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Enhancing Student Explanations of Evolution: Comparing Elaborating and Competing Theory Prompts

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Abstract

In this study we explore how two different prompt types within an online computer-based inquiry learning environment enhance 392 7th grade students' explanations of evolution with 3 teachers. In the *elaborating* prompt condition, students are prompted to write explanations that support the accepted theory of evolution. In the *competing* prompt condition, students are prompted to write explanations that differentiate two views of evolution associated with Darwin and Lamarck. Data sources included a pretest and posttest, an embedded item, observations, logged teacher guidance, and teacher interviews. Findings show similar pretest to posttest gains in students' understanding of evolution for both conditions, but this pattern was not uniform across all three teachers. For one teacher, students who received competing theory prompts produced significantly higher gains than those who received elaborating theory prompts. A closer look at embedded student work reveals a higher degree of teacher participation (i.e., grading and guidance) than for the other teachers. Our findings illustrate how helping students distinguish between competing scientific claims can support learning in an inquiry unit, but may require a higher degree of teacher participation and reinforcement. We discuss the implications of these findings for enhancing students' scientific explanations.

Keywords: science explanations, prompting, evolution, knowledge integration, online learning

Introduction

Understanding complex and potentially controversial topics in science, such as evolution, often requires distinguishing between plausible ideas to develop valid and coherent understanding. For example, while the ideas of Darwin and Lamarck were both considered plausible in different historical contexts, exploring their differences highlights underlying mechanisms of evolution (Jensen & Finley, 1996). In this study, we examine how students develop an understanding of evolution while studying a unit that simulates habitat destruction in virtual experiments. We compare two forms of inquiry prompts. In the *elaborating* condition, students are prompted to write explanations that support the accepted theory of evolution. In the *competing* condition students are prompted to write explanations that differentiate two views of evolution associated with Darwin and Lamarck. We compare how each of these prompting approaches impacted students' scientific explanations.

Facilitating student construction of scientific explanations is both a priority in science instruction (National Research Council, 2011) and a substantial challenge (Krajcik, Blumenfeld, Marx, Bass, & Fredericks 1998). Students have limited experience interpreting, writing, and justifying explanations (Krajcik, et al., 1998; Sadler, 2011; Sandoval & Reiser, 2004). However, students develop better explanations when provided with increased opportunities to write and receive effectively designed inquiry prompts (Osborne & Patterson, 2011; Sandoval, 2003; Wang, 2015). Additionally, inquiry prompts can be further enhanced by teacher guidance when teachers draw on nuanced knowledge of their students (Fogleman, McNeill, & Krajcik, 2011). In this study, we explore alternative prompt approaches within a computer-based inquiry learning environment to investigate the following research questions:

- Is an elaborating or a competing prompt more likely to help students improve their understanding of evolution during an inquiry unit?
- How do variations in teacher implementation of the unit impact student learning outcomes?

Alternative Explanations of Evolution

Evolution is a slow process that can be difficult to observe directly, particularly for certain species. For this reason, early theorists such as Darwin and Lamarck disagreed about the mechanisms of evolution (Gillispie, 1958). Darwin's view centered on survival and reproduction of organisms with adaptive traits. Lamarck's view, which preceded Darwin's, centered on the inheritance of acquired characteristics.

This historical controversy provides an opportunity for students to distinguish divergent views and develop a coherent understanding of evolution. Middle school curriculum can take advantage of these opportunities by illustrating the development of ideas relating to evolution in a historical context (Cook, 2009; Jensen & Finley, 1996; Kampourakis & McComas, 2010; Passmore & Stewart, 2002) and depicting controversies related to these ideas (e.g., the "Scopes Trial", Duveen & Solomon, 1994; Mead & Scharmann, 1994). In addition to clarifying the differences between alternative models of evolution, the historical context provides students with an opportunity to see science as an ongoing, accessible, and relevant activity (Linn & Eylon, 2011).

Prompting for Better Explanations

When teaching topics with alternative, plausible explanations, instructors can either focus on normative ideas or address a range of alternatives (Glaze & Goldston, 2015; Schwendimann & Linn, 2016; Yasri & Mancy, 2016). In this investigation, we compare prompts designed to ask students to articulate the accepted theory to those designed to ask students to consider two competing theories. The elaborating theory approach focuses students on strengthening their central argument (Driver et al., 1996; Mayer, Dow, & Mayer, 2003). The competing theory approach encourages students to engage directly with potentially conflicting ideas to determine how evidence fits with alternative ideas (Davis, 2003; Linn & Eylon, 2011; White & Frederiksen, 1998; 2000). In the context of evolution, the latter approach would place more critical attention on the views of Lamarck, whose views are now considered incorrect.

Each of these approaches may have benefits and drawbacks. A number of researchers have noted that children often display intuitive ideas that are similar to Lamarck's, e.g., changes due to environmental effects can be inherited (Brumby, 1979; Engel Clough, & Wood-Robinson, 1985; Kampourakis & McComas, 2010). Some consider students' ideas to be stable, persistent misconceptions that are highly resistant to change and should be thought of as resources for cognitive development as opposed to ideas to be replaced (Enderle, Smith, & Southerland, 2009; Evans and Lane, 2011; Smith, diSessa, & Roschelle, 1994). In this case, instruction should address students' ideas directly, thus allowing them to weigh alternative ideas for new insight (Chi et al., 1989; Renkl, 2014; Mulder, Lazonder, & De Jong, 2014; Osborne & Patterson, 2011; Sandoval, 2003; Sinatra, Brem, & Evans, 2008). However, even with opportunities to consider alternative ideas, students may instead develop hybrid frameworks of normative and non-normative ideas rather than completely rejecting non-normative ideas (Evans & Lane, 2011).

Effective instructional approaches are needed to help students overcome naïve scientific views (Posner, Strike, Hewson, & Gertzog, 1982). Several studies indicate the value of instructional approaches that include some form of comparison to support students in developing more sophisticated understanding (Gadgil, Nokes-Malach, & Chi, 2012; Gil et al., 2010; Ziegler & Stern, 2016). For example, high school and university students develop better explanations when reading texts with competing theories as opposed to students who read about the two theories in separate texts (Rukavina & Daneman, 1996).

For the topic of evolution, comparison type approaches have been suggested by having explicit instruction on the Lamarckian perspective (Enderle et al., 2009; Jensen & Finley, 1996; Passmore & Stewart, 2002). In one such curriculum (Passmore & Stewart, 2002), students explored different "models" of evolution including Darwin and Lamarck's, as well as Intelligent Design. The students studied evidence that is typically used to support each of the alternative models, and then investigated the capacity of each model to explain the other models' evidence. For example, a Lamarckian model could not explain why some animals, trained for a specific task, produce offspring with no more inherent capacity for the task than untrained animals (Passmore & Stewart, 2002).

