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The Right "Fit": Exploring Science Teacher Candidates' Approaches to Natural Selection Within a Clinical Simulation

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Abstract Teachers and students struggle with the complexities surrounding the evolution of species and the process of natural selection. This article examines how science teacher candidates (STCs) engage in a clinical simulation that foregrounds two common challenges associated with natural selection—students' understanding of "survival of the fittest" and the variation of species over time. We outline the medical education pedagogy of clinical simulations and its recent diffusion to teacher education. Then, we outline the study that situates each STC in a one-to-one interaction with a standardized student who is struggling to accurately interpret natural selection concepts. In simulation with the standardized student, each STC is challenged to recognize content misconceptions and respond with appropriate instructional strategies and accurate explanations. Findings and implications center on the STCs' instructional practices in the simulation and the use of clinical learning environments to foster science teacher learning.

Keywords Clinical simulation · Situated cognition · Natural selection · Science teacher education

Introduction

The concept of natural selection is a fundamental building block in the teaching and learning of biology (Futuyma 1998; Mayr 2001; National Academy of Sciences 1998). In preparation for licensed practice, science teacher candidates (STCs) are challenged to solidify their conceptions of natural selection and prepare for their future students' engagement with this complex

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subject (Nehm and Reilly 2007; Nehm and Schonfeld 2007; Settlage 1994). Preparing for the teaching of natural selection, though, suggests practice in classrooms that focus on evolutionary biology. There lies the pervasive challenge, and the impetus for this study. Even with dedicated field partners and thoughtfully structured practicum environments, teacher education field placements often result in highly variable instructional experiences (Ball et al. 2009; Hatch and Grossman 2009; Putnam and Borko 2000). This variability yields infrequent and unpredictable opportunities for STCs to practice engaging with and teaching natural selection. One STC may gain a wealth of experience teaching natural selection in a particular classroom, while a peer STC may by placed in a classroom that instead requires instructional focus on the Krebs Cycle. If STCs must firmly grasp the biological building block of natural selection, then the challenge lies in providing them *all* with opportunities to engage with, and learn from the navigation of, secondary students' (grades 9–12) ideas about natural selection.

We know that members of the general public (Gregory 2009) and more specifically, teachers (Nehm and Schonfeld 2007), hold misconceptions about natural selection. There exist valid instruments to assess one's knowledge and conceptions of natural selection (e.g., Conceptual Inventory of Natural Selection; Assessing Contextual Reasoning about Natural Selection). Our inquiry does *not* center on a straightforward examination of STCs' knowledge of natural selection. Instead, our study examines the complex meld of science content knowledge (i.e., natural selection) with science instructional practices in a simulated instructional context. In this inquiry, we designed a clinical simulation to explore how STCs engage with and respond to student ideas about natural selection. Two research questions support this inquiry: Do STCs recognize common natural selection misconceptions embedded within a clinical simulation? If so, how do STCs engage with a standardized student to address these misconceptions? Our inquiry does not focus solely on the recognition of misconceptions, but rather the instructional and conceptual repertoires that STCs might employ "in situ"—in a situation that demands STCs immediately synthesize and enact knowledge of content, pedagogy, and interpersonal engagement (Brown et al. 1989). Beyond a straightforward identification of content misconceptions, we sought to explore the complexities of STCs' approaches and responses to student errors in a simulated environment that guaranteed that each STC would have the opportunity to engage and practice, regardless of whether the STC was placed in field practice where natural selection was taught.

We begin by describing medical education's long-standing use of clinical simulations with standardized patients and the recent diffusion of this model to teacher education. We outline our design and implementation of a clinical simulation focused on natural selection misconceptions surrounding "survival of the fittest" and genetic variation. We close with a discussion of the resulting data from this particular simulation and the implications of this clinical approach as an instructional and diagnostic tool in science teacher education.

Review of Literature

Clinical Simulations

In 1963, Howard Barrows, a medical educator at the University of Southern California, began using standardized patients to give his medical students opportunities to practice and enhance their diagnostic and communication skills (Barrows and Abrahmson 1964). A standardized patient is a lay person, actor, or real patient who is carefully trained to present distinct symptoms and to communicate questions and concerns to medical professionals in training (e.g., pre-service physicians, nurses, physical therapists) in a consistent, standard manner (Barrows 1987; Barrows 1993; Barrows 2000). Barrows's approach allowed large cohorts of medical students to engage with a small group of standardized patients who were carefully trained to enact a specific medical case. Even though each medical student engaged individually with a single standardized patient, the large cohorts of students shared a common medical situation, providing them opportunities to analyze and reflect on their potentially different approaches to the same shared (medical) context.

In 2007, the first author began working with nearby SUNY Upstate Medical University (UMU) to diffuse the concept of clinical simulations from a medical institution to a teacher preparation institution. The foundational objective was to craft professional situations that very closely mirrored the school and classroom-based contexts in which teacher candidates would soon engage everyday. The foundational logic was twofold: to provide teacher candidates opportunities to practice translating what they know about teaching into what they can actually do; and to situate them in specific professional experiences that teacher educators cannot otherwise guarantee through traditional field placements within schools. The foundational objective and logic model build from the theoretical construct of situated cognition; in clinical simulations, teachers' knowledge and skill sets are constructed and honed through "in situ" practice within authentic environments (Brown et al. 1989).

The experiences of teacher candidates, their cooperating K-12 teachers, and their faculty supervisors consistently point to the reality that individual field placements, and the professional challenges therein, are idiosyncratic and vary widely (Ball et al. 2009; Hatch and Grossman 2009; Putnam and Borko 2000). Recognizing this variance, more recent scholarship on teacher learning emphasizes the practices of teaching (e.g., Ball et al. 2009), where the formation and rehearsal (Grossman et al. 2009) of instructional techniques, approaches, and dispositions occurs within designed learning environments (Lampert 2005). Clinical simulations are one such designed environment. Each simulation serves as a discrete "approximation of practice" (Grossman et al. 2009, p. 2076), where the teacher engages in the simulation, reflects on the resulting video, self-critiques her/his practices, and compares/contrasts approaches with pre-service colleagues who had the same (simulated) experience. To forge ground on the oft-cited gap between preparation and practice (Korthagen and Kessels 1999), a pedagogical bridge between traditional coursework and varying field placements must introduce the uncertainties of teaching in a way that *all* teacher candidates can engage and learn within common and subject-specific (simulated) professional practices (Dotger 2015).

While the concept of clinical simulations rests on situated cognition and contributes to the emerging practice-based scholarship in teacher education (Zeichner 2013), simulations are specifically designed in further accordance with the same four tenets used in the design of medical simulations—*prevalence*, *clinical impact*, *social impact*, and *instructional importance*. Barrows (1987) emphasizes the design of clinical simulations in consideration of the *prevalence*, or frequency with which challenges/issues emerge in one's professional practice. In the context of science education, consider how frequently biology teachers receive questions and misconceptions from students about evolutionary biology and natural selection. Consider further how frequently teachers of earth sciences engage with questions related to scale. The *clinical* and *social impact* design tenets result in simulations that present pre-professionals with situations that might be experienced less frequently, but that introduce either a variable of great importance (*clinical*) or one that has a potentially high impact on a broader community if it is overlooked or mishandled by the professional (*social*). In the context of science classrooms, consider how science teachers approach and navigate students' questions about climate change, the age of the earth, or the role of scientific evidence in cultural decision-making. The *instructional importance* design tenet allows for simulations that are fundamental to a discipline and require different and/or specific skills and bases of knowledge.

