade students' ideas about heredity in the context of a new, six-week, model-based science unit that uses corn as a model organism to support students' ideas about heredity. We analyzed data collected during implementation of the unit, including student artifacts and interviews. We compared these data to those from a pilot version of the curriculum – implemented in the prior year – that was focused on the same disciplinary concepts but was not designed around scientific modeling. Our findings illustrate levels of understanding in students' ideas about three target concepts underlying heredity: life cycles, trait inheritance, and trait variation. We also found that students experiencing the model-based version of the unit exhibited higher levels of understanding for two of the three target concepts than those experiencing the non-model-based curriculum. Analysis of student interviews also showed that students experiencing the model-based curriculum were better able to use key elements of life cycle, such as pollination and reproduction to support their explanations about inheritance. We discuss implications of this work for design and enactment of model-based curricula in elementary grades that can support students' learning about heredity.

Key Words: *Heredity education; genetics education; elementary school science; modeling-based instruction; modeling; agricultural literacy.*

○ Introduction

Calls from researchers and policymakers emphasize teaching and learning about heredity from the elementary grades onward (e.g., Duncan et al., 2009; National Research Council [NRC], 2012; NGSS Lead States, 2013). Heredity-related concepts focus on the processes and mechanisms that explain how characteristics or traits of organisms are transmitted from one generation to the next, divided into two disciplinary core ideas (DCIs; NRC, 2012). At the third- to fifth-grade levels, these DCIs focus on trait variation, inheritance, and life cycles. Prior research has shown that early learners enter school with ideas about these concepts based on everyday experience (Lewis & Wood-Robinson, 2000), intuitive theories (Duncan et al., 2009), or kinship (Springer, 1995; Venville et al., 2005).

Ideas about heredity, however, tend to be challenging for learners of all ages (e.g., Ronald, 2011; Elmesky, 2013; Anderson et al., 2014), including elementary students (Venville & Donovan, 2008; Cisterna et al., 2013; Ibourk et al., 2017). They may struggle to explain how offspring traits resemble parental traits and use scientific principles to formulate explanations of heredity (Venville et al., 2005; Cisterna et al., 2013). Although young children tend to recognize that living things develop from other living things, they struggle to identify eggs or seeds as stages of animal and plant life cycles (Lewis & Wood-Robinson, 2000; Tytler et al., 2004; Barman et al., 2006; Anderson et al., 2014; Zangori & Forbes, 2014). These ideas pose challenges for elementary students, given the cognitive demands of connecting traits, structures, and processes – which require higher levels of abstraction and use of specific vocabulary (Duncan & Reiser, 2007; Ronald, 2011; Elmesky, 2013; Anderson et al., 2014). This may be particularly true for plants, which early learners tend to underemphasize (Patrick & Tunnicliffe, 2011; Wynn et al., 2017).

One approach to help students learn about inheritance is through use of scientific modeling (Rotbain et al., 2006; Venville & Donovan, 2008; Zangori & Forbes, 2014; Ibourk et al., 2017), one of the seven Science and Engineering Practices articulated in the *Next Generation Science Standards* (NGSS Lead States, 2013). Scientific modeling affords students opportunities to create representations of a phenomenon and display interactions and processes in an explicit way (Gilbert, 2004; Krajcik & Merritt, 2012). It has been shown to be effective to support elmentary students' learning about a diverse array of disciplinary concepts (Acher et al., 2007; Schwarz et al., 2009; Manz, 2012; Forbes et al., 2015; Louca & Zacharia, 2015; Zangori & Forbes, 2015; Zangori et al., 2017). However, we know little about how elementary students learn about heredity or how the use of scientific modeling can support students in reaching a deeper understanding of these concepts (Puig et al., 2017). To address this need, we developed a six-week,

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NGSS-aligned curricular unit that uses corn as a model organism to support third-grade students' learning about heredity. After the first iteration (year 1), the curriculum was refined (year 2) to foreground scientific modeling in student learning experiences. Here, we report on findings from research on the implementation of both versions of the curriculum to answer two research questions: (1) What are the differences in students' understanding of heredity-related concepts between a model-based curriculum and a non-model-based one? (2) How do students' ideas about heredity-related concepts differ between a model-based curriculum and a non-model-based one?