Other researchers argue against introducing non-normative ideas directly in the curriculum. In the context of a controversial topic, Cherif, Adams, and Lehr (2001) suggest that historical and narrative context are avoided in favor of a more evidence-centered approach to reduce introduction of entrenched points of views. Although Cherif et al. (2001) were specifically attempting to avoid religious arguments against evolution, this approach may be equally valid for Lamarckian ideas because of their intuitive appeal. Likewise, others focus on reconstructing evolutionary ideas through guided activities and simulations, rather than focusing on historical narratives (Demastes, Settlage, & Good, 1995; Fifield & Fall, 1992; Geraedts & Boersma, 2006).

This study investigates whether the task of evaluating competing theories makes the curriculum more effective than the task of finding evidence solely for the accepted theory (Chin & Osborne, 2010; Hoadley, 2000; Linn & Eylon, 2011; Sampson & Clark, 2008). Despite the tradeoffs inherent in these prompting alternatives, studies from a range of science disciplines show benefits for each approach (Davis, 2000; Raes et al., 2012; Sandoval & Reiser, 2004). In general, competing theories may foster deeper engagement and produce more robust outcomes, but elaborating the accepted theory may be more efficient (Linn & Eylon, 2011).

To inform educators and designers we compare these approaches, and consider the conditions that lead to one being more beneficial than another. In particular, given that explaining competing theories may be more challenging than explaining the accepted theory, the teacher is likely to play a critical role in the effectiveness of these prompting approaches.

Role of the Teacher

Teachers can reinforce the impact of instruction (Linn & Eylon, 2011) or undermine the curriculum unit or experimental treatments (Barab & Luehmann, 2003; Penuel & Means, 2004). Teachers impact how students perceive and thus engage in classroom activities (Vitale et al., 2015; Hutchison & Hammer, 2010). For example, teachers' prompts may focus on logistical aspects of a classroom, where they mostly encourage students to add ideas for 'completion' (Donnelly, McGarr, & O'Reilly, 2014; Vitale et al., 2015; Linn & Eylon, 2011). In contrast, teachers' prompts may concentrate more on conceptual aspects, where they encourage students to distinguish and to reflect on ideas to develop coherent understanding (Fishman et al., 2003; Linn & Eylon, 2011)

Online inquiry learning environments provide new opportunities for teachers to give students guidance within and outside of class through real-time monitoring and guidance tools (Donnelly, Linn, & Ludvigsen, 2014). However, teachers may differ in how they take advantage of such features (Cuban, 1986). Also, when using such online features, similar approaches to classroom practice may emerge, where teachers focus on logistical aspects such as completion, rather than prompting students to distinguish or reflect on what they have written (Vitale et al., 2015). Hence, how often students are prompted to add ideas or consider competing ideas may vary significantly across teachers.

Curriculum Design for Knowledge Integration

In this study, students explored the hypotheses of two important evolution-focused scientists, Darwin and Lamarck, in the context of habitat destruction. In the unit, students investigated important concepts of evolution, such as how variation within various populations leads to survival of those with beneficial characteristics, how those that reproduce pass their traits to their offspring, and how evolution occurs over many generations with changes in the overall population (Kampourakis & Nehm, 2014). Students investigated a series of simulations that depicted changes to populations of fish, visualized in a pond, to distinguish among the hypotheses of each scientist (See Method Section for more detail on the simulations).

The habitat destruction unit was designed following the Knowledge Integration (KI) framework that involves eliciting, adding, distinguishing, and reflecting on ideas (Linn & Eylon, 2011; Williams et al., 2012). Student ideas were elicited by asking them to make predictions about which pond would have fish with a faster average speed and why, given conditions of the pond. Students added ideas by studying a video about habitat destruction designed to support debate amongst students. Students then used the simulations to explore the impact of habitat destruction, distinguishing and reflecting on how this impact connected to evolution.

The simulations provide students with direct evidence of evolutionary processes that impact populations over long time periods (Pusceddu et al., 2014; Driver et al., 1996). The simulations also illustrate how habitat destruction impacts the evolution of fish populations (Faria & Chagas, 2012; Puig et al., 2012; Vincent & Harris, 2014). Using the simulations, students conduct experiments comparing the traits of different fish populations under varied environmental conditions (See *Figure 1*) such as food scarcity (Mazzei, 2008; Tereul, 2006). The simulations allow students to test whether acquired traits are directly inherited (i.e., "Lamarackian evolution") or whether adaptive traits increase in a population through natural selection (i.e., "Darwinian evolution").

[Insert Figure 1 here]

The simulations were designed to provide evidence for the Darwinian understanding of evolution. To help students understand this complex theory, we guide students to link predictions, evidence, and conclusions to construct a coherent narrative (Ha, Haury, & Nehm, 2012; Long, 2012; Linn & Eylon, 2011). The challenge of helping students link ideas across multiple investigations is further complicated by students' potential affinity for Lamarckian ideas. We designed guidance to clarify normative ideas about Darwinian evolution. We reviewed the unit to ensure that Lamarckian ideas were not inadvertently reinforced. To support distinguishing ideas, students were prompted to compare their predictions and their findings. Students reflected on these experiments throughout, but demonstrated their overall understanding after conducting all of the fish experiments, by explaining evolution.

To help students keep track of their elicited ideas and evidence throughout the unit, an "Idea Basket" icon was available for students to click on and add new ideas as they completed the unit. Students could also share ideas 'publicly' with their classmates using the Idea Basket, but only within their assigned condition. Previous research has illustrated that prompting students to add to an Idea Basket throughout a unit helps students develop and organize their ideas, and write better explanations, as opposed to asking student to write complex scientific explanations solely from memory (Matuk & King Chen, 2011; Matuk & Linn, 2014; 2015). Building on this previous research, the Idea Basket provides an embedded assessment that allows us to evaluate the impact of the prompts.

Study Design for Knowledge Integration

Along with the curriculum, the KI framework also informed the design of this study. Despite arguments for or against teaching competing theories of evolution, as previously discussed, the KI framework suggests that students will have more coherent scientific explanations if they are effectively supported to add and distinguish ideas, as opposed to only being encouraged to add ideas (Linn & Eylon, 2011). Building on the adding and distinguishing features of the KI framework, our intervention investigates how prompting focused on adding accepted ideas of evolution (elaborating theory condition) versus prompting focused on adding and distinguishing ideas of evolution through Darwin and Lamarck (competing theory condition) affect students' overall explanations. If the competing theory condition were properly supported, the KI framework would predict that students in this condition should develop more sophisticated explanations of evolution.

