Nice to Run into 'Roo: Examining Middle School Students' Conceptual Understanding of Change over Time

Rochelle C. Cassells, Harini Krishnan, & Louisa A. Stark

Paper presented at the 2024 National Association for Research in Science Teaching International Conference

Subject/Problem

Evolution is fundamental to understanding biology and is widely accepted as a unifying cross-disciplinary concept in science, integrating content from multiple disciplines (Dobzhansky, 1973; Gould, 2002). The Next Generation Science Standards (NGSS; 2013) encourage vertical scaffolding for connecting and unifying evolution-related topics from early grades through high school (Borgerding, 2015; Gregory, 2009). Furthermore, research has shown that students who understand the concepts of heredity and inheritance are better able to grasp the concepts of evolution and change over time (Mead et al., 2017; Wyner & Doherty, 2017). However, these concepts are often disconnected in time across instruction (Mead et al., 2017); for example, inheritance may be taught in a different grade level from natural selection, which contributes to weaker conceptual understanding.

Despite its foundational importance, students often have difficulty understanding the concept of evolution (Nehm & Reilly, 2007; Nehm & Schonfeld, 2008). Previous research has shown that students have several misconceptions about change over time, some of which are often resistant to instruction (Gregory, 2009; Sinatra et.al., 2008). The most common student-held misconceptions about natural selection are rooted in misunderstandings about heredity (Bishop & Anderson, 1990; Kalinowski et al., 2010). In one study, Beardsley (2004) found that after receiving instruction on evolution, less than half of the eighth-grade students understood that traits acquired during one's lifetime cannot be passed onto offspring. Students often believe that organisms change because they want or need to adapt to changes in the environment (Nehm & Schonfeld, 2008). They also have a poor understanding of evolutionary time (Catley et al., 2010) and tend to believe that population-level changes happen quickly.

These findings are indicative of seductive alternative explanations that must be openly challenged in order for students to be ready to entertain new ideas (Glaze and Goldston, 2015). The current paper is rooted in the literature on conceptual change, most notably the work of Posner and his colleagues (1982), who argued that central concepts will only be accommodated if there is dissatisfaction with the current conception (i.e., the current concept fails to solve problems), and the new concept is understandable and able to solve past, present, and future problems. Vertical scaffolding and early instruction are insufficient in producing a strong understanding of evolution and change over time when a temporal discontinuity is present and where strongly-held alternate views abound.

In response to these findings, there have been calls for developing curriculum materials that position students as active sensemakers and give them opportunities to actively confront and work through their misconceptions (Andrews et.al., 2011; Murphy & Mason, 2006). The current study examines students' conceptual understanding of evolution and *change over time* following engagement with a novel, NGSS-friendly curriculum unit that integrates heredity and evolution concepts and is designed to address students' misconceptions.

Design

Students from four middle school science classrooms participated in this study. They were engaged in a five-six week-long week unit that integrates concepts from genetics and natural selection. The unit is comprised of four modules–*Traits, Inheritance, Reproductive Success,* and *Natural Selection* that incorporate central ideas used to explain change over time.

Each module has 3-6 NGSS-friendly activities that engage students in individual and collaborative work. This paper presents data from a subset of students who participated in paired student interviews, which were conducted within two weeks following the end of the unit. Students completed a performance task and the stimulated recall technique (Dempsey, 2010) with a classmate; the performance task and stimulated recall were counterbalanced across student pairs. This paper will only discuss results from the stimulated recall.

We purposefully selected five central activities from the four modules to administer the stimulated recall (descriptions not included due to space limitations). We asked students to elaborate aloud on their thinking as they re-engaged with the activities This paper will focus its attention on the unit's capstone activity called *MythUnderstood* as it best represents the integration called for by science (biology) curriculum developers.

MythUnderstood

While most of the activities in the unit focused on one or two science ideas in isolation, *MythUnderstood* integrates the four scientific ideas needed to offer an accurate and complete explanation of *change over time* (see Table 1). These critical ideas also run parallel to popular misconceptions about evolution held by students (Gregory, 2009). In this activity, the students read illustrated tall tales about how certain animals acquired their traits and identify the myths in the stories (Kipling, 2009).