○ Methods

In this sequential and exploratory mixed-methods study (Creswell & Plano Clark, 2007), we compared evidence of student learning from two iterations of a third-grade curriculum focused on heredity-related concepts that addresses three target ideas about inheritance: life cycle, trait inheritance, and trait variation. The curriculum utilizes corn as a model organism. Since this project is situated in the Corn Belt of the United States, this is a plant species that is easily recognizable to students. Since many students hold persistent misconceptions about plants (e.g., Wynn et al., 2017), we hypothesized that foregrounding corn in a heredity-focused curriculum may increase elementary students' opportunities to learn about plants (Patrick & Tunnicliffe, 2011) and, ultimately, foundational heredity-related ideas. Informed consent from student and teacher participants and approval from the institutional review board were obtained for this study.

○ Curriculum Design & Implementation

The curriculum design, implementation, and research involved collaboration with teacher and partner school districts. We mapped the curriculum according to the standards and research (Duncan et al., 2009; NRC, 2012; Elmesky, 2013; NGSS Lead States, 2013), as well as our own previous research work on modeling practices in elementary science learning environments (Zangori & Forbes, 2014, 2015; Forbes et al., 2015; Zangori et al., 2017). The unit was focused on the three target concepts: trait inheritance, life cycle, and trait variation. The year 1 curriculum was refined to include model-based activities to support students' organization of ideas about processes and mechanisms of heredity (see curriculum sequence in Appendix A and examples of model-based activities in Appendix B) prior to implementation in year 2. The curriculum was implemented in third-grade classrooms by eight teachers in year 1 and by six teachers in year 2. All participating teachers were provided with instructional materials and resources before and during implementation.

○ Data Sources

We collected students' responses to unit-embedded tasks ($n_{\text{year1}} = 68$, $n_{\text{year2}} = 59$), which were included in both versions of the curriculum (for alignment of student tasks with year 1 and year 2 unit lessons, see Appendix C). The three student tasks were aligned with the three target concepts for the curriculum. Task 1 had students describe similarities and differences in the life cycle of a plant (corn) and an animal (chicken or butterfly) and was completed after learning about life cycle stages in plants and animals. Task 2 had students describe the characteristics of a seed, as well as the similarities and differences between seeds that evidenced different traits (e.g., color, shape), in lesson 5. In task 3, students compared and contrasted similarities and differences between a plant of teosinte (an ancient relative of corn) and modern corn and justify the selection of a particular type of organism on the basis of particular traits.

We also conducted semi-structured (Patton, 2002) student interviews ($n_{\text{year1}} = 21$, $n_{\text{year2}} = 21$) grounded in the student tasks to provide *in-depth* exploration of students' ideas regarding the three target concepts of the unit. Interview protocols were focused on elaboration of students' ideas around the three target concepts as elicited in each student task (Appendix D). Students were selected in collaboration with teachers to reflect a range of academic performance and interest in science. Student interviews ranged from 15 to 20 minutes and took place at the conclusion of the curriculum and during non-core-subject class times. Interviews were audio recorded and transcribed.

○ Data Analysis

We used parallel evidence from student tasks and interviews to compare both versions of the curriculum. First, we created rubrics (Appendix C) to score student tasks informed by research on learning progressions about heredity (e.g., Duncan et al., 2009; Elmesky, 2013). The rubrics considered four levels of understanding (scores 0–3). Student tasks were scored for the three target concepts, so each task had three different scores – one for life cycle, one for trait inheritance, and one for trait variation. We double scored 20% of the data to ensure inter-rater reliability; a level of 88% inter-rater reliability was achieved prior to discussion. Where we found discrepancies in the coding, we discussed and recoded our responses. In some cases, we made minor changes in the rubrics for clarification and accuracy. Ultimately, 100% inter-rater reliability was achieved after discussion.