Building from the aforementioned theoretical assumptions and design tenets, the first author's initial simulations focused on general problems of practice, challenges, and issues common to public school service that do not center on a specific content area (Dotger 2013). In these simulations, teachers and school leaders engage in live, one-to-one conversations with standardized students, parents, paraprofessionals, community members, and other school administrators. As in medical education simulations, each standardized individual is carefully trained to issue both verbal and non-verbal "triggers"—questions, comments, background information, and/or mannerisms designed to pose professional problems or challenges to the pre-service teacher or school leader sitting in the same conference room. While each standardized individual (SI) in a clinical simulation is carefully trained and directed, the learner (i.e., the teacher or school leader) is not influenced or directed in any way. Instead, each teacher or leader must enact her/his professional knowledge, judgment, and acumen while engaging with the SI sitting across the table. These early clinical simulations were implemented in a variety of pre-service and in-service teacher and school leader contexts, yielding a broad range of research questions and data streams on teacher and leader identity (Dotger and Smith 2009), dispositional development (Dotger 2010), and pre-service approaches to specific problems of practice (Dotger et al. 2015).

The procedural and instructional successes of early simulation efforts led to a transition from simulations focused on general problems of practice to ones that specifically centered on content-specific challenges. The exploration of content-specific simulations began with an examination of how STCs interacted with a standardized parent who strongly questioned the teaching of evolutionary Biology, and suggested the incorporation of Intelligent Design concepts in a high school Biology classroom (Dotger et al. 2010). That early inquiry is the only published study of the use of clinical simulations in an investigation of STC preparation and practice. Findings from that study highlighted a wider array of STC approaches and practices to the same simulated challenge, suggesting many follow-up questions about if and how science teachers are prepared to approach very specific situations that will likely arise in public school teaching. In essence, that particular study cast open the doors to a wide range of clinical simulations that challenge STCs to enact content and pedagogy in real-time as they engage with SIs. Building from that initial study, and from a broader National Science Foundation Discovery Research in K-12 (NSF DR-K12) education grant focused on the design and implementation of secondary science and mathematics simulations, we sought to design and study additional science and mathematics clinical simulations that challenge teacher candidates to transition *from what they know* about teaching and learning *to what they can do* when working with a struggling student or concerned parent.

Natural Selection Misconceptions

Evolutionary biology is clearly represented in the Next Generation Science Standards (NGSS). The core ideas of *Inheritance of Traits* (LS3A), *Variation of Traits* (LS3B), *Evidence of Common Ancestry and Diversity* (LS4A), *Natural Selection* (LS4B), *Adaptation* (LS4C), and *Biodiversity and Humans* (LS4D) constitute nearly half (6 of 14) of the objectives in the Life Science portion of the NGSS (NGSS Lead States 2013). These standards place emphasis on how natural selection leads to adaptation and the use of genetic information to identify ancestry (NGSS Lead States 2013). With this emphasis in the standards, understanding teachers' approaches to working with students on this key content is critical for improving classroom pedagogy in the life sciences. Building from the input of experienced science teachers, and the emphasis of natural selection in the NGSS, we sought to build a *Natural Selection* simulation that directly reflected real-life classroom events, phrasing, and misconceptions of students.

"Three decades of research have produced unambiguous data revealing a strikingly high prevalence of misconceptions about natural selection among members of the public and in students at all levels" (Gregory 2009, p. 163). Students struggle with the ideas of evolution, genetic mutation, adaptation, and variation (Gregory 2009), with particular emphasis on the common misconceptions of anthropomorphism, use/disuse propositions, soft (e.g., "Lamarckian") inheritance of acquired traits, and the event vs. process of evolution (Gregory 2009). Students misuse the terms *use* and *disuse* in explanations of trait development and frequently associate terms such as *need*, *necessary*, *adapt*, and *mutation* to further support the reasoning for evolution, trait development, and a "spontaneous change" in genotype (Settlage 1994, p. 451). These trends are also seen among teachers. In a study with 44 secondary biology teachers, many teachers had the same nature of science and natural selection misconceptions as students, and "more than 25 % of teachers employed 'use and disuse' arguments" (Nehm and Schonfeld 2007, p. 708).

Student misconceptions of natural selection may be linked to how successful teachers are presenting these complex ideas in discernable, but not simplistic classroom form (Moore et al. 2002). The language used in classrooms is chosen to support student learning, but language can distort meaning (Moore et al. 2002). Extending beyond language, instructional approach is also critical. For example, Demastes, Settlage, and Good (1995) studied teachers' presentations of evolution in the classroom. Teachers were given lessons that included hands-on activities and videos to present the information. Students in the inquiry learning treatment group were given time to work in small groups and discuss the ideas they had about natural selection and evolution using the information from the provided teacher materials. They found that creating an environment with inquiry-based learning led to higher student understanding, concluding this was due to the opportunity students had for discussion and the increase in opportunities for the instructor to ask questions (Demastes et al. 1995).

Building upon this research foundation and literature base, this article reports data from a new *Natural Selection* clinical simulation, where STCs engaged with a standardized student who expressed common misconceptions on natural selection. This *Natural Selection* simulation is part of a larger initiative to design, clinically test, and iteratively redesign eight mathematics and science simulations appropriate for secondary pre-service teacher preparation. In an effort to simulate authentic problems of practice that are grounded in everyday secondary classroom contexts, semi-structured interviews were conducted with 25 mathematics and science teachers from urban, suburban, and rural school districts in the northeastern United States. These interviews resulted in a number of mathematics and science-specific problems of practice that could inform the design of clinical simulations. Additionally, responding science teachers placed emphasis on natural selection as a common challenge for their students. In recognition of the aforementioned misconceptions surrounding natural selection, and in consideration of these science teachers' suggestions, our design of this *Natural Selection* simulation is grounded in Barrows's aforementioned design tenet of *instructional importance*. Natural selection serves as a fundamental building block in Biology, is often misunderstood by students and teachers (Gregory 2009; Moore et al. 2002; Settlage 1994), and thus holds importance for both pre-service and licensed science teachers. Recognizing its instructional importance, we elected to design a simulation that situated STCs in front of a standardized student who benignly presented misconceptions on natural selection. We wanted to know if STCs recognized these misconceptions, and if so, how they began to navigate them. In the following section, we outline our methods for designing the simulation and exploring our research questions.

Methodology

Our study investigated whether or not STCs recognized natural selection misconceptions, and if so, how they engaged with a standardized student to address these errors. To investigate these research questions, we situated each STC in a one-to-one interaction with a standardized student who presented two natural selection misconceptions. We begin by describing the protocols and training processes that support this simulation and the standardized students operating therein. Then, we provide demographic information on the participating STCs, including their enrolment within two different teacher preparation programs. Finally, we outline the data collection procedures and analytic framework that support this study.

Simulation Protocols and SI Training

Teacher education simulations are supported by two different sets of documents—protocols for the teacher candidate and the standardized individual (SI). Using these different protocols, the STC and the SI prepare for the upcoming simulation, where they will engage face-to-face. By design, the Teacher protocol provides each STC with relevant background information leading up to his/her interaction with the SI, and does not in any way script or direct what the STC says or does in the clinical simulation. In contrast, the SI protocol serves as a strict guide to which the standardized student is expected to adhere.

For this simulation, the SI protocol is divided into two sections. The first section gives each actor a detailed account of the student—"Jennifer Phillips"—she is to embody during the simulation. This includes extensive background personal context, an academic history outlining scholastic strengths and areas for improvement, and a clear description of the factor(s) that have motivated the (standardized) Jennifer Phillips to approach her teacher for assistance. In this simulation, Jennifer submits a Ticket-out-the-door (TOTD)[1] at the end of a Biology class session. As Jennifer submits the TOTD, she verbally indicates that she "do(es) not really understand" and asks if she can stop by after school for some help. This request establishes the context for each actor portraying Jennifer Phillips to sit down, one-to-one, with each STC.

The second and most important section of the SI protocol contains the verbal triggers—the questions, comments, and misconceptions—that each "Jennifer Phillips" will present to each STC, outlined as follows:

[1] A ticket-out-the-door (TOTD) is a tool teachers use to quickly assess students' understanding of a given topic. Typically, a TOTD consists of one to two questions/prompts for students to complete and submit before leaving class, thereby giving a teacher a brief snapshot of student thinking/conceptions on the subject matter at hand.