Method

Participants

Four-hundred-and-sixteen 7th grade students (12-14 years old) taught by three different teachers from one of two middle schools in the western United States participated. Three-hundred-and-ninety-two of these students answered the same 4 items for the pretest and posttest, one of which was a transfer item on global climate change (GCC). Students also answered an embedded item 'Explain Evolution'. The 24 students not included were either absent and/or did not complete one or more of the items to be analyzed. To ensure that students from different conditions could not collaborate in a face-to-face discussion, teachers randomly divided their classrooms into two sections and assigned a different condition to each section. Students completed the pretest and posttest individually, but completed the unit in pairs, including the 'Explain Evolution' item.

All three teachers (referred to as Jane, Rose, & Tom) had previous experience teaching the unit. At Jane and Rose's school there were 25% of students eligible for free lunch, while Tom's school had 32% of students eligible for free lunch. All teachers had access to enough laptops for their students, all teachers had previous experience using the open-source online learning environment including the habitat destruction unit, and all teachers had attended professional development summer workshops focused on supporting student inquiry using the online learning environment, factors identified as important in the literature (Donnelly, McGarr, & O'Reilly, 2011; Edelson, Gordin, & Pea, 1999; Linn & Eylon, 2011). Before the study, the teachers were only told that the study involved different prompts to see what effect they had on students' explanations. The teachers were unable to view students' ideas in the Idea Basket within the online learning environment, but could view responses to other steps. Teachers did not receive specific training or professional development for this study.

Web-based Inquiry Science Environment (WISE)

The prompts were embedded in a unit on habitat destruction called "Ocean Bottom Trawling, What a Drag!" within the Web-based Inquiry Science Environment (WISE; wise.berkeley.edu). WISE is an open-source inquiry learning environment consisting of multiple middle and high school science curriculum units. WISE has features designed to promote knowledge integration such as virtual experiments, graphing, and modeling

(Donnelly, Linn, & Ludvigsen, 2014). WISE features teacher tools such as a 'Classroom Monitor' that allows teachers to view student essays and give guidance on student responses. Students completed all activities in the unit including five fish race virtual experiments.

The unit required 7 50-minute classes to complete, including the pretest and posttest. Teachers generally supported students in completing the unit through technical support signing into WISE, setting time limits for activities to be completed, and answering conceptual questions throughout the unit as needed. Teachers also had brief openers at the start of lessons that asked students to answer questions on material they had covered in the previous lesson, before continuing on with the unit. For example, teachers would ask students what they found out in a particular fish experiment and what that might suggest about evolution.

The five fish race virtual experiments were designed to illustrate key features of evolution. The first three experiments focused on genetic inheritance while the last two experiments highlighted variation and selective pressure. In the first experiment, students investigated the speed of fish in two similar ponds (Pond A and Pond B), finding their average speed to be about the same. In the second experiment, Pond A was fed slow fish food while Pond B was fed faster fish food. Students then found that fish from Pond B had a higher average speed than fish in Pond A. For the third experiment, students investigated the average speed of offspring from Pond A and Pond B from the second experiment under same pond conditions as Experiment 1. Students found that the speed of the parents had not been inherited by the offspring.

In the fourth experiment students investigated the average speed of fish from Pond A and Pond B, where Pond B had less food than needed for the amount of fish in the pond. Students found that Pond B fish had a much higher average speed than Pond A fish as a result. For the fifth experiment, students investigated the offspring of Experiment 4 under normal conditions and found that Pond B fish still had a higher average speed than Pond A fish and hence, the trait was inherited.

Prompt Designs

Using the idea basket, a WISE feature that is continuously present while students complete the unit, students were prompted to add ideas after each activity. In the competing theory condition students were asked to add two ideas, one that related to Darwin and one that related to Lamarck. Students in the elaborating theory condition were asked to add two ideas about evolution. Having students in the elaborating theory condition add two ideas made the task demands in both conditions as similar as possible. *Table 1* includes some examples of the prompts for each condition. There were six distinct prompts for the idea basket in total throughout the unit, before students answered the 'Explain Evolution' item embedded towards the end of the unit. This embedded item came after the students had completed all five of the fish race virtual experiments. When students shared ideas publicly, the ideas were only shared to classmates within their condition. No ideas were shared across the two conditions through the WISE platform.

[Insert Table 1]

Data Sources

Data included four pre- and post-test items, an embedded prompt to 'Explain Evolution', observations, teacher guidance provided to students throughout the unit, and teacher interviews. The pre- and post-test items included four items, three about evolution concepts and one transfer item about climate change. The three items on evolution concepts were a fruitfly/elephant item about the rate of reproduction of each specie, a giraffe item about how giraffes evolved to have long necks, and a guppies item asking if different colors of guppies is beneficial for the species' evolution. The climate change item asked students to consider two graphs of climate change and explain which had the better evidence to support climate change. This item addresses how climate change emerges as an overall trend in noisy data over a long period of time and links to a similar concept of evolution as a process emerging over many generations.

For the embedded item 'Explain Evolution', students were given the opportunity to sort their ideas, collected in the Idea Basket, into spaces labeled as "Ideas about: Lamarck's theory" and "Ideas about: Darwin's theory" in the competing theories condition or "Ideas about: Natural selection" and "Ideas about: Inheritance" in the elaborating theory condition. This provided students in the competing theories condition another opportunity to distinguish between the competing claims of each theorist, while in the elaborating condition students had an opportunity to think about two general themes related to evolution. Following the sorting of ideas, students wrote an explanation for the 'Explain Evolution' item.

Observations were used to gain insight into each teacher's implementation of the unit, in particular to see how teachers interacted with students and if there was regular or limited teacher prompting within the classroom. We were also interested to see if the teachers implemented the unit in ways that we may not have anticipated.

Teachers were familiar with the 'Teacher Comments' feature in WISE where they could give students additional guidance on students' responses. We did not ask teachers to use this feature. Teachers typically do not use this feature during class time, as they are interacting with students. Instead teachers often use these features after class when reviewing student work (Linn & Eylon, 2011). All information from the 'Teacher Comments' feature was logged within WISE.

Finally, after the posttests were completed, the first author interviewed teachers in a semi-structured format that lasted 15-20 minutes. The two conditions were explained to teachers and teachers were simply asked to discuss what they saw as the advantages and disadvantages of either approach. The purpose of these short interviews was to have some discussion from teachers that may provide insight on findings from the analysis of the pre/post items.

Data Analysis

We developed rubrics aligned with the KI framework to analyze all four pre/posttest items and the embedded item (Linn & Eylon, 2011). KI rubrics typically involve assigning a student a score from 0-5, thus the three evolutionary items gave a combined score of 0-15. These scores are intended to support students in moving from non-normative or partial ideas to more normative and complex ideas for a more sophisticated understanding. The development of these KI rubrics involved several rounds of discussion and iteration that focused on the key ideas for each question and how links were made between these ideas. *Table 2* provides an example of the rubric for the

'Guppies' item. For this item, students were asked 'Small fish called guppies can be many different colors. Do you think this variation helps them? Please explain your answer'.