Interviews were coded according to the three target concepts included in the curriculum by using a thematic analysis (Clarke & Braun, 2014). When a student mentioned an idea that was related to a particular target concept, this particular idea was labeled by student identification number and listed by target concept and implementation year. The list of ideas initially created was then refined and reorganized on the basis of target concepts. Coded data were queried to organize student responses by target concept. This process helped us create a narrative that described similarities and differences between both curriculum iterations and target concepts.

○ Results

Research Question 1

In research question 1, we asked, "What are the differences in students' understanding of heredity-related concepts between a model-based curriculum and a non-model-based one?" Table 1 presents students' composite scores by target concept for years 1 and 2. In two of the three target concepts, composite scores from students in year 2 were significantly higher than those from students in year 1. These differences were statistically significant, with high effect sizes for the target concepts of trait inheritance ($d = 0.9$) and

Table 1. Comparison of mean student scores by target concept and implementation year.

Target concept	Curriculum Iteration[a]	*n*	Mean ± SD	Min.	Max.	*t*	df	*P*
Life cycle	Year 1	68	2.41 ± 0.77	1	5	1.164	125	0.247
	Year 2	59	2.22 ± 1.04	1	5			
Trait inheritance	Year 1	68	2.97 ± 1.01	1	7	5.109	125	0.000
	Year 2	59	3.86 ± 0.96	0	5			
Trait variation	Year 1	68	3.29 ± 0.95	1	6	6.427	125	0.000
	Year 2	59	4.41 ± 1.00	1	6			

[a]Year 1: model-based curriculum; year 2: non-model-based curriculum.

trait variation (*d* = 1.14). No statistically significant difference, however, was observed in scores for the target concept of life cycle.

Figures 1, 2, and 3 present the distribution of students' responses based on their level of understanding by student task, curriculum iteration, and target concept (i.e., life cycle, trait inheritance, and trait variation). Overall, the distribution of student scores in both curriculum iterations suggests that in the majority of the target concepts and student tasks, the proportion of students at the higher levels of understanding tended to be greater in year 2 than in year 1. Furthermore, this trend tended to be stronger for the target concepts of trait inheritance and trait variation.

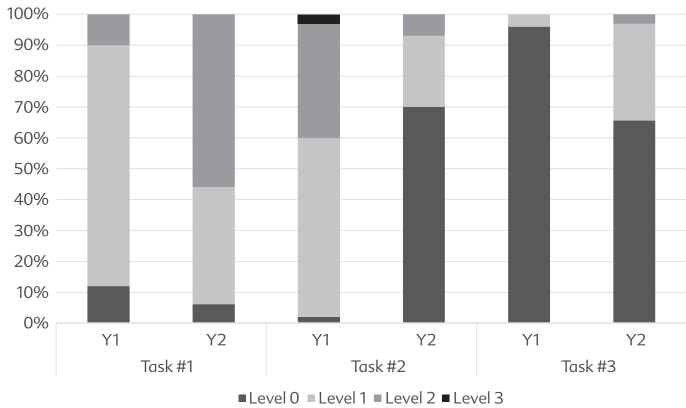

Figure 1. Proportion of students' responses to the life cycle target concept, according to level of understanding and student task.

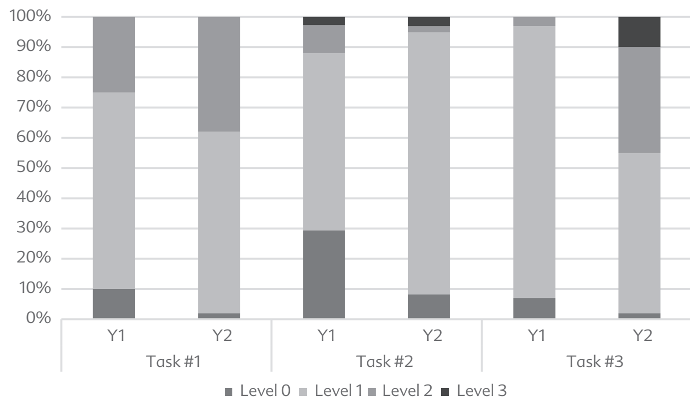

Figure 2. Proportion of students' responses to the trait inheritance target concept, according to level of understanding and student task.