(1) Jennifer's initial concern about her performance on the TOTD, as the conference begins;
(2) An explicit gesture to the TOTD lying on the desk, verbal insecurity about "not understanding," and her word-for-word review of the TOTD question and written response:

> In your own words, what does "survival of the fittest" mean?
> "*Survival of the fittest means that the strongest, fastest, or smarter animals will use those traits to get the food/shelter they need and live longer*"

(3) A direct question on the degree of accuracy of her first TOTD response and a direct prompt (if needed) for a correct response.
(4) A second expression of insecurity over the second TOTD question and her response:

> Choose an animal and describe its environment. Describe a way that the species might change over time.
> "*Cheetahs live on the grasslands of Africa. Cheetahs spend lots of time running after other animals like gazelles. The cheetahs that do the most running build up their muscles and are really fast and then pass on their strength and quickness to their babies. This is what we mean by genetic variation.*"

(5) A direct question on the degree of accuracy of her second TOTD response and a request (if needed) for a different example.
(6) A request for suggestions on how to "keep straight" the different natural selection concepts;
(7) A closing two-pronged question: "*Am I still evolving? I mean, is this stuff still happening?*"

After reviewing UMU's roster of medical simulation actors, the Director of UMU's Clinical Skills Center (CSC) and the first author selected three females between the ages of 19 and 22 who could reasonably approximate a 16- or 17-year-old high school student. Three actors, and not one single actor, were selected for this study. The CSC habitually "rests" an actor after three medical simulation sessions, thereby ensuring the actor remains accurate in her triggers during a given simulation. Aligned with this practice, we trained three actors to be standard and consistent in their portrayal of Jennifer Philips, giving the researchers the flexibility to consistently provide the STCs with the same simulated experience, while also ensuring that no single actor engaged in too many simulations in sequence and erred or omitted the required triggers. The first author, UMU's Director of the CSC, and these three actors gathered for a 2-h SI training session 1 week prior to the actual simulations. The sole purpose of this session was to guide these three actors through the SI protocol, carefully coaching them on exactly how to become a high school student who presents each STC with some basic natural selection misconceptions.[2] Importantly, strong emphasis is placed on actor portrayals being standard and consistent, such that the questions and misconceptions one STC hears from one "Jennifer Phillips" are the same that other STCs encounter in their respective simulations with Jennifer.

In contrast to the SI protocol, the Teacher protocol outlines the teacher's (i.e., the STC's) broader instructional responsibilities at a fictional high school that operates on a seven-period

[2] Dotger (2013) gives a detailed account of the training procedures for standardized individuals.

bell schedule. This description included the type and frequency of courses taught (i.e., two sections of General Biology, two sections of Honors Biology, one section of Earth Science). Building from this background, the Teacher protocol further outlines an introductory Think-Pair-Share on their students' understandings of natural selection. This document indicates that students initially struggled, but when the teacher rephrased the Think-Pair-Share and asked that students brainstorm what they knew about evolution, students generated a wide array of misconceptions and religiously grounded responses. The Teacher protocol then describes how each teacher built on the Think-Pair-Share to give an overview of natural selection, including:

1) The ability of organisms to increase their population to very high levels;
2) The fact that resources for survival are limited, thereby limiting the number of offspring that can survive;
3) Organisms within populations exhibit variations in appearance and behavior;
4) Some traits are passed from parents to offspring through genes;
5) The selection by the natural environment that leads to some organisms surviving and reproducing, and others not.[3]

The final portion of the Teacher protocol outlines a closing Ticket-Out-the-Door (TOTD) activity that the teacher had his/her students complete before class ended. The TOTD consisted of two prompts:

1. In your own words, what does "survival of the fittest" mean?
2. Choose an animal and describe its environment. Describe a way that species might change over time.

The final paragraph in the Teacher protocol indicates that one student—Jennifer Phillips—approached the teacher (i.e., the STC) as the bell rang and other students hurriedly submitted their TOTDs. Jennifer said, "*I don't know how I did. If it's ok, can I stop by after school*?" According to their protocol, each teacher encouraged Jennifer to stop by after school and placed Jennifer's specific TOTD document into the pile with the others for her class, as the next class of students began to enter the classroom.

It is important to pause and consider a particular portion of the Teacher protocol, and its overview of natural selection as it was presented to the (standardized) student and her peers. We ground our construction of these conceptions of natural selection primarily in Mayr (2001), his description of Darwin's five theories of evolution (see p. 86), and specifically his outline of Darwin's explanatory model of natural selection (see p. 116). Our (above) language in the Teacher protocol is meant to represent a broad overview of the fundamental ideas of natural selection, as it would be presented in an initial secondary school (grades 9–12) overview.

As an example of how this broad overview is both used and misused in teaching and learning, though, consider the TOTD description and its reference to the misconception of "survival of the fittest." We understand that in advanced study of evolutionary theory, scholars recognize Herbert Spencer's initial use of this phrase and Darwin's later use of the phrase in describing natural selection (Gregory 2009). However, our focus for this study was in *students*'

[3] See Gregory's (2009) discussion of the misconception of nature as the active, intentional "Selecting Agent" (pp. 170–171).

frequent misuse of this persistent phrase, not as recognized by evolution scholars, but as recognized by the high school Biology teachers that we interviewed in designing this simulation and this study. Our secondary science education colleagues frequently referenced the challenges associated with teaching natural selection, and in doing so, frequently referenced the misuse of "survival of the fittest" in association with physical prowess. In considering both the overview of natural selection, and the initial TOTD, one must also consider the role of the TOTD in quickly assessing students' initial understandings and misunderstandings. The initial overview and the two-prompt TOTD represented in this study are not meant to encapsulate all that a high school Biology teacher might teach about, or all the examples and language that the teacher might use to assess students' understanding of, the concept of natural selection.

Participants

Thirteen STCs from two different institutions—one public (institution A) and one private (institution B)—participated in the *Natural Selection* simulation. STCs from both institutions were included to increase sample size and to honor prior agreements between researchers to involve teacher candidates in new simulated learning experiences. Both institutions employed a traditional preparatory approach, in that general science content knowledge was expected to be developed through science coursework outside of the respective schools of education, but complimented by traditional science education methods courses that focused on the effective teaching of science content. Like many schools of education, both institutions place their STCs in multiple field placements, where they are expected to enact and practice the methods and manner in which they teach science content. Unfortunately, though, these two institutions have no control over the experiences of STCs in the teaching of evolutionary biology; some may have the opportunity, some may not. Table 1 provides basic demographic information for participating STCs, including the delineation of either a Bachelor of Science (BS) or Master of

Table 1 Science teacher candidate demographic information

Pseudonym and institutional affiliation (A/B)	Age range and gender (F/M)	Race/ ethnicity	Degree program (BS/MS/ MAT) and certification	Number of biology credits
Fillip (A)	19–23 (F)	Caucasian	MAT - Biology	30 undergrad
Stenson (A)	19–23 (F)	Caucasian	MAT - Biology	30 undergrad
Cartwright (A)	19–23 (F)	Asian	MAT - Biology	30 undergrad
Nilson (A)	19–23 (F)	Caucasian	MAT - Earth Science	6 undergrad
Martinez (A)	19–23 (F)	Caucasian	MAT - Biology	30 undergrad
Saunders (B)	19–23 (F)	Caucasian	BS - Biology	3 undergrad
Greensby (B)	19–23 (M)	Caucasian	BS - Biology	45 undergrad
Chambers (B)	19–23 (F)	Caucasian	BS - Chemistry	14 undergrad
Denson (B)	19–23 (M)	Caucasian	BS - Earth Science	4 undergrad
Gartman (B)	19–23 (F)	Caucasian	BS - Earth Science	4 undergrad
Luther (B)	19–23 (F)	Caucasian	BS - Biology	44 undergrad
Wallace (B)	19–23 (F)	Caucasian	BS - Biology	36 undergrad
Hartwell (B)	19–23 (F)	Caucasian	MS - Biology	11 graduate

Arts in Teaching (MAT) degree program, as well as the number of credits from undergraduate and graduate science courses.