[Insert Table 2]

Initial coding was conducted on 50 responses of each item by two researchers. The initial coding was discussed by all researchers and refinements were made to each rubric before the larger data set was analyzed. The majority of the coding was conducted by the second and fourth author, and the first author facilitated discussion on resolving disagreements in the coding. Consistent with previous research involving the use of KI rubrics (Donnelly, Vitale, & Linn, 2015), interrater agreement was generally high for the second and fourth authors. The interrater agreements for the items were 82.7% for the 'Giraffe' item (kappa = .70, 784 responses), 81.1% for the 'Fruitfly' item (kappa = .67, 784 responses), 80.3% for the 'Guppies' item (kappa = .68, 784 responses), 91.3% for the 'Global Climate Change' item (kappa = .86, 764 responses), and 94.3% for the 'Explain Evolution' item (kappa = .81, 392 responses).

Results

Pretest and Posttest

The pretest results showed that students had limited prior knowledge about evolution. On the pretest students averaged about 2.5 on the KI scale. On the posttest they averaged close to 3 on the KI scale. Both conditions made significant gains. There were no differences by condition (see *Table 3*).

[Insert Table 3]

To determine whether condition interacted with prior knowledge we looked at performance of low prior knowledge (LPK) and high prior knowledge (HPK) students.

Effect of prior knowledge

There was no interaction between condition and prior knowledge for students overall ($F (2, 390) = .641$, $p = .424$), so we looked at the performance of LPK and HPK students. We formed the LPK and HPK groups using a median split of students' overall score on the pretest. The average score in the pretest was 7.72, so students scoring 7 or less were categorized as LPK while students with 8 or higher were categorized as HPK. The results of this categorization are shown in *Table 4*.

[Insert Table 4]

Overall the treatment had more impact on LPK, although this result is also consistent with regression towards the mean. Comparing gain scores for LPK and HPK, there is a significant difference in favor of LPK students ($F (1, 391) = 16.09$, $p = 0.001$). The proportion of LPK students did not differ significantly across the three classes (Rose: 61 LPK, 68 HPK; Jane: 53 LPK, 81 HPK; Tim: 59 LPK, 70 HPK; $\chi^2(2) = 1.8$; $p > .1$).

Effect of teacher

To investigate interactions between teacher and condition, we analyzed effects by teacher. Students of each teacher made significant pretest to posttest gains (see *Table 5*).

There was a significant teacher effect for pre/post scores, with students in teacher Rose's class starting with the lowest scores and making the greatest gains (F (2, 390) = 7.65, p = 0.001).

[Insert Table 5]

There was also an interaction between teacher and condition. Results show that teacher Rose's students made significant gains in both conditions (see *Table 6*) and were more successful in the competing theory condition than in the elaborating theory condition (F (1, 127) = 4.03, p = .047). There was no significant effect of condition for teacher Jane (F (1, 132) = 3.22, p = .075) or teacher Tim (F (1, 127) = 0.19, p = .663). Teacher Rose's students gained more than students in each condition taught by the other teachers (see *Table 6*).

[Insert Table 6]

Effect of Conditions on a Transfer Item (Climate Change)

For the transfer item on climate change, there was a significant gain for 382 of the 392 students who completed the pre/post item (see *Table 7*). There was no effect of condition overall for the transfer item (F (1, 381) = .115, p = .824) or between condition and teacher (F (2, 380) = 10.36, p = .109), but similar to the 3 core items, there was an effect for teacher (F (2, 380) = 46.08, p = .001).

[Insert Table 7]

For the climate change item, there was no effect of condition for each teacher (Jane: F (1, 132) = 2.52, p = .335; Rose: F (1, 117) = 3.01, p = .085; Tim: F (1, 127) = .115, p = .735). Thus the condition effect found for teacher Rose was not maintained for the transfer item.

Embedded Item

The embedded item was completed within the final activity of the unit. When we control for pretest, there is an effect of teacher (Jane, School A: n = 73, M = 4.94, SD = 1.03; Rose, School A: n = 72, M = 4.81, SD = .91; Tim, School B: n = 70, M = 3.38, SD = 1.00; F (2, 213) = 59.96, p = 0.001). Jane's and Tim's students scored higher overall in the elaborating theory prompt condition while Rose's students did better in the competing theory prompt condition (see *Table 8*).

[Insert Table 8]

When we control for pretest, there is also a teacher by condition interaction (F (2, 213) = 11.19, p = 0.001; *Table 8*).

A total of 105 pairs received teacher guidance from Jane and Rose on the 'Explain Evolution' item. Tim did not provide guidance to his students using WISE. The 105 pairs who received guidance from Jane and Rose had significant gains overall in WISE (Table 9). A repeated measure on overall pre/post scores for students receiving guidance showed no difference in gain by teacher (F (103, 2) = 0.28, p = .858). Similarly, no difference was found by condition (F (103, 2) = 1.66, p = .200).

[Insert Table 9]

We looked at each teacher individually that gave guidance on the 'Explain Evolution' item and found no effect of condition for Jane (F (54, 2) = 2.01, p = .162), but there was a significant effect of condition for Rose in favor of the competing theory condition (F (47, 2) = 16.48, p = 0.001; Table 10).

[Insert Table 10]

Teacher Guidance

In WISE, teacher's guidance prompts and scores reflect engagement with student work (Gerard et al, 2015). The teachers demonstrated nuanced approaches in their use of the guidance tools (see *Table 11*).

[Insert Table 11]

There is a large effect for use of guidance tools since teacher Tim did not provide comments or scores to students. Both Rose and Jane provided comments and scores. These comments were not pre-set, so teachers were free to write any comments they wanted. Jane and Rose differed from each other in their number of comments. As rows 1 and 2 display, all three teachers had over 1600 opportunities to provide comments across 23 steps that asked students to write a response. These 23 steps were writing steps that did not include the 6 prompts for the Idea Manager. Rose commented on significantly more (41%) of these steps than Jane (20%).

In regards to scoring (*Table 11*, Rows 3 & 4), Rose and Jane did not differ from each other in either total number of steps scored or in the number of unique steps scored. Notably, Rose scored significantly more writing steps than Jane; although, the number of unique steps scored was similar.

These results suggest that both Rose and Jane utilized the WISE teacher tools to provide guidance and maintain student accountability, but differed in their emphasis. For the 'Explain Evolution' item, Rose provided 37 unique comments to students and 27 repeated comments. Jane provided only 2 unique comments to students and 54 repeated comments [$\chi^2(1) = 37.6$, $p < .001$]. While many of Rose's comments were variations on a single theme, they demonstrate greater attention to the characteristics of student responses than those of Jane. Rose asked students to clarify ideas consistent with the response of the student. For example, when students made clear reference to the controversy between Lamarck and Darwin, the teacher encouraged the students to explain differences more clearly (see *Table 12*).