Research Question 2

In research question 2, we asked, "How do students' ideas about heredity-related concepts differ between a model-based curriculum and a non-model-based one?" Some consistent trends were observed in students' responses in both years. Students recognized that plants and animals share life stages, that seeds can make a new plant, and that growth is a distinctive stage of the life cycle. For example, one student explained,

> First it's like a seed. . . . You have to put it in the ground and you have to wait over time. Then you can see part of it sticking out off the ground. . . . The second step is the next thing, so when it's like corn. It's growing. You can see the stem growing really high. (student 15)

Students also recognized corn traits and were able to explain that characteristics of a particular organism were specific, given its particular structures and functions. The majority of students identified specific traits in corn seeds and plants such as seed color and shape. Some students also referred to plant height and functional traits, such as drought or insect resistance. Students recognized different traits in seeds and adult plants and provided some explanations about the influence of the environment in trait expression.

However, differences were also observed when comparing the student responses from years 1 and 2. Overall, our findings show that in year 2, students made more connections between plant inheritance and the stages of reproduction within life cycles. Students also tended to use their specific knowledge about plant structures (e.g., the seed) and processes (e.g., reproduction) to make explanations about mechanisms of inheritance. By contrast, students' ideas in year 1 tended to focus more on the characterization of observable plant structures and traits, but their ideas tended to lack substantial connections to explain how plant structures and functions can support ideas about inheritance.

Life cycles (target concept 1). First, students in year 1 tended to focus on plant growth and corn production but to not include reproduction as a key stage that allows for making new seeds. They noted, for example, that "it's going to grow roots" (student 16) and "you can see the stem growing really high. . . . It's like growing

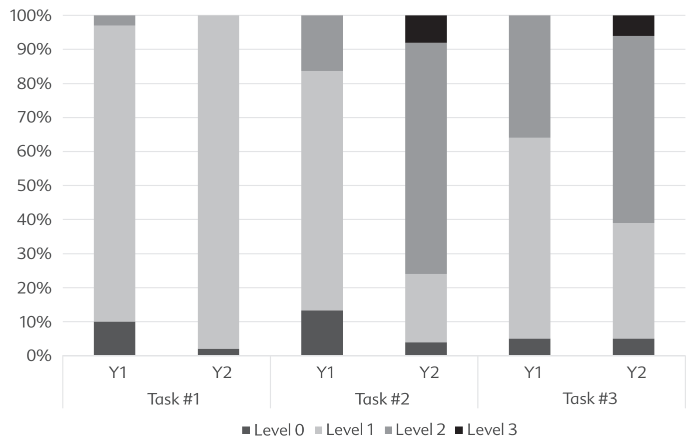

Figure 3. Proportion of students' responses to the trait variation target concept, according to level of understanding and student task.

corn around it" (student 37), but they rarely emphasized seeds or germination. By contrast, students in year 2 were more prone to include reproductive structures and processes as part of their life cycle descriptions. In year 2, the majority of the students interviewed (20 out of 21) described the process of germination and, within this, that seeds have specific components such as the embryo, the endosperm, and the seed coat. The majority of students described seed growth (or germination) as the stage that results in an adult plant and used specific vocabulary. They were able to identify some connections between plant structures and the plant life cycle by explaining that seeds, even after parent plants' death, can create a new organism. Several students also described the process of reproduction and its participant structures. For instance, nine out of 21 students explicitly mentioned the tassel as one structure that is involved in reproduction. They also described characteristics of reproduction in plants, such as that corn plants had "male" and "female" structures. Other students made explicit references to pollination ("You have to take some pollen from a blue corn and you have to mix it with the yellow one to make it yellow and blue" [student 107]) and fertilization ("The pollen gets on kind of like the eggs, and that's how they fertilize the eggs; and then the female part of the plant, it puts the eggs kinda on the leaves" [student 36]).