At the time of the study, both STC cohorts were approximately halfway through their respective programs of study, were currently enrolled in a science methods teacher preparation course, and represented the entirety (n = 13) of the STC cohorts at both institutions. The first author initiated recruitment by contacting the secondary science education faculty members at each institution and inviting their STCs to engage in the *Natural Selection* simulation. No incentive(s) were provided for participation in this study. The respective faculty members, and the reporting first author, indicated verbally and through an IRB consent form (#11–135) that the STCs may choose to participate in the *Natural Selection* simulation as a learning experience, and were under no obligation to give consent to anyone (peer, accompanying faculty member, or researcher) to review and analyze their respective simulation video data.

Procedures

One week prior to the clinical simulation, the Teacher protocol for the *Natural Selection* simulation was distributed to each STC by email, thereby providing the opportunity to carefully read the protocol, and review outside sources on natural selection if desired. Importantly, though, the cooperating faculty and researchers offered no additional direction beyond the Teacher protocol, other than encouraging STCs to engage in the simulation "using (their) prior knowledge and best professional judgment." On the day of the simulation, STCs gathered in the CSC for a 10-min orientation that explained the background of medical simulations, the diffusion of this concept to teacher education, and the steps each STC would engage in during the *Natural Selection* simulation.

After this brief orientation, each STC was assigned a CSC simulation room and was given login and password information. In five different groups (two to three each), the STCs were situated outside of their respective simulation rooms, and encouraged to login to the computer positioned beside each simulation room entryway. The login process turned on the cameras in each simulation room. The researchers then prompted each STC to enter the simulation room, indicating that the standardized student—Jennifer Phillips—would join the STC momentarily. Once STCs were situated in their simulation rooms, the actors portraying Jennifer Phillips were cued to knock on the simulation room doors and enter. From that point, the simulation was entirely in the hands of the standardized Jennifer Phillips and the STC. When STCs decided their respective conversations with Jennifer were complete, they were instructed to leave the simulation room, and click "Stop Encounter" on the same computer.

As STCs exited their simulation rooms, they were met by one of two reporting researchers who serve as science education faculty. Taking turns, the science educator ushered the STC to a different simulation room, logged into that room, and guided the STC through a post-simulation debriefing. To guard against interviewer bias, this debriefing was strictly structured around three prompts, where STCs were asked to "describe (their) objective(s) when conversing with Jennifer, (2) explain (their) approaches to her TOTD questions, and (3) to reflect on the degree to which (their) anticipations and (their) actual simulated experienced aligned." Because this debriefing occurred in a different simulation room, the researchers were also able to capture the STCs' post-simulation reflections and reactions on camera, with each debriefing session lasting between 5–7 min.

Analysis

Each STC's simulation with Jennifer Phillips, as well as the subsequent one-to-one debriefing with a science educator, was transcribed in full. Our analysis of the transcript data was framed by a modified symbolic interaction approach (Bogdan and Biklen 2003; Miles and Huberman 1994), as we sought to understand how STCs navigated the (simulated) situation they were immersed in, without assumption that there would be one absolute course of action or set of decisions. Further, we recognized the illumination of the professional 'self' in these transcripts, as STCs exhibited their novice efforts to navigate within a common, but complex, scientific concept, constructing meaning in situ (Brown et al. 1989) and later in post-simulation debriefing as STCs reflected upon their respective interactions (Bogdan and Biklen 2003). Our modification to the symbolic interaction approach came in our use of a detailed coding scheme (Miles and Huberman 1994), where we sought to categorize and understand STCs' interpretations within the (simulated) situation (Bogdan and Biklen 2003). In similar fashion to another investigation of a mathematics simulation (Dotger et al. 2015), we began our analysis from four guiding code constructs—STC's diagnoses, explanations, science-specific and general teaching repertoires (Clermont et al. 1993; Magnusson et al. 1999). With these four guiding code constructs as our initial coding guide, we open-coded a 10 % subset of the data in accordance with the first and second primary triggers, with each coder carefully documenting and assigning additional codes to emerging data. Because we did not direct our STCs on how to engage in this simulation (i.e., what to say or how to say it), we could not accurately predict the specific actions or decisions they would enact during the simulation. As a result, we used our four guiding coding constructs to support the open coding for the 10 % subset of data, allowing us to gather the range of content and pedagogical enactments in the simulations. This subset coding process yielded a series of codes that we then compared, discussed, negotiated, and reconciled to build our open coding lists into one single list of codes that was organized according to our four guiding code constructs.

To exemplify this coding process, consider the first trigger (T1). It (T1) was assigned a guiding Diagnosis (D) code, where the STC either agreed with Jennifer's definition of "fitness" (T1D1) or recognized a problem with what Jennifer proposed (T1D2). As the STCs moved from an initial bifurcated diagnosis (D) of Jennifer's thinking to instead examine STCs' explanations (E) to Jennifer, the coding process became much more involved. Open coding the 10 % data subset, we compiled a larger number of sub-codes related to how STCs explained "survival of the fittest." Thus, we again engaged in extensive discussion, practice coding, and code reconciliation for the Explanation (E) data, determining and documenting which of 21 sub-codes would be assigned to STCs' verbal explanations to Jennifer. The same open coding, 10 % data subset process was repeated for the Teaching Repertoire (TR) data, as the investigators discussed and determined operational definitions for STCs' instructional actions in the simulation. For example, the researchers discussed and clarified the difference between TR1 (asks a question) in comparison to TR12 (questions student's response), with the former focused on the interrogative nature of a question in driving the conversation forward, and the latter used to critique or call attention to a misconception. Table 2 gives a full representation of our codes for the first trigger; Table 3 provides codes associated with the remaining triggers, and Table 4 outlines the emergent codes for the debriefing sessions.

After two further revisions to our full list of codes, the first and second authors independently coded the entire data set. Additional coding discrepancies between these authors were marked, discussed, and reconciled. Then, data summaries were constructed in accordance with

Table 2 Guiding code and subcode matrix for trigger 1

Trigger #1

[T1D] Diagnosis
- T1D1. Agrees with student's definition of fitness
- T1D2. Recognizes problem with student's definition of fitness

[T1E] Explanation
1. Differential survival
   - a. some things survive/some don't
   - b. some organisms have traits that make survival more likely
2. Competition
   - a. Organisms compete for resources
   - b. Better adapted will get resources
3. Variation
   - a. Not all organisms in a population are the same
   - b. Variation in populations can be caused by mutation
   - c. Variation can confer an advantage to some organisms in a population
   - d. Variation in populations caused by migration
4. Relationships to the environment
   - a. Relationship between organisms/traits and environment
   - b. Relationship between organisms/traits and environment confers an advantage
   - c. Environments vary
   - d. Camouflage
   - e. Predator/prey relationships
5. Reproduction and inheritability
   - a. organism have offspring that are like them
   - b. organisms have traits that are passed on
   - c. organisms have genes that are passed on
   - d. only inherited (genetic) characteristics are passed on (distinguishing between inherited and acquired characteristics)
6. Clarifying fitness
   - a. fitness is match to environment that provides advantage
   - b. Distinguishing between everyday fitness (strength, stamina) and scientific fitness
   - c. Fitness is ability to have offspring (no reproduction means no fitness)
   - d. Fitness is the ability to have offspring that have offspring
7. Natural selection- broad reference

[T1SR] Science repertoire
- T1SR1. Giraffes
- T1SR2. Cheetahs
- T1SR3. Lions
- T1SR4. Other