During classroom implementation, students were instructed to compose a more accurate version of what could lead to new traits in a population and were given the four scientific ideas to guide their thinking (see Table 1). However, the stimulated recall employed a different methodology; students were asked to identify where the story got the scientific idea wrong and offer an explanation based on what they learned during the unit. The stimulated recall employed open-ended questioning to organically generate the science ideas from students. This approach is more suitable for revealing conceptual accommodations.

Table 1: *Science ideas explored in MythUnderstood*

Science Idea 1	Individuals' genetic traits vary because of mutation and recombination during reproduction— not because they decide to change them.
Science Idea 2	Only differences in genetic traits can pass from parents to offspring. Traits an individual acquires during their lifetime are not inherited.
Science Idea 3	Natural selection acts on a population, not an individual organism.
Science Idea 4	It takes many generations for a trait to become common in a population

The *MythUnderstood* activity was preceded by the other four activities in the stimulated recall interview. Therefore, students had reviewed each of the central concepts prior to completing this activity except the level at which natural selection operates and evolutionary time. Students were given four of the *MythUnderstood* stories during classroom implementation, but only *"Nice to Run into 'Roo"* was used for the stimulated recall as it poses moderate difficulty compared to the others. The text from this illustrated story is presented below:

> *Long long ago, Kangaroo was a very different animal. Slim-legged and slow-moving, with thick gray wool. She had no interest in running around all day. But, that did not matter to Dingo, because Dingo was very hungry. Afraid, Kangaroo ran away and Dingo ran after her. Through forests, she ran. And deserts she ran. Over mountains she scrambled. And rivers she leapt. Across grasses and shrubs, she hopped. Her hind legs growing stronger, her wool blown away. Her front legs growing smaller, her tail grew thicker. And just when it seemed that the Kangaroo was done for, she used all her new attributes–long strong feet and legs, a thick powerful tail and sleek fur and finally left Dingo in the dust. And all Kangaroo's children and their children too have been that way ever since.*

Participants

Participants were selected based on student interest, teacher input, and classroom observations by researchers during curriculum implementation. The authors observed students' engagement in the classroom based on whether they were actively sensemaking (Odden & Russ, 2019) or doing school (Jiménez-Aleixandre, et.al., 2000). The students were interviewed in groups of two or three allowing for collaboration and naturalistic peer influence. A total of 21 groups across the four classrooms participated (see Table 2; teacher names are pseudonyms). Please note Ms. Katerina participated in a pilot study enactment of the unit the prior year and was the only returning teacher participant. There were initially three groups from her classroom, but since she was the first to complete the implementation, two groups from her classroom were used to validate our protocol. Principal, teacher, and parent permissions were obtained per the institutional IRB requirements; district approval was also obtained where required.

Table 2: *Number of student groups per teacher*

Teacher	*# of student groups*
Ms. Visenya	7
Ms. Katherine	7
Ms. Sasha	6
Ms. Katerina*	1

Data Analysis

The student interviews were audio recorded and transcribed. We analyzed the interview data and traced student ideas that aligned with or indicated one of the four science ideas in Table 1. While some students used keywords that could be connected to the science ideas (such as acquired traits, mutations, etc.), others presented their ideas in everyday language. For example, in one student's explanation, no keywords were present that could be traced to the science ideas from Table 1:

> *"It's that they just think that just from running for a little, that you can get different genes, and stuff-**I just think that what they (the story) got wrong is that they think that from just running for a little while they can just, automatically, change and have different traits in genes and stuff.** So from then, they said, from then, on, ever since it's*

been that way" (Maxine, when asked to elaborate why the changes in the traits of the Kangaroo are not possible)

However, her use of the words *"they think that from just running for a little while"* indicated that the student was thinking how traits acquired during one's lifetime (for example, by running) cannot be passed on to the offspring and that the process of change takes a long time.

Our analysis considered a group of students interviewed together as one unit of analysis. In other words, if a science idea was expressed by one student in the group, we counted the idea for the whole group. We decided to keep the group as our unit of analysis for two reasons. Firstly, students were asked during the interview whether they agreed or disagreed with their peers. Secondly, disagreements or divergent ideas within pairs seldom occurred without researcher prompting.