Trait inheritance (target concept 2). Second, the majority of students in year 1 (non-model-based) were able to identify characteristics and traits of corn seeds and plants, focusing on observable features such as size, shape, and color. For example, students in year 1 noted that plants were "not that tall" (student 94), "are green and then turn brown" (student 73), and "have the same shape of leaves" (student 50). However, fewer students in year 1 were able to explain that traits from the offspring resembled those of the parent plants. A few students indicated that seeds have instructions that guide plant growth. Only five students (out of 21) mentioned that seeds have an embryo, and only one student explained that the seed has information about traits that were passed on. By contrast, students in year 2 were not only able to identify plant traits in parents and offspring, but also were able to connect these traits with coded information that is passed on in the seed. Many students also recognized that this information from the parent plants provides specific "instructions" about the new plant's growth and development. The majority of students mentioned that (1) traits of a new plant are related to the parent plants' and (2) traits of the offspring resemble those of the corn parent plants. Students tended to describe the process of germination with accuracy, by making explicit references to seed structures. Students referred to the embryo as the structure that will make a new plant and/or has the "information" about traits. As an illustration of this trend, one student from year 2 explained that "the embryo stores the information from the parent plant . . . it needs information from the parent plant so it kinda knows how to grow" (student 44). Another student from year 2 explained that the seed makes a plant grow because

> it has coded instructions that make it look like the parent plant that provided the seed to grow. So those coded instructions make it look like what the parent plant looked like and grow how tall the parent plant. (student 18)

Moreover, some students used some processes and structures related to reproduction to explain inheritance, as illustrated in this quote (see prompt in Appendix B):

> Well the girl parts of the plant would be the silk, and the boy part would be the tassel, and each would be the parent part since it's the silk that would transfer . . . her coding instructions and the pollen from the tassel would transfer his part of the coding instructions there. (student 83)

Trait variation (target concept 3). Third, students in year 1 recognized that the expression of particular traits is influenced by the environment. For example, many students in year 1 recognized that a drought-resistant variety will have better outcomes in an environment of water scarcity (e.g., more yield, more height) compared to a traditional variety. However, while students in year 1 tended to describe different traits and that these traits are specific for a particular organism, students from year 2 tended to go beyond this level of reasoning, making some connections with the seeds and their coded information. They identified characteristics in corn seeds and plants, and specific traits within these characteristics. Students also explained that plant traits are affected by the environmental factors, pointing out how changes in particular environmental factors resulted in changes of trait expression. For instance, a student explained:

> Let's say I planted a corn seed in, in like the bottom of a road. Let's say this is a road. It will just break and die. But if it's in soil, it can easily get through. But get leaves and then get that flower on top and then pollinate all the other corn and then it can die, but it still has more corn. (student 102)

As illustrated by this quote, students in year 2 were better able to establish connections between the influences of environmental conditions on gene expression and, in turn, implications for successive generations of corn plants through reproductive processes.

○ Summary of Results

Our findings show that students experiencing the model-based version of the curriculum (year 2) held – for equivalent student tasks – more sophisticated ideas about two of three target concepts (trait inheritance and trait variation), in comparison to students experiencing the non-model-based (year 1) version of the curriculum. Based on student interviews, we also found differences in the types of ideas held by students experiencing the two versions of the curriculum. Students' ideas in year 1 tended to focus primarily on the characterization of observable plant structures and traits, but their ideas tended to be piecemeal and lacked substantial connections to explain how plant structures and functions can support ideas about inheritance. By contrast, students in year 2 started to make more connections between plant inheritance and the stage of reproduction within life cycles. Students also tended to use their specific knowledge about plant structures (e.g., the seed) and processes (e.g., reproduction) to make explanations about mechanisms of inheritance.