(TR) Teaching repertoire

TR1: Asks a question	TR12: Questions student's response
TR2: Uses repetition	TR13: Prompts student's action
TR3: Uses textbook/Outside materials	TR14: Offers student a learning strategy (e.g., mnemonic, starting point, steps to consider/use, underlining/highlighting, draw a picture)
TR4: Corrects student's incorrect response	TR15: Reduces content down to essential components
TR5: Gives new/revised language to student	TR16: Checks for student's understanding
TR6: Uses a visual/diagram/drawing	TR17: Praise or acknowledgment
TR7: Interprets student's response	TR18: Defer to next class
TR8: Reads problem	
TR9: Reads student's solution	
TR10: Scaffolds student's thinking	
TR11: Confirms student's response	

Table 3 Guiding code and subcode matrix for trigger 2

Trigger #2
[T2D] Diagnosis
T2D1. Agrees that student's answer is correct (not seen)
T2D2. Recognizes problem with student's description of how change in species occurs
a Teacher identifies student as misunderstanding variation
b Student thinks that acquired characteristics are passed onto offspring
c Unable to articulate nature of student's problem
[T2E] Explanation
T2E1. Differential survival
a Some things survive/some don't
b Some organisms die before they reproduce
T2E2. Characteristics
a Characteristics vary within a population
b Some characteristics confer an advantage in particular environments
c Some characteristics are a result of the genes from the parents being expressed in the offspring
d Some characteristics are acquired, these do not change genes, these do not pass on to offspring
e Organisms can acquire characteristics they need to survive (teacher misconception)
T2E3. Advantage
a Catching prey
b Avoiding predator
c Acquiring food
d Attracting mate
T2E4. Evolution
a Occurs at a population level, not at an individual level
b Over time, evolution occurs because individuals survive and reproduce
[T2SR] Science repertoire
T2SR1. Example used to demonstrate how acquired characteristics not responsible for evolution
T2SR1a. Humans that lose hands still have children that have hands
T2SR1b. Classic experiment with mice that lose tails
T2SR1c. Cheetahs gaining muscle from running not passing on that characteristic T2SR1d. Using the analogy of physical vs. chemical change
T2SR2. Examples use to demonstrate natural selection at work
T2SR2a. Darwin and finches
T2SR2b. Cheetahs on the plain
T2SR2c. Peppered Moths
T2SR3. Example used to demonstrate variation within a population
T2SR3a. Using classmates to demonstrate the variation within the class
T2SR3b. Using family members to demonstrate variation
(TR) Teaching repertoire (repeat from above)
Keeping it Straight/Evolving? (KS/E)
KS - R: Resources
KS - T: Techniques
E - Ind: Response to cue of individual evolution
E - Spe: Response to cue of species evolution
E - T: Temporal factor in evolution

each trigger, allowing the authors to then analyze STCs' interactions by focusing on a specific trigger and how the STCs approached and navigated each specific trigger. Of note, we intentionally organized our analysis by trigger, and report our data by the themes for specific triggers and not broader themes across triggers. We wanted to analyze our data for potential patterns in how the STCs engaged with a distinct question or misconception (i.e., a trigger), rather than place emphasis in a case study format on each STC's distinct path through the

Table 4 Guiding code and subcode matrix for debriefing

(D) Debrief - teacher reflection codes	
D-SC: Self-critique	D-T1D1: Referencing Trigger 1 misconception
D-TR: How to help student understand (which teaching move to make)	D-Con: References to surrounding context to problem of practice
D-VR: References to reviewing video	D-ER: Recognition of teacher error
D-MC: References to meta-cognition	D-Ap: Reflecting on approach
D-TR15: What is important/not important to convey to students	D-Int: Other possible interpretations
	D-PL: Things I did well
D-SP: Teacher speech patterns	D-Appl: Application to classroom
D-Δ: Things to work on (deltas)	D-Dis: Disposition in SIM
D-M: Acknowledging mistakes	D-NV: Non-verbal teacher action

triggers. Thus, our findings are organized by trigger and the theme(s) that emerged as STCs engaged with Jennifer Phillips in that particular line of dialog.

Findings

Two research questions guide this study: Do STCs recognize common natural selection misconceptions embedded within a clinical simulation? If so, how do STCs engage with a standardized student to address these misconceptions? We have not organized our findings according to these two questions because we did not want to artificially separate data on STCs' recognition (or not) of Jennifer's misconceptions from immediately subsequent data on STCs' engagement with these misconceptions. Thus, our findings are organized by triggers and presented in four sections. First, we report how STCs navigated the second and third triggers—where Jennifer Phillips describes her response to the first TOTD prompt about "survival of the fittest." Next, we report how STCs engaged with the fourth and fifth triggers, surrounding Jennifer's description of how a species changes over time. Then, we report on the sixth and seventh triggers in this simulation, where STCs faced questions about "keeping this stuff straight" and whether or not an individual evolves over time. Finally, we discuss the data resulting from the post-simulation debriefings.

STCs' Navigation of "Survival of the fittest" Trigger

As the simulations began, each actor portraying Jennifer verbally paraphrased the written TOTD response aloud for the STC: "*Survival of the fittest means that the strongest, fastest, or smarter animals will use those traits to get the food/shelter they need and live longer.*" After stating this response, each Jennifer then asked each STC, "Am I on the right track?"

STCs took a number of approaches to this first TOTD and Jennifer's direct question of accuracy. STCs confirmed Jennifer's TOTD response, but did so in incomplete fashion. For example, Hartwell introduces the 'goodness of fit' concept by saying that animals survive because "they are best for that particular situation." Through her description, Hartwell works against the idea of physical prowess as the conception of 'fitness' by noting, "…there's those little weaklings that kind of get by, and what is that? They're the best fit to survive in their particular environment." Stenson also confirmed Jennifer's response, and then more fully extended it by saying, "It could be the fastest or strongest animal, but I think the better way to describe it is the animal that's the most adapted to the environment." One particular STC's response, though, shows a more sophisticated confirm-and-extend approach. Martinez indicates the Jennifer's "strongest, fastest, smartest" explanation "can be the case, but it doesn't have to be." From there, Martinez extends the conversation by indicating to Jennifer "there's basically three parts to this (understanding survival of the fittest)." Through a series of statements, Martinez outlines the concepts of variation of species, advantages of particular characteristics, and surviving to reproduce. Importantly, Martinez returns later in her explanation to how particular characteristics serve as a good fit between the organism and its environment.

Another STC correctly ascertained Jennifer's misconception of what it means to be fit, and countered with direct explanation;

> …it doesn't have to be the strongest, fastest, or smartest. Its, uh, the traits that will make animals survive in their particular environment. So, uh, there are many different environments…It really depends on the environment. So I would say, um, animals that have traits that are, um, most adaptable to that specific environment, those traits will be passed on (Cartwright).

What is notable about Carwright's explanation is that it does not extend. Cartwright continues to repeat herself, indicating that it could a be a slow(er) or weak(er) animal, as opposed to the strongest or fastest, but does not extend this explanation with an example. Then, Cartwright introduces Jennifer to a textbook she brought to the simulation, an instructional move no one else attempted. The silence is clear on video as Cartwright tries in vain to quickly find examples where "goodness of fit" is represented by an organism that is not the strongest or fastest. After this extended silence, Cartwright eventually puts down the textbook and instead summarizes the conversation with no further detail or allusion beyond, "So, it doesn't have to be the strongest or smartest, it could be (the strongest or smartest) but…" Similarly, Hartwell suggests that Jennifer think of animals that actually do not fit the layperson's conception of fitness, but offers no concrete example, and instead moves to the second TOTD prompt. Two other STCs struggled to extend the conversation from broader concept to specific example. They notably struggle in their respective interactions with Jennifer, when she asks for examples of organisms that are not necessarily strong or fast, but do indeed fit well within their environment.