Findings

Our analysis revealed that middle school students had difficulties identifying and explaining problems in the scientific ideas pertaining to evolution and change over time. Figure 1 shows the percentage of student groups who could identify the problems in the story with respect to the science ideas in Table 1. The majority of student groups were able to identify and explain that Kangaroo's traits in the story were acquired and could not be inherited by her offspring (science idea 2, 81%) and that the changes in the traits cannot happen in a short period of time (science idea 4, 72%). However, only 42% of the student groups were able to articulate that the trait changes in the Kangaroo population are not possible when only the traits of a single kangaroo are altered (science idea 3). Only five student groups (24%) across the four classrooms could identify the problems in the story and discuss all four science ideas from Table 1.

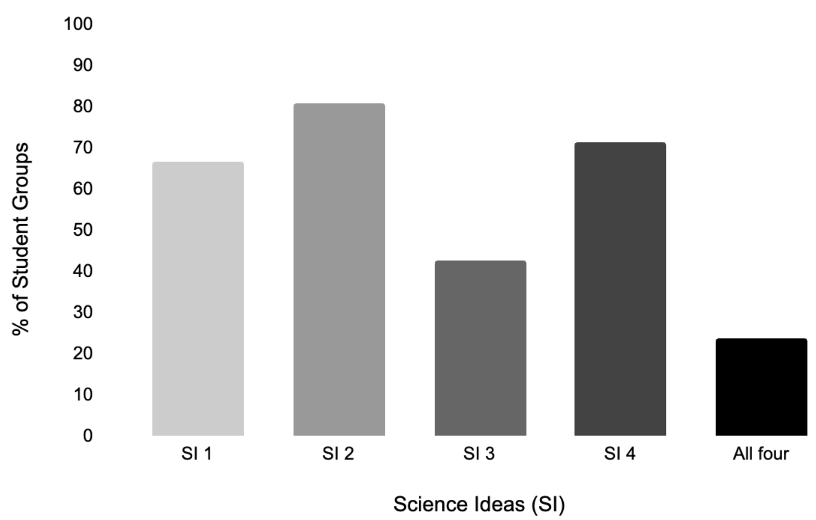

Figure 1: Percentage of student groups identifying the Science Ideas (SI) from Table 1 in the story, individually and combined

The initial reaction of the majority of the students after reading the story *"Nice to Run into 'Roo"* was incredulity. Most of them felt that the story was exaggerated *("It's just like an obviously exaggerated fairytale"; "I know animals can run a lot, but for probably a few weeks?*

That's insane. And I know I can barely run a mile within 15 minutes"; "Your fur can't just blow away. I mean, you can lose hair and fur, but it can't just blow away in the wind"). Thus, students' initial reaction indicated an awareness that the story was not scientifically sound.

The results showed that all the groups were able to identify problems with at least one of the four science ideas presented in Table 1. However, many groups were unable to explain the scientific rationale. In other words, the students knew that the story got the science idea wrong but were unable to argue why based on the evidence covered in the unit. For example, with respect to the first science idea in Table 1, 14 out of the 21 groups of students (67%) demonstrated their awareness that the Kangaroo cannot change her traits just because she wanted to, but only 7 groups expressed that mutation could be one of the mechanisms by which the Kangaroo had different traits *("If the Kangaroo looked like this (with long, strong feet and legs, a thick, powerful tail and sleek fur), through evolution or mutations or different things, it might happen and they might end up looking like this, but they can't happen over just one run").* It is worth noting that even though this student was able to articulate the mechanism while others could not, there remains some fuzziness in the concepts. In the quote above mutation and evolution appear synonymous in their mind, which indicates persistent misunderstanding.

Discussion and Contributions

The current study examined students' conceptual understanding and use of heredity and evolution concepts to explain *change over time* after engagement with an NGSS-friendly curriculum unit connecting the concepts of genetics and natural selection. The activities in the unit targeted misconceptions prevalent among students about heredity, natural selection, and change over time, in line with prior research suggesting that in order to facilitate conceptual change in students, they need to explicitly engage with the misconceptions (Kalinowski et al., 2013; Nehm & Schonfeld, 2008).