[Insert Table 12]

To further illustrate the effect of Rose's guidance on both conditions, we provide examples of students' explanations and revised explanations alongside Rose's guidance (see *Table 13*).

[Insert Table 13]

Teacher Comments on the Prompts

All three teachers indicated advantages and disadvantages for elaborating and competing theory prompts. In terms of the elaborating prompt condition, teachers tended to explain that the prompt would keep things simple for students. Jane, for example, explained that focusing on only one theory results in "less confusion with the kids". However, the advantage of the elaborating prompt to keep things simple also led to the disadvantage of not representing the contested nature or historical aspects of science.

> *"The disadvantage would be you don't get the historical picture you don't get the scientific method you don't get like the idea of how you figure things out in science."*
>
> Rose

> *"There are other theories, you know people have different ideas, and it takes a lot of evidence to prove one or the other. It isn't just one guy comes along thinks up this stuff."*
>
> Jane

For the competing theory prompt, all teachers indicated positive aspects especially for the students they considered higher level who are better prepared to distinguish ideas based on the evidence presented.

> *"I think the higher level students have an easier time understanding sort of the history that there was this one and then there was this other evidence and then now this one is accepted and they somehow grasp the big picture better."*
>
> Rose

> *"Top students are going to be more engaged. They would be, get more out of looking at different ideas and see how ideas may have been changed."*
>
> Tim

Teachers discussed many issues with the competing theory, in terms of assessment and in terms of students' overall perception of the teacher. For assessment, Rose explained that students can doubt their understanding of Darwin when they see a question mention

Lamarck as "[7th graders] are so suggestible", while Tim expressed concerns that students would think he was teaching the wrong ideas about evolution.

> *"They get it, they talk about Darwin, and then the test comes along and it says you might want to talk about Lamarck but in their mind they are oh gosh I was thinking it was Darwin but it must be Lamarck and they change."*
>
> Rose

> *"Some kids don't get all the information and may misinterpret and think that I am actually a proponent for an incorrect theory*."
>
> Tim

Overall, teachers were not unanimous in their preferred instructional condition. Jane preferred the elaborating theory prompt as "It's much more straightforward just doing the one theory". Rose stated that she favored the competing theory prompt condition, but emphasized the importance of making "sure we really understand the accepted version". Tim, like Rose, also favored the competing theory condition:

> *"I like the idea that students get to see how the ideas that we have today what we believe to be true today, how they come about, why we think this way I think that's an important part of learning."*
>
> Tim

Discussion

In general, the two conditions were equally beneficial to student learning, as illustrated by the pre/post-test improvement. Since both conditions benefitted from knowledge integration guidance, this is understandable. Consistent with prior research on knowledge integration (and regression towards the mean), students with low prior knowledge learned significantly more than those with high prior knowledge (Donnelly et al., 2015). These results show the benefit of guidance for low prior knowledge students.

Students of each teacher made significant gains from pretest to posttest, but Rose's students learned more overall, consistent with Rose's use of more comments and grades than the other teachers. The significant effect for condition found for teacher Rose, favored the competing theory approach. Along with the effect for competing theory prompting, Rose's students in the elaborating theory prompting condition also had greater gains than students taught by the other two teachers. This is consistent with the overall emphasis on knowledge integration in both conditions. Because teacher Rose refined her guidance depending on the student response she strengthened both conditions and revealed an advantage for the competing condition.

Teachers often adapt and use technology in ways that support their existing practice (Donnelly et al., 2011; Cuban, 1986). Each teacher in this study was familiar with the WISE platform, but they took three distinct approaches to the 'Teacher's Comment' guidance tool within WISE. Teacher Tim provided no online guidance, preferring students to complete the unit independently. Similar to our observations, he only intervened in class when students sought assistance. Teachers Jane and Rose provided online guidance with distinct approaches. As evidenced in the 'Explain Evolution' step, teacher Jane provided the same generic comment to all students, encouraging them to add more ideas. Teacher Rose used a generic comment for some students, but also provided more frequent individualized and targeted prompts that encouraged students to distinguish between ideas. Based on our classroom observations, both Jane and Rose were active in monitoring and supporting students' progress throughout the unit.

The learning outcomes of students for each teacher align with previous research that illustrates the importance of teacher guidance (Ruiz-Primo & Furtak, 2007; Gerard et al., 2015; McNeill & Krajcik, 2009). In a review of inquiry-supported instruction, Furtak et al. (2012) found learning gains for inquiry based curricula, but these gains tended to be greater when students were supported with teacher guidance. This synthesis clarifies why teacher Rose and Jane's students did better than Tim's in the embedded item, as he provided limited guidance to students.

Research shows that guidance providing students with individualized, targeted guidance that focuses on integrating ideas results in better learning outcomes than procedural and logistical guidance (Gerard et al., 2015; Ruiz-Primo & Furtak, 2007; Vitale et al., 2015). Rose and Jane both provided effective guidance. As was evident from Rose and Jane's comments, Rose provided many individually tailored comments to her students while Jane provided guidance aimed at increasing ideas to all of her students. The more nuanced guidance provided by Rose may account for the greater gains of Rose's students compared to Jane's. While Jane focused on adding ideas (a necessary step if students lack ideas), Rose focused on distinguishing ideas (consistent with the importance of distinguishing ideas in the KI framework).

Despite the teachers expressing concerns about students choosing an incorrect theory, our quantitative results indicate that there is no clear risk of introducing alternative ideas by directly addressing Lamarck's ideas through prompts. Students in the competing theories condition were no more likely to express incorrect "Lamarckian" ideas than those in the elaborating condition. Thus introducing alternative models of evolution (Jensen & Finley, 1996; Passmore & Stewart, 2002) provides a good opportunity for students to develop normative concepts and engage with science practices (National Research Council, 2012). However, these results also suggest that the value of addressing competing theories is moderated by the classroom teacher. A classroom teacher, such as Rose, helps to reinforce distinctions between alternative ideas by paying close attention to students' work. Distinguishing between alternative theories is a challenging task for students so responsive teaching is necessary to guide students through this process.

More generally, this study reinforces the importance of the teacher in the implementation of inquiry instruction (Penual & Means, 2004). In addition, the results illustrate an unanticipated consequence of the comparison study. Guidance was left to teachers' discretion for this study. Although we encouraged the teachers to follow their usual instructional practices, following the implementation, teacher Tim expressed reluctance to interfere with the experiment by providing student guidance. In contrast, teachers Rose and Jane saw their role as guiding students to foster learning across both conditions. These practices were consistent with the teachers' prior use of WISE units. Future research is needed to compare guidelines for teacher guidance and to clarify when encouraging guidance aligned with the treatment is beneficial.