Several STCs extended Jennifer's written TOTD response by immediately introducing a particular species (e.g., lions, mice, and polar bears) as an example on which they could both focus. For example, Gartman cites polar bears in reference to arctic environments and how individuals in those species have greater camouflage. She contrasts polar bears with brown bears to illustrate a fit or "blend" within an arctic environment, but omits the idea of variation of traits and their expression over time. In very similar fashion, Denson offers an explanation by citing different colors of butterflies and the degree to which they exist within environments that camouflage or contrast them for predators. Denson offers a clean explanation, noting that a butterfly is not strong or fast, but is instead "fit to survive in its specific environment." Her concise example and explanation, though, stop short though in her complete omission of reproduction and the diffusion of traits to future offspring.

Luther's explanation also warrants attention, as she is the only STC to introduce a temporal element alongside her example of a moth. Luther begins by telling Jennifer of a white moth in

England, that "fits" well where "all the (beech) trees are white." Using questions, she coaxes Jennifer to understand that white moths against the white tree would be camouflaged from predators. Then, Luther suggests, "Okay, so now the situation turns in England. There's a lot of smog in the air. It's actually turning moths' wings black. So now the wings are black. The trees are staring to turn black as well. So now, what moth is going to be eaten first?" Note that Luther has introduced a misconception. She is correct in that the trees are discolored from area pollutants. Importantly, though, she does not clarify that the black moths, which are naturally occurring, are now more 'fit' for the darker environment.

Luther continues just a moment later, by connecting the rather sudden environmental changes (i.e., smog and the Industrial Revolution) to the idea of species adaptation:

Luther: So, the animal is…remember the word 'adapted'?
Jennifer: yeah
Luther: 'Adapted', so what does it mean?
Jennifer: The animal is the one that adapted to its environment, so it had to change how it goes about things in order to survive
Luther: Yeah, so it made itself survive. Exactly, so the animal that's most adapted to its environment…"

Through this interchange, we see Luther transition from an earlier discussion of the fit between an organism and its environment to an organism's adaptations to environmental change. The example she has given—discussing pollutants from the Industrial Revolution—and her follow-up emphasis of *adapted* suggests to Jennifer that survival of the fittest is a concept that applies to the individual animal, and not to the expression of specific traits over generations. In essence, Luther is fostering the misconception of anthropomorphism (Futuyma 1998, pp. 581–582; Gregory 2009), with her emphasis on the intentionality of the individual, and how the moth "made itself survive" through deliberate adaptation from white to black wings.

The concept of camouflage emerged as other STCs used examples in their explanations of survival of the fittest. Some asked Jennifer the very basic question about why camouflage would be important. Other STCs used questions to gather more information on Jennifer's thinking. For example, Chambers asks Jennifer to clarify the degree to which her TOTD response extends beyond an individual animal; "…when you're talking about survival of the fittest for this (TOTD) question, are you thinking survival of the fittest for just one animal or for the whole species?" Jennifer references the species, and Chambers compliments her; "so, let's look at it from that, cause that's good, that's exactly the angle you're supposed to be looking at it from." As a second example of effective questioning, after Jennifer reads aloud her written TOTD answer, Greensby asks plainly, "…let me ask you why you would think that first?" Greensby quickly asks a follow-up, "So when you say fit, what's the definition that you give to fitness?" Per her training, Jennifer doesn't extend her thinking beyond what she written in her TOTD response, and she responds with "smarter, faster, stronger" language. Through these quick, early questions, Greensby now has determined Jennifer's misconception, and explains it back to her through a common analogy; "…it's really difficult for a lot of students, because, you know, wherever you go, you hear, 'oh, come in to this gym to get fit'…you hear that a lot on t.v. But actually in science we talk about fitness, we're talking about two things…its two questions—does the animal survive, so can it stay alive and does it reproduce?"

STCs' Navigation of 'Change over time' Trigger

The second TOTD prompt asked for a description of how species might change over time. Jennifer's TOTD response—focused on cheetahs—is shown below:

> "*Cheetahs live on the grasslands of Africa. Cheetahs spend lots of time running after other animals like gazelles. The cheetahs that do the most running build up their muscles and are really fast and then pass on their strength and quickness to their babies. This is what we mean by genetic variation.*"

Ten of the 13 STCs directly acknowledged Jennifer's misconception in her second TOTD response. Nine of these ten STCs extended beyond diagnosing the misconception by immediately offering examples to Jennifer they deemed correct and applicable. For example, Luther transitioned back to her earlier explanation of the survival of the fittest concept, stressing traits that are passed from one generation to the next. As she addresses the second TOTD and how species change over time, she offers brief references to the beak length of finches, human eye color, and then says, "Does this help this one? Do you understand why a cheetah wouldn't be able to pass along its strength?" At no point in her explanation does Luther use the phrase "acquired characteristics." That is, her explanation does not distinguish between genetic traits and what Jennifer alludes to in her TOTD response—the diffusion of characteristics acquired by individuals within a single generation. In contrast, Gartman more succinctly links back to her survival of the fittest example and then forward with a clearer example of how an individual's acquired characteristics are not expressed in offspring;

> When you have animals changing…they change because they have random mutations that cause it to be more beneficial to the environment….so maybe something happened way back where a cheetah had stronger muscles and then that cheetah survived and it mated and they (offspring) had stronger muscles. So, its not so much in a lifetime…Like if I started running and I got huge muscles and I had a baby, then that's not saying that my baby's gonna have strong muscles too."

Other teachers did not bridge back to discussions of survival of the fittest, and instead immediately addressed the acquired characteristics misconception. Like Gartman, Saunders also offered an example geared toward human muscle building. Citing the concept of a "strong man contest", Saunders proposed that such athletes might one day have a baby. "Have you ever seen a really strong, muscular baby? No, the same thing happens for animals. They can't reproduce strong babies. So, they can pass along their genes…but not muscular traits."

Perhaps the clearest example, though, comes from Greensby, who directly cites, but does not name, August Weismann's late 19th century study of mice and tail growth. Using the whiteboard provided in the simulation room, Greensby guides Jennifer through an overview of the experiment by drawing several mice, figuratively cutting the tails off half of them, and asking Jennifer to make predictions if the mice, with and without tails, produced offspring; "…if we reproduced this mouse with this (other) mouse that had a tail cut off, what would you expect their babies to have, tails or no tails?" Jennifer makes the correct prediction, and Greensby connects his example back to Jennifer's original TOTD response;

> Basically what they found is that even if you change something of an animal, it's still genetically the same…Its tail still grows. It's the same thing with cheetahs. Even if a cheetah can build lots of muscle, when it has its babies, that muscle, that strength, that's

> all physical strength that is developed in its lifetime…but genetically it's still the same as it was before it had those muscles.

Of the ten STCs who correctly identified Jennifer's misconception, Martinez was the only one to actually link Jennifer's TOTD response to the Lamarckian concept of inheriting acquired characteristics. In referencing Larmarck, Martinez cites an example of giraffes and long necks, indicating

> So he (Lamarck) was the one that kinda said giraffes have long necks because they basically wanted it (using air quotes). It (longer necks) happened within their lifetime and now they passed those on. So, he still had the acquired characteristics but it was more they wanted it so it happened, as opposed to them being born with a long neck and outcompeting the ones with the smaller neck.

STCs' Navigation of 'How can I keep it straight?' Trigger

The final two triggers in this simulation prompt each STC to address questions about conceptual organization and the capacity of an individual to evolve.

After the second TOTD prompt was addressed, each actor portraying Jennifer is trained to say, "This stuff is complicated. Do you have suggestions on how I can keep it straight?" Three STCs responded with textbook references, suggestions for extra help sessions, and "…just studying what's in your notes…" A fourth STC offered to bring in extra materials in the form of videos, suggesting that these unnamed videos would offer Jennifer more perspectives on the concepts of survival of the fittest and evolutionary change over time.