○ Discussion

Prior research has shown that heredity-related concepts are challenging topics for students of all ages (e.g., Ronald, 2011; Elmesky, 2013; Anderson et al., 2014), including early learners in grades K–5. However, these concepts are central outcomes for science learning (Duncan et al., 2009; NGSS Lead States, 2013). The results we present here contribute to the research body on elementary students' reasoning about heredity (e.g., Venville & Donovan, 2008; Cisterna et al., 2013) and model-based instruction in elementary science learning environments (Acher et al., 2007; Schwarz et al., 2009; Manz, 2012; Zangori & Forbes, 2014, 2015; Forbes et al., 2015; Louca & Zacharia, 2015; Zangori et al., 2017).

First, our findings show that students experiencing the year 2 (model-based) version of the curriculum held more sophisticated ideas about two of three target concepts (trait inheritance and trait variation) than did students in year 1. For elementary students, it is critical that curriculum design support students in addressing these concepts about heredity because they will form a foundation for learning in subsequent grades. The use of model-based curricula has the potential to help elementary students better organize their ideas about heredity (Venville & Donovan, 2008; Puig et al., 2017) and represent the complexity of science phenomena (Zangori & Forbes, 2014, 2015; Forbes et al., 2015; Zangori et al., 2017). Our results reinforce this perspective, and we argue that the inclusion of model-based tasks can help students organize and represent their ideas about trait inheritance and trait variation (Rotbain et al., 2006; Venville & Donovan, 2008).

Second, our findings illustrate ways in which students' ideas were more robust in year 2. Prior research suggests that students tend to struggle with making explanations about heredity-related concepts (e.g., Venville et al., 2005; Duncan & Reiser, 2007), specifically plant structure and function (Zangori & Forbes, 2015; Wynn et al., 2017). Evidence shows that students experiencing the model-based version of the curriculum made stronger connections between corn structures and processes and used their knowledge to explain how traits were passed from parent plants to offspring. Students were also able to recognize the role of the specific structures involved in plant reproduction (Lewis & Wood-Robinson, 2000; Tytler et al., 2004) and better understand that plants are living organisms (Barman et al., 2006; Zangori & Forbes, 2014). We tentatively posit that the model-based curriculum allowed students to sequence and organize their ideas (Krajcik & Merritt, 2012), make key processes and mechanisms about inheritance explicit (Duncan & Reiser, 2007; Ronald, 2011; Elmesky, 2013), and develop heredity-specific vocabulary (Venville & Donovan, 2008). Our results suggest that organizing a heredity-based curriculum around scientific modeling may support students' learning about target concepts such as trait inheritance and trait variation.

○ Limitations & Conclusions

We recognize the limitations of the present study. First, our comparative analysis of curriculum iterations is based on similar curricular tasks and student interviews. The student tasks, in particular, may not represent the complete variety of ideas about the three target concepts. Rather, these tasks were selected because they remained as comparable "checkpoints" in the two versions of the curriculum. Second, we did not include pre/post measures for these three target concepts that would have allowed us to more directly assess the impact of both curriculum iterations. Since students were not randomly assigned to the curriculum iterations, it is possible that observed differences do not account for preexisting differences in the populations of students. Future studies could replicate this research with a larger sample size of randomly assigned students and classrooms. Despite these limitations, and given the importance of developing students' heredity-related ideas from the earliest ages, this study provides in-depth evidence about elementary students' ideas about heredity-related concepts and contributes to efforts to support effective teaching and learning in the life sciences.

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Appendix A. Sequence of activities in both curriculum iterations.