Limitations

The results of this study are limited by the curriculum and conditions of implementation. They may not generalize to other similar curriculum materials, topics, schools, and teachers. They deserve testing in other contexts and with different curriculum units.

Certain features of the inquiry unit may have contributed to the results discussed here, including the lack of differences between conditions for some teachers. In particular, to focus our experiment on a single feature of the curriculum (guidance prompts), thereby avoiding confounds, both sets of students engaged in a largely similar curriculum. Because all students were introduced to both Lamarck and Darwin this study cannot be considered a comparison between a contextualized and decontextualized curriculum, although our results suggest that a contextualized curriculum is more likely to generate robust gains when the teacher plays a proactive role. The way in which context forms, and in some cases restricts student ideas, is one of the most important open topics in learning research. The evolutionary context represents an ideal area to study how intuitive non-normative ideas play a role in contextual development. We advocate for continued study in this area.

Additionally, the affordances of the Idea Basket, may have inadvertently reduced differences between conditions. In particular, while other online activities could be reviewed by the teacher in WISE, Idea Basket responses were not directly available to teachers. Although we believe that students were unaware that their Idea Basket responses would not be reviewed by teachers, we do not know whether students exerted similar effort for these responses as other formats. In future work we plan to continue the investigation of the competing theories approach with a wider range of student tools and greater teacher access.

Conclusions

The results of this study raise important questions about how we design guidance within online curriculum units. As this study suggests, guidance is valuable in multiple formats. In addition, if students are effectively guided by the teacher to distinguish amongst competing ideas, they develop deeper understanding than when guided to elaborate on ideas. Automated guidance studies have shown some promise in offering not just additional, but targeted prompts to encourage further revision by students (Gerard et al., 2015). These results offer insight for both design of automated prompts and design of professional development for inquiry teaching.

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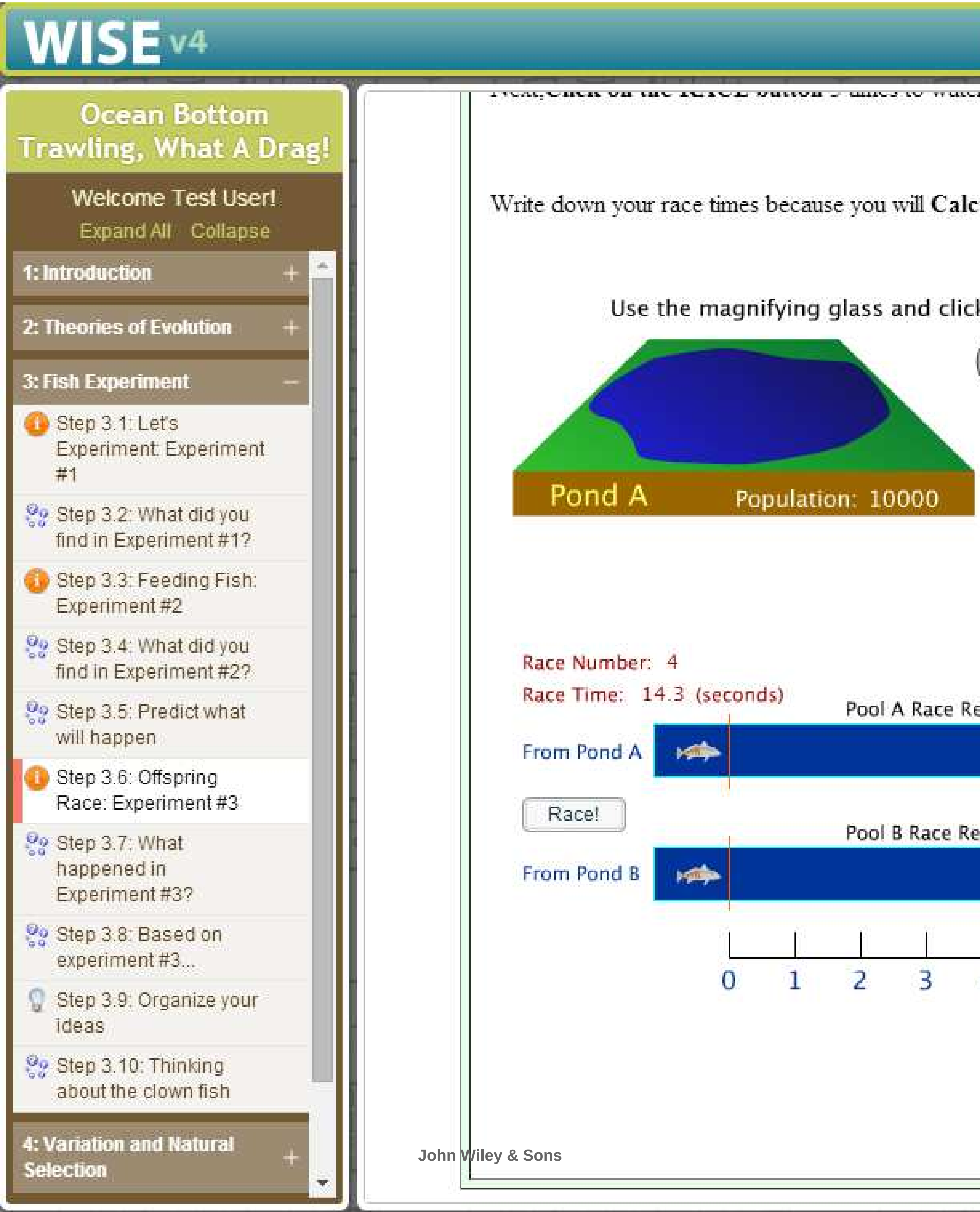
WISE v4
Ocean Bottom Trawling, What A Drag!
Welcome Test User!
Expand All Collapse
1: Introduction
2: Theories of Evolution
3: Fish Experiment
Step 3.1: Let's Experiment: Experiment #1
Step 3.2: What did you find in Experiment #1?
Step 3.3: Feeding Fish: Experiment #2
Step 3.4: What did you find in Experiment #2?
Step 3.5: Predict what will happen
Step 3.6: Offspring Race: Experiment #3
Step 3.7: What happened in Experiment #3?
Step 3.8: Based on experiment #3...
Step 3.9: Organize your ideas
Step 3.10: Thinking about the clown fish
4: Variation and Natural Selection
Write down your race times because you will Calc
Use the magnifying glass and click
Pond A
Population: 10000
Race Number: 4
Race Time: 14.3 (seconds)
Pool A Race Re
From Pond A
Race!
Pool B Race Re
From Pond B
0
1
2
3

Table 1 – Examples of Elaborating Versus Competing Theory Prompts

Prompt Number	*Elaborating Theory Prompts*	*Competing Theory Prompts*
2	Use the evidence from the three experiments to add: two more ideas related to evolution.	Use the evidence from the three experiments to add: one more idea related to Darwin's theory AND one more idea related to Lamarck's theory.
3	In experiments 4 and 5 you observed how selective pressures and variation affect a population of fish. Add: two ideas about how this evidence is related to evolution.	In experiments 4 and 5 you observed how selective pressures and variation affect a population of fish. Add: one idea about how this evidence is related to Darwin's theory AND one idea about how this evidence is related to Lamarck's theory.
5	Choose two of YOUR best ideas to make public. One idea should be related to population or many generations. The other idea should be related to variation or natural selection.	Choose two of YOUR best ideas to make public. One idea should be related to Darwin's theory of evolution. The other idea should be related to Lamarck's theory of evolution.