The other nine STCs addressed Jennifer's question directly, offering a wide variety of suggestions for conceptual organization. Recognizing the implicit message in Jennifer's question, several STCs tried to offer a streamlined approach to help Jennifer "keep straight" the concept of natural selection. In the example that follows, Luther tries to offer a few key points for Jennifer to remember; "Okay, well, just think, evolution is what was able to survive…and the reason they're surviving is because they could breed and they passed on those traits…so that's how you can think of, so think of something, well how did it evolve, how does it fit in its environment?" Saunders takes a similar, streamlined approach, noting, "It's all about passing down their genes…whether survival of the fittest, like the best genes get passed on, and in the case of like the cheetah, their muscles don't get passed on but the more fit cheetahs that, you know, outwit their prey, they (their genes) get passed on."

Martinez responds very succinctly to Jennifer's question about conceptual organization, suggesting that she focus on an "individual species." Hartwell offers a variation of this suggestion, encouraging Jennifer to remember the concept of 'goodness of fit to the environment' by thinking of an specific organism that would generally be considered contrary to popular conceptions of "fitness"; "If you come up with an example that is kind of contrary to what you originally thought…like don't say the strongest cheetah is going to pass on strong genes. Come up with like something that's more specific, like maybe you can use the zebra thing…." When Hartwell references zebras, she is directing Jennifer back to an earlier part of their conversation, where Hartwell had referenced zebras, variations of color and stripe, and camouflage within the grassland environment. Importantly, though, Hartwell does not take Jennifer back through that conversation stem, step-by-step; she quickly references the past zebra example. Two other STCs referenced their earlier explanations as well, but unlike

Hartwell, they did not streamline their explanations or offer additional suggestions/ clarifications to help Jennifer keep these concepts 'straight'. Instead, these two STCs took Jennifer, again, through examples of how organisms change over time and survive within given environments. When Gartman responds to Jennifer's question, she does so by constructing a visual map with the provided whiteboard and markers. Although she does add a visual support to help Jennifer "keep it straight", Gartman also takes her back through every point of their earlier discussion of the TOTD prompts.

STCs' Navigation of 'Am I still evolving?' Trigger

As the simulation concludes, Jennifer issues her final trigger, asking each STC two quick, successive questions about evolution and the individual. Following the "keep it straight?" trigger, Jennifer inquires, "Am I still evolving? I mean, is this stuff still happening?" By design, these questions provide the STC opportunities to distinguish between the individual and the species. Several STCs recognized the contrasting questions and offered delineating responses. For example, Gartman suggests, "Evolution happens over thousands of years…so humans are still evolving, but its not like you would see a change in your lifetime." Chambers offers an initial response, but then hints at difficulty of the concept; "So, you can't talk about evolution necessarily, like as a single person evolving, you know, but if you look at humans over time, humans are, humans are a hard example to talk about…" Other STCs do address evolutionary time, more specifically pointing out the assumption that individuals evolve. Wallace notes, "Here's another common misconception, like a particular organism does actually evolve over its lifetime. So, when we're talking about evolution, we're talking about the evolution of an entire species and it takes a long, long time." Greensby also captures the dual nature of the trigger—acknowledging Jennifer's references to both the individual and the species;

> Greensby: "So, when we talk about change over time, it's not just one cheetah or individuals; its how does the group change over time.
> Jennifer: Okay, so I'm not evolving?
> Greensby: We, as a species, we may evolve. But you personally, no. Like, we're not necessarily evolving at the time, evolution's very slow. It takes a long time to happen.
> Jennifer: Okay.
> Greensby: So, in a lot of years, the humans may, like, the human species may evolve a little bit, but its little things, not like, we're not growing wings or gills or anything like that, but little changes.

Discussion and Implications

We begin our discussion of STC performance in the *Natural Selection* simulation with the first TOTD prompt, where data indicate STCs offered confirmations of Jennifer's TOTD response, with varying degrees of qualification. While survival of the fittest could apply to organisms that do align with traditional understandings of fitness or strength, there are numerous examples that work against this assumption and serve as examples of a "goodness of fit" within specific environments. STCs acknowledged and confirmed that a fast animal could be an appropriate example, but struggled to extend beyond Jennifer's example. For those who did confirm and extend, working to focus on a “goodness of fit” example, all but one omitted the importance of reproduction, genetic expression, and/or levels of change across species and over significant time periods. In essence, STCs’ responses to the first TOTD prompt were either inaccurate or incomplete. In contrast, STCs were more accurate and used more examples in response to the second TOTD prompt. Some utilized examples commonly used to refute Lamarck’s idea of the inheritance of acquired characteristics, though only one STC directly referenced Lamarck. While working with Jennifer on the second TOTD prompt, STCs more frequently referenced reproduction, gene expression, and generational change.

Our design of the sixth trigger, where Jennifer asks each STC how to “keep straight” the concept of natural selection, was intended to assess STCs’ abilities to streamline the concept for a struggling student. Their responses varied widely. The closest alignment of data centered on STCs’ suggestions to study more materials, more frequently. We do see a couple of examples from STCs that move toward suggestions for future clarification. For example, Hartwell referred Jennifer back to their earlier discussion of zebras that tied together the first and second TOTD prompts. Those STCs who moved beyond “study more” responded by repeating earlier explanations.

Our final trigger offered STCs the opportunity to differentiate between the individual and the species, where one does not evolve in a single lifetime, but the population does across generations. During the SI training sessions, we prepared the actors portraying Jennifer to deliver this trigger’s two questions in successive, back-to-back fashion, challenging STCs to parcel out the individual (“Am I still evolving?”) from the broader question about the continuation of evolution. Most STCs did acknowledge this distinction in response to Jennifer. Several referenced evolution across generations and over significant expanses of time. Interestingly, two STCs introduced references to media and popular culture, indicating that evolution does not occur at the individual level through dramatic mutation.

Data from this study suggest two implications for science teacher preparation and practice. Our first implication centers on evidence of teaching practices within this data set and their potential connections to practices in other mathematics and science simulations. Our second implication extends this idea, emphasizing the applicability of simulations within content-specific teacher preparation contexts to ensure opportunities for pre-service practice and development.

In an article about mathematics teachers’ orchestration of whole-group discussions around cognitively challenging, student-centered tasks, Stein et al. (2009) present five key teaching practices: *anticipating, monitoring, selecting, sequencing*, and *making connections between student responses*. We intentionally highlight this study of mathematics teacher preparation because its practice-oriented conceptual framework serves as an appropriate lens through which we interpret STCs’ practices in this study. Comparing their five-practice framework to our simulation data, we see direct application for two of the five practices—*anticipating* and *monitoring*. Stein et al. (2009) define *anticipating* as a teacher’s efforts to “actively envision how students might mathematically approach the instructional task(s) they will be asked to work on” (p. 322). Such anticipation includes attention to how a student might interpret a given problem, the strategies s/he might employ, and the alignment of the interpretation and strategies to the mathematical concept in consideration (Stein et al. 2009). Although grounded in mathematics education, we posit the practice of *anticipation* applies to science teacher preparation and practice. For STCs to navigate this simulation with the greatest success, they need to *anticipate* potential student responses/patterns. We intentionally gave STCs the TOTD questions one week prior to the simulation, with encouragement to prepare for the simulation by using professional judgment and knowledge. We expected the TOTD questions would adequately prompt STCs to anticipate the range of scientific ideas they could potentially discuss with Jennifer.

In addition to *anticipation*, there is also the practice of *monitoring*—"paying close attention to the mathematical thinking in which students engage as they work on a problem…" (Stein et al. 2009, p. 326). This practice also extends mathematics teaching, and in this study, the practice of *monitoring* applies as the STC attends to and notices students' thinking on natural selection, choosing portions for discussion and further exploration. While this study frontloaded the practice of *anticipation* through the Teacher protocol, we did not structure the practice of *monitoring* student thinking. This is where our research questions emerge, in an examination of the approaches and instructional practices that are utilized in simulation.