Our analysis shows that, in spite of students engaging in activities that incorporated science practices and gave them opportunities for sensemaking about ideas that are components of understanding evolution, they struggled to link the ideas together to provide full explanations of evolutionary-related concepts. While the individual activities were designed to support the students in developing an understanding of and connections within each concept, the students were not able to make connections across the unit, as seen from their responses to *MythUnderstood*. Significant gaps remained in students' ability to use inheritance concepts to explain natural selection and change over time.

This work suggests that more effort is needed during instruction to both frame and connect the different topics across the unit. Engaging students in learning via science practice-based experiences is not enough for them to make connections across the multiple ideas involved in a full understanding of change over time. Although the unit provided guidance for teachers in the understandings students should gain from each module, additional supports may be needed. In order to study teacher implementation and student learning in the most likely adoption format, teachers participating in this study did not receive professional development on implementing the freely-available online unit before enactment. Future work may seek to understand how the teachers' own conceptual understanding of evolution supports or interferes with the way an integrated unit is perceived, framed, and implemented.

References

Andrews, T. M., Leonard, M. J., Colgrove, C. A., & Kalinowski, S. T. (2011). Active learning not associated with student learning in a random sample of college biology courses. *CBE—Life Sciences Education, 10*(4), 394-405.

Beardsley, P. M. (2004). Middle school student learning in evolution: Are current standards achievable?. *The American Biology Teacher, 66*(9), 604-612.

Bishop, B. A., & Anderson, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching, 27*(5), 415-427.

Borgerding, L. A., Klein, V. A., Ghosh, R., & Eibel, A. (2015). Student teachers' approaches to teaching biological evolution. *Journal of Science Teacher Education, 26*(4), 371-392.

Catley, K. M., Novick, L. R., & Shade, C. K. (2010). Interpreting evolutionary diagrams: when topology and process conflict. *Journal of Research in Science Teaching, 47*(7), 861-882.

Dobzhansky, T. (1973). Nothing in biology makes sense except in the light of evolution. *The American Biology Teacher., 35* (3), 125-129.

Glaze, A. L., & Goldston, J. (2015). U.S. science teaching and learning of evolution: A Review of the literature 2000-2014. *Science Education*, *99*(3), 500-518. https://doi.org/10.1002/sce.21158

Gould, S. J. (2002). *The structure of evolutionary theory.* Harvard university press.

Gregory, T. R. (2009). Understanding natural selection: essential concepts and common misconceptions. *Evolution: Education and Outreach, 2*(2), 156-175.

Jiménez-Aleixandre, M. P., Bugallo Rodríguez, A., & Duschl, R. A. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science education*, *84*(6), 757-792.

Kalinowski, S. T., Leonard, M. J., Andrews, T. M., & Litt, A. R. (2013). Six classroom exercises to teach natural selection to undergraduate biology students. *CBE—Life Sciences Education, 12*(3), 483-493.

Kipling, R. (2009). *Just so stories for little children.* Oxford University Press.

Mead, R., Hejmadi, M., & Hurst, L. D. (2017). Teaching genetics prior to teaching evolution improves evolution understanding but not acceptance. *PLoS biology, 15*(5), e2002255.

Murphy, P. K., & Mason, L. (2006). Changing knowledge and beliefs. *Handbook of educational psychology*, *2*, 305-324.

Nehm, R. H., & Reilly, L. (2007). Biology majors' knowledge and misconceptions of natural selection. *BioScience, 57*(3), 263-272.

Nehm, R. H., & Schonfeld, I. S. (2008). Measuring knowledge of natural selection: A comparison of the CINS, an open-response instrument, and an oral interview. *Journal of Research in Science Teaching, 45*(10), 1131-1160.

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academy Press.

Odden, T. O. B., & Russ, R. S. (2019). Defining sensemaking: Bringing clarity to a fragmented theoretical construct. *Science Education*, *103*(1), 187-205.

Posner, G. J., Strike, K.A., Hewson, P.W. & Gerzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66(*2), 211–227.

Sinatra, G. M., Brem, S. K., & Evans, E. M. (2008). Changing minds? Implications of conceptual change for teaching and learning about biological evolution. *Evolution: Education and Outreach, 1*(2), 189-195.

Wyner, Y., & Doherty, J. H. (2017). Developing a learning progression for three-dimensional learning of the patterns of evolution. *Science Education, 101*(5), 787-817.