Table 2 – Sample of Knowledge Integration Rubric for the Guppies Item

KI Score	Student Response Type	Example(s)
0	No answer	…
1	I don't know or Off-task response	idk
2	Irrelevant or Non-normative ideas	They have adapted in a specific way for a specific reason, therefore it is most likely necessary.
3	Partial Idea - not linking to consequences of the variation, focus on individual rather than population as a whole.	I think this variation helps because different fish have different strengths so some might be good at different things than others which can benefit both fish.
4	One Link - Variation allows some members of a species to survive certain: conditions, diseases, threats. OR population level thinking	I think this variation helps because if predators start to be able to hunt large guppies, the small guppies will still survive, and increase the population. This way, if predators can only hunt one type of guppy, the guppies don't have to worry about extinction.
5	Two links - Variation allows some members of a species to survive certain: conditions, diseases, threats. AND population level thinking (as opposed to individual survival rate)	I think this variation does help because the different colors help them survive better. It might help them blend in with their environment. Also, different color scales may also mean other variations. Without variation, evolution could not occur. If all the fish in the pond were exactly the same, one environmental change/disease could wipe all the fish out. There would be no evolution happening.

Table 3 - Overall Score of the Combined Pre/Post Items

Pre/Post Items	*n*	*Mean Gain*	*Mean Pretest Score (SD)*	*Mean Posttest Score (SD)*	*t*	*p*	*d (ES)*
Total	392	1.06	7.72 (1.41)	8.78 (1.73)	14.79	<.001	0.67
Elaborating	199	1.06	7.67 (1.42)	8.73 (1.76)	10.79	<.001	0.67
Competing	193	1.05	7.78 (1.4)	8.83 (1.71)	10.11	<.001	0.67

Table 4 – LPK and HPK score gains

Prior Knowledge	*n*	*Mean Gain*	*Mean Pretest Score (SD)*	*Mean Posttest Score (SD)*	*t*	*p*	*d (ES)*
LPK	173	1.38	6.5 (.74)	7.88 (1.38)	12.90	0.001	1.24
HPK	219	0.81	8.69 (1)	9.50 (1.64)	8.66	0.001	0.60

Table 5 - Overall Score of the Combined Pre/Post Items by Teacher

Pre/Post Items	*n*	*Mean Gain*	*Mean Pretest Score (SD)*	*Mean Posttest Score (SD)*	*t*	*p*	*d(ES)*
Jane – School A	134	0.90	7.81 (1.42)	8.71 (1.79)	7.42	0.001	0.56
Rose – School A	129	1.45	7.59 (1.44)	9.04 (1.82)	10.83	0.001	0.89
Tim – School B	129	0.83	7.75 (1.37)	8.58 (1.56)	7.61	0.001	0.57

Table 6 - Gains by Condition and Teacher

Elaborating Theory	***n***	***Mean Gain***	***Mean Pretest Score (SD)***	***Mean Posttest Score (SD)***	***t***	***p***	***d (ES)***
Jane	67	1.12	7.73 (1.56)	8.85 (1.99)	6.6	0.001	0.63
Rose	62	1.19	7.52 (1.27)	8.72 (1.66)	6.56	0.001	0.82
Tim	65	0.88	7.75 (1.41)	8.63 (1.63)	5.47	0.001	0.58

Competing Theory	**n**	***Mean Gain***	***Mean Pretest Score (SD)***	***Mean Posttest Score (SD)***	**t**	**p**	**d (ES)**
Jane	67	0.69	7.90 (1.27)	8.58 (1.57)	4.0	0.001	0.48
Rose	62	1.73	7.68 (1.61)	9.40 (1.93)	8.96	0.001	0.98
Tim	64	0.78	7.77 (1.33)	8.55 (1.50)	5.26	0.001	0.56

Table 7 – Gains on climate change Item Overall and by Teacher

Pre-Post	*n*	*Mean Gain*	*Mean Pretest Score (SD)*	*Mean Posttest Score (SD)*	*t*	*p*	*d (ES)*
Overall	382	0.75	2.82 (1.43)	3.57 (.91)	9.4	.001	0.63
Jane	134	1.07	2.60 (1.64)	3.67 (.92)	6.97	.001	0.81
Rose	119	.90	2.89 (1.49)	3.79 (.83)	6.31	.001	0.75
Tim	129	.28	2.98 (1.10)	3.26 (.89)	2.70	0.08	0.28

Table 8 - Scores on the Embedded Item - Explain Evolution (Elaborating Theory (Elab. Theo) And Competing Theory (Com. Theo).)

Teacher	*n*	*Mean Score (Overall)*	*n (Elab. Theo)*	*M (Elab. Theo)*	*SD (Elab. Theo)*	*n (Com. Theo)*	*M (Com. Theo)*	*SD (Com. Theo)*
Jane	73	4.94	37	5.18	1.0	36	4.69	1.0
Rose	72	4.81	37	4.43	.93	35	5.20	.72
Tim	70	3.38	34	3.62	.95	36	3.14	1.0

Table 9 – Pre/Post Teacher Guidance Scores on 'Explain Evolution' Item

	n	*M*	*Pre (SD)*	*Post (SD)*	*t*	*p*	*d*
Overall	105	0.97	3.82 (1.28)	4.79 (1.01)	9.08	0.001	0.85
Jane	56	1.07	3.79 (1.32)	4.86 (1.05)	7.02	0.001	0.91
Rose	49	0.86	3.86 (1.24)	4.71 (0.96)	5.77	0.001	0.77

Table 10 – Pre/Post Guidance Scores by Condition

Teacher – Condition	*n*	*M*	*Pre (SD)*	*Post (SD)*	*t*	*p*	*d*
Jane – Elaborating	25	1.16	3.96 (1.49)	5.12 (1.09)	4.53	0.001	0.91
Jane – Competing	31	1.00	3.65 (1.17)	4.65 (.98)	5.39	0.001	0.94
Rose – Elaborating	23	0.74	3.39 (.99)	4.13 (.87)	3.23	0.001	0.81
Rose – Competing	26	0.96	4.27 (1.31)	5.23 (.71)	4.91	0.001	0.93