Year 1 (Non-model-based)	
Lesson	Content and activities
1. Exploring midwestern state agriculture	• Using interactive digital maps • Putting corn within geographic and economic context of regional agriculture
2. The evolution of corn	• Putting corn in a historical context • Moving from teosinte to modern corn
3. Corn growth and life cycle	• Comparing plant and animal life cycles

(continued)

Continued

Year 1 (Non-model-based)		
4. Passing on traits: Focus on seeds	• Seed characteristics, seed structure and function, growth from seed to plant • Matching seeds to parent plants	
5. Variation in corn	• Investigation of corn types and traits • Characteristics are passed from generation to generation	
6. Influence of the environment	• Influence of environment on corn production and varieties	
Year 2 (Model-based)		
Lesson	Content and activities	Inclusion of modeling practices
1. How do corn plant structures function to meet basic needs?	• Observation and identification of corn structures • Recognition of survival needs of plants	
2. Developing models of corn life cycle	• Identification of life cycle stages for plants and animals • Comparison of plant and animal life cycles	Students develop a model that compares and contrasts life cycles of plants and animals
3. What is inside a seed?	• Corn seed dissection and observation • Compare and contrast corn seed traits	
4. Why do offspring parents look like parent plants?	• Developing a model for corn inheritance • Recognition that seeds carry "coded instructions" for traits • Prediction of possible offspring based on parent plant traits	Students construct, use, share, evaluate, and revise a model of inheritance in corn
5. Are all corn plants the same?	• Analyze data and create graphs of different traits in a corn population	Students create graphs to represent variation in traits
6. How does the environment affect corn growth and production?	• Identify variation in corn traits according to the influence of environmental traits	Students interact with a web-based game in which environmental factors affect corn production
7. Where did modern corn come from?	• Exploration about traits of modern corn and old teosinte • Students compare and contrast traits of both organisms	

Appendix B. Example of activities in the model-based curriculum.

Activity 5.1: Draw the life cycle of corn
Directions:

1. Draw a model that explains the life cycle of corn.
2. Label the important parts of your model.

Your model should:

- Include what a plant MUST HAVE to complete its life cycle
- Include what a plant MUST DO to complete its life cycle
- Explain HOW corn continues growing year after year

With a partner, USE your model to explain what happens to corn during the life cycle, why it happens, and how it happens.

Activity 8.1: Creating a model of inheritance Directions: 3. Draw a model that explains how a parent plant uses an embryo to produce offspring that looks and functions in a similar way. 4. Label the important parts of your model. Your model should: • Include what a plant MUST HAVE to make another plant • Include what a plant MUST DO to make another plant • Explain HOW the traits are passed from parent to offspring Evaluating and revising your model. With a partner, USE your model to explain why a corn seed grows into a corn plant.

Appendix C. Rubrics for student tasks.

1. Student task: Life cycle comparison	
Year 1 (Non-model based curriculum)	Year 2 (Model-based curriculum)
Task 3b. Comparison of life cycle of corn and butterfly	Task 2.4. Comparison between chicken and corn

Rubric			
	Concept: Life cycle	Concept: Trait inheritance	Concept: Trait variation
Level 1 (Novice)	Mention one stage of the life cycle OR Only mentions that organisms have “stages”/the “life cycle”	Identify at least one trait (physical, functional, food value, needs) OR Describes characteristics from the species (e.g., a corn plant has corn traits)	Identify traits (physical, functional, food value, needs)
Level 2 (Intermediate)	Describe two stages of the life cycle OR Recognize that seeds/eggs make a new organism OR Recognize that plants/animals reproduce	Identify traits in both organisms AND connect traits to different stages of development AND recognize that both organisms make offspring or reproduce	Mention differences in traits across life stages (e.g., the traits from the larvae are different from the adult) OR Recognize that individuals have different traits (within the same organism) OR Describe different traits for a particular characteristic
Level 3 (Advanced)	Describe three stages of the life cycle of both animals and plants AND Connect seeds/eggs to subsequent stages, including reproduction	Describe that organisms reproduce and that this implies passing traits from parents to offspring. (it may connect to coded information)	Describe diverse traits/ characteristics in both organisms (e.g., connected to function) AND Explains differences in life cycles stages and organisms