We see examples of anticipation and early monitoring in the data. For example, when a STC brings a text to the simulation, she does so anticipating this tool will help her. However, we consider her anticipation here very incomplete, as there is evidence she did not know which portion of the text could be used to illustrate the concept. Additionally, we know from the post-simulation debriefing that several STCs anticipated a conversation about creationism. We are concerned, however, that they focused more on this possibility than the content clearly outlined by the TOTD questions. As we consider the practice of monitoring, all the triggers in the simulation were designed to reveal common student ideas, as documented in the broader literature base on natural selection. Our data show STCs monitoring Jennifer's thinking, centering this practice generally around the TOTD question at hand. What also emerges in our data, though, are suggestions that most STCs were unsure what to do beyond the practice of monitoring Jennifer's thinking. Some STCs tried to provide Jennifer with a general explanation out right; others selected examples of other species to expand her understanding of fitness. Others constructed illustrations, as in the case with the mice, and asked Jennifer to reason how that experiment helps explain the types of characteristics offspring inherit. Some STCs asked questions about the content, while others only asked her if she understood. In essence, when STCs tried to extend beyond the practices anticipating and monitoring, our data show no clear patterns of selecting and sequencing examples and explanations.

Our future research with clinical simulations in science and mathematics education will include cross-simulation analyses. Building from the work of Stein et al. (2009), we intend to examine potential patterns in the kinds of work STCs do when interacting with students. Specifically, are there evident patterns of practice, and can multiple simulations boost, or fine-tune, the ability of STC to enact these patterns and foster student learning? Beyond anticipating and monitoring student thinking, can multiple simulations help STCs build strategies for selecting, sequencing, and connecting ideas (Stein et al. 2009) in smaller instructional settings like one-to-one, teacher and student interactions? Additionally, might the introduction of these five practices (or others) serve as supportive anticipatory sets for STCs? That is, might these practices serve as both an analytic framework for teacher practice, but also a framework to help STCs prepare for various courses of action and dialog around a given topic? Similarly, how might clinical simulations align with other practice-based frameworks (e.g., Forzani 2014) and the detailed scrutiny of content-specific practices (e.g., navigating a geometric proof) in simulation? We acknowledge that this study is a snapshot of STCs' practices as they engage with natural selection. Akin to the repetition of classroom practices, particularly as a novice teacher encounters some of the very same questions from different students, future studies might examine the development of science teacher conceptual knowledge and pedagogical practices around a very specific topic. In consideration of this study, how might these same

STCs engage with the complexities of natural selection if they encountered similar questions and misconceptions in follow-up simulations? Across 3–4 different simulations about natural selection, do data show any development in STCs' abilities to anticipate or monitor student misconceptions, and more decisively select, sequence, and/or connect examples and explanations that they either intentionally introduce or that the (standardized) student introduces? Can multiple simulations help STCs develop the ability to select examples from immediate conversation, and then sequence those concepts to build from straightforward to increasingly complex explanations?

Further, there is a need to explore potential patterns of practice and clearly identify a continuum of effective science teaching practices. Data in this particular study indicate our STCs' responses varied greatly. For example, in response to the first trigger, some STCs asked Jennifer to provide a different example of the fit between an animal and its environment; other STCs provided the example directly. Our stance is that asking Jennifer to think of another example is the more effective instructional approach. In a different part of this study, we were encouraged by Greensby's response to Jennifer and his use of the mice example. Citing such an example from the literature is important, provided it is timed appropriately and connected back to student thinking (Stein et al. 2009). In both examples—knowing when to prompt students for more examples and knowing when to provide a clear example oneself—we question how we are evaluating or coaching STCs to sequence such practices.

Our second implication builds from the range of 9–12 science and engineering content outlined by the NGSS and the formidable challenge teacher educators face in teaching the finer points of content and pedagogy associated with specific standards. Consider this study, and the concepts within that require deliberate attention from science teacher educators to prepare STCs to accurately and thoughtfully teach natural selection in secondary classrooms. As noted earlier in our discussion of the practice-based teacher education movement, teacher educators cannot strictly control the types of instructional experiences their STCs engage in through field placements. Using traditional approaches, there is no way to ensure that all STCs will have opportunities to distinguish the differences between mass and weight, support students through stoichiometry, or clarify for parents and school administrators the importance of studying climate change. Through traditional approaches, there is no way to ensure that all STCs will have opportunities to practice teaching the complexities of natural selection before they are licensed professionals. Thus, our second implication rests on the use of simulations as a non-traditional pedagogy in science teacher education.

Clinical simulations offer each STC the individual opportunity to engage immediately with a very specific problem of practice (e.g., natural selection). Later, when the broader cohort gathers, STCs use their simulation video data to identify their own and each other's struggles, mis-steps, and successes. Engaging in the same simulation provides them a shared experience, a content-specific common denominator on which to identify and dissect their instructional decisions and actions. Importantly, while they all share the same (simulated) experience, they have the professional freedom to enact different practices (e.g., anticipation, monitoring, etc.) in that simulation. Future studies might examine the impact of post-simulation debriefings on the formation of practice, where all teacher candidates who engaged in a given simulation utilize the resulting simulation video data to scrutinize the degree to which their practices align in response to the same simulated challenge. Finally, future studies might examine the alignment (or not) of enacting the practices of simulated teaching compared with enactments of the same practices in fully contextualized classrooms.

Finally, we acknowledge the limitations of this study to best contextualize the scope of this study. We report data from STCs' interactions within a single, episodic simulation, and in this particular study, we do not examine how STCs might develop in knowledge and instructional approach as a result of many different interactions with students' misconceptions about natural selection. The *Natural Selection* simulation was the first these STCs engaged in, situated around a professional challenge they (likely) had not yet faced as pre-service science teachers. Without question, follow-up studies of their practices—in either clinical settings or fully contextualized classrooms—are worthwhile to examine potential changes in approach in guiding students toward an understanding of natural selection.

Another limitation of this study hinges on the positioning of clinical simulations within the broader framework of teacher preparation. Simulations are never intended, nor do they hold the capacity, to replace fully contextualized instructional experiences in classrooms. Simulations are bounded "approximation of practice" (Grossman et al. 2009, p. 2076) focused on very distinct scholastic or curriculum challenges. While this study focuses on natural selection, engaging in this simulation does not supplant STCs' full engagement in science classrooms with this same challenging content. As noted in this resulting data, and evident across other simulation studies, this clinical approach illuminates teacher candidates' actions and decisions in authentic environments, where they must immediately synthesize professional training, disposition, and content knowledge into professional actions and decisions.

A final limitation is the structure of the post-simulation debriefing session. Recall that STCs were prompted to describe their objective(s) for, explain their approaches within, and reflect on whether what they anticipated and what they experienced aligned within the simulation. Without simulation video data to guide the debriefing discussion, several STCs reflected on anticipating tense conversation about evolutionary theory and religion verses the simulated experience they engaged in about natural selection misconceptions. Without having simulation video data available in the debriefing, the researchers were unable to effectively direct the debriefing reflections toward STCs' approaches within simulation. In essence, the brief mention of a potential controversy in the Teacher protocol clouded, for several STCs, their attention to preparing for other student misunderstandings of natural selection. Later in post-simulation debriefing, the STCs did not yet have video data to guide their reflection, and thus their debriefing comments located around the same anxieties they held prior to simulation.

The scope of this study is an exploratory investigation of how STCs engage with and respond to student ideas about natural selection. This formal inquiry began with one simple, informal question among the reporting researchers: Will our STCs recognize the right "fit" in a basic discussion about "survival of the fittest"? As this study builds to other inquiries, those studies might also employ assessments of STC knowledge and reasoning of natural selection (e.g., Conceptual Inventory of Natural Selection (CINS), Assessing Contextual Reasoning about Natural Selection (ACORNS)). Certainly, there is room to further examine the relationship between STC knowledge (determined through such instruments) and STCs' actual instructional performances in simulation. In doing so, we may potentially begin to unpack the link what teacher candidates know and how they actualize knowledge in situ. The aforementioned teaching and scientific repertoire data also suggest other areas of future inquiry. STCs drew from their individual science repertoires, citing examples and concepts (e.g., camouflage