Table 11 – Teacher Use of Guidance Tools

Measure	*Rose School A*	*Jane School A*	*Tim School B*	*χ^2(2) Rose vs. Jane vs. Tim*	*χ^2(1) Rose vs. Jane*
1. Comments on written steps (out of # - differs by class size)	704 (1709)	343 (1679)	0 (1770)	912.0 ***	170.0 ***
2. Comments on unique written steps (Out of 23 possible steps)	20	9	0	35.8 ***	9.3 **
3. Scores on written steps (out of # - differs by class size)	1471 (1709)	1306 (1679)	0 (1770)	3166.3 ***	38.8 ***
4.Scores on unique written steps (Out of 23 possible steps)	20	18	0	42.6 ***	0.2

*** $p < .001$ ** $p < .01$ * $p < .05$

Table 12 - Comparison between guidance comments from Rose and Jane

Teacher	*Unique comments to "Explain Evolution"*	*# reps*
Rose	Use the opener from 2/4 as a guide for the process of evolution. Be sure you've explained the whole process.	20
	Good start. Use the opener from 2/4 as a guide for the process of evolution. Be sure you've explained the whole process.	5
	those are my words, not yours	1
	This is not really correct. Please call me over today to help you work this out.	1
	The start of this is great. When you start to compare Darwin and Lamarck, I am getting lost in your logic. Can you explain it a little more clearly? Use the opener from 2/4 as a guide for the process of evolution. Be sure you've explained the whole process.	1
	this is a good start. Use the opener from 2/4 as a guide for the process of evolution. Be sure you've explained the whole process. If you are going to talk about Darwin and Lamarck, be sure to differentiate between them, and to talk about who turns out to be right.	1
	[30 more unique comments]	
Jane	Your explanation should include all 4 parts of evolution we discussed in 2/4/14 warm-up and evidence for each part	55
	Your explanation should include all 4 parts of evolution we discussed in 2/4/14 warm-up and evidence for each part re-read Darwin's theory to improve your answer	1
	[0 more unique comments]	

Table 13 – Examples of Rose's Guidance on Student Work

Student/ Condition	Initial Explanation	Teacher Guidance	Final Explanation
1/ Elaborating	Evolution is living things changing over generations to adapt to their surroundings.	Use the opener from 2/4 as a guide for the process of evolution. Be sure you've explained the whole process.	Evolution is living things changing over generations to adapt to their surroundings. For evolution to occur, there has to be variation, or a difference in a population. Selective pressure or natural selection can cause evolution, but may cause some to die. Also, only in many generations, there can be small changes in the species. For example, the fish in experiment 5 evolved from their parents, so they could survive and they evolved by their parents having selective pressure.
2/ Elaborating	French scientist Lamarck proposed that the mechanism of evolution is the USE AND DISUSE of physical characteristics of individual members of a species. Evolution occurs through two important ideas, which are Inheritance and Natural Selection. Charles Darwin, an English naturalist, proposed that NATURAL SELECTION was the mechanism for evolution. Species evolve in order to survive when put under selective pressure. Lack of a food source, a home, and other resources are examples of selective pressure.	This is a good start. Use the opener from 2/4 as a guide for the process of evolution. Be sure you've explained the whole process. If you are going to talk about Darwin and Lamarck, be sure to differentiate between them, and to talk about who turns out to be right.	French scientist Lamarck proposed that the mechanism of evolution is the USE AND DISUSE of physical characteristics of individual members of a species. Evolution occurs through two important ideas, which are Inheritance and Natural Selection. Charles Darwin, an English naturalist, proposed that NATURAL SELECTION was the mechanism for evolution. Species evolve in order to survive when put under selective pressure. Lack of a food source, a home, and other resources are examples of selective pressure and may lead to some individuals to die. Through the process of natural selection, individuals with advantageous traits survive to reproduce.
3/ Competing	If there was variation in a population, then one species would die because they wouldn't have the necessaries to survive and the small bit of the population that has it would be able to survive and make babies and eventually the species without it would die off.	Try again. Part of this is incorrect. Use the opener from 2/4 as a guide for the process of evolution. Be sure you've explained the whole process.	If there was variation in a population, then one group would die because they wouldn't have the necessaries to survive and the small bit of the population that has it would be able to survive and make babies and eventually the species without it would die off. The variation in this experiment are big and smaller tails. The selective pressure can cause some to die. Through the process of natural selection, individuals with advantages genetic traits survive to reproduce. Over many generations, different changes that happen can add up to the group evolving.

4/ Competing	Evolution is when a species changes from one way to another in a advantage way. There is always variation in a population, some fish are quicker than others. For evolution to work, there has to be selective pressure, like lack of food. If there is a lack of food, the faster fish would take all the food, while the slower fish dies. This is called natural selection. After many generations, the faster fish dominate, and the slower fish dies.This is just one example of evolution. There are many theories of evolution. For example. Darwin and Lamarack's theory. Lamarack's theory say that offspring can have parents learned abilities, while this is false, in experiment 5, this can work, it is really a genetic trait, not a learned trait. Another counter-example of lamarack's theory is that in experiment 3, the offspring does not get the speed that the parents had. Darwin's theory on the other hand says that offspring dont get the learned traits, is true, if it is a genetic trait, it is false. So another theory could be that darwins theory work if it is a learned, enviremental trait, while lamaracks theory work when it is a genetic trait.	The start of this is great. When you start to compare Darwin and Lamarck, I am getting lost in your logic. Can you explain it a little more clearly? Use the opener from 2/4 as a guide for the process of evolution. Be sure you've explained the whole process.	Evolution is when a species changes from one way to another in a advantage way. There is always variation in a population, some fish are quicker than others. For evolution to work, there has to be selective pressure, like lack of food. If there is a lack of food, the faster fish would take all the food, while the slower fish dies. This is called natural selection. After many generations, the faster fish dominate, and the slower fish dies.This is just one example of evolution. There are many theories of evolution. For example. Darwin and Lamarack's theory. Lamarack's theory say that offspring can have parents learned abilities, while this is false, in experiment 5, this can work, (its not learned traits though, it was really a genetic trait) it is really a genetic trait, not a learned trait. Another counter-example of lamarack's theory is that in experiment 3, the offspring does not get the speed that the parents had.(it was a learned trait, because they exercised, meaning it is a learned trait, but is was not passed down)Darwin's theory on the other hand says that offspring dont get the learned traits,which is true, if it is a genetic trait, it is false(meaning a genetic trait gets passed down while a envirmental trait does not). So another theory could be that darwins theory work if it is a learned, enviremental trait, while lamaracks theory work when it is a genetic trait.