2. Student task: Seed characteristics	
Year 1 (Non-model based curriculum)	Year 2 (Model-based curriculum)
Task 4.1. What does a seed do? 4.2. What is a seed? 4.3. Are all the seeds the same?	Task 3.1. Dissecting a corn seed and making observations 3.2. Connecting seed structures to functions 3.4. Identifying plant traits (seed traits)

Rubric			
	Concept: Life cycle	Concept: Trait inheritance	Concept: Trait variation
Level 1 (Novice)	Mention one stage of the corn life cycle OR Mention that seeds make or grow plants. However, no details are provided OR Make only one connection between plant and animal life cycle OR Only mention the words "life cycle" or "passing traits"	Mention the words "trait," "characteristics," or "stuff" OR Make one example of plants characteristics resembling the parent OR Only describe that traits of the species are specific ("corn traits are of corn") OR Describe that a seed is just a product of a parent plant	Mention the seed looking like the plant they came from (but it is not descriptive) OR Mention one trait from a seed that is specific (examples may include: Pumpkin=Pumpkin and Corn=Corn) OR List one trait that is shared with other plants/animals (grow, making food, start a new life cycle)
Level 2 (Intermediate)	Mention two stages of the life cycle of corn OR Make two or more connections between plant and animal life cycles OR Describe seed/germination as first stage of growth. Some details are provided (e.g., different seeds grow into different plants)	Make clear connections between parent plants and a seed/new plant (e.g., mention parent or adult and include making seeds) OR Mention "passing" traits from parents, or that offspring comes from "somewhere" OR Mention parents and offspring resemble each other	List 2 or 3 characteristics or the specific traits OR Mention two ways a seed might be unique OR Describe traits of a plant (but doesn't connect to seeds traits)
Level 3 (Advanced)	Mention three stages of the life cycle AND Make three or more connections between plant and animal life cycles OR Describe the role of the seed in reproduction and inheritance	Connect to reproduction and inheritance and include parent/adult plants AND Describe that a seed is "carrier" of traits from a parent plant and/or pass coded info to the next generation OR Mention sexual reproduction or gametes OR Mention plants have male and females structures	List 4 or more characteristics and its traits similarities (different type) AND Describe that traits are "passing of traits from the adult" or "getting traits from an adult" OR Name 3–4 characteristics and specify the differences (it is not listing characteristics only)

3. Student task: Comparison between teosinte and corn	
Year 1 (Non-model based curriculum)	Year 2 (Model-based curriculum)
2.1. What are similarities and differences between teosinte and corn?	7.1. Comparing characteristics of teosinte and corn (complete all the questions that compare both plants)

Rubric			
	Concept: Life cycle	Concept: Trait inheritance	Concept: Trait variation
Level 1 (Novice)	Mention one stage of life cycle OR Mention a comparison point between plants, or to an animal	Name observable traits of the seed	Focus is on physical characteristics of both plants that can be easily observed OR Mention seed growth (e.g., seeds grow from the ground)
Level 2 (Intermediate)	Mention two life cycle stages OR Mention two comparison points between plants or to an animal	Make connections to the seed/ embryo OR Recognize that corn and teosinte traits are somewhat linked (e.g., old relatives)	Identify physical characteristics/traits (or palatability). Corn can be described as "edible" and a food source OR Describe relationships between traits and particular structures and functions
Level 3 (Advanced)	Describe three or more stages of life cycle (birth/start/ beginning, grow/make/ develop, reproduction/saving seed, death/harvest)	Connect different traits from the seed and the parent plant OR Make explicit connections to inheritance of traits (traits are passed from parents to offspring) or to coded information	Comparison foci: physical, palatability, time, seed as a source of energy, and aspects of food production or agriculture

Appendix D. Student interview protocol.

- Where do plants come from?
- What is a seed? How does a seed become a plant? Show pictures of a seed being planted – what will happen next?
- How are corn and chicken alike? How are they different?
- Why are some corn plants short and why are some tall?
- What is a trait?
- Can you think of an example of a trait that helps the corn plant grow in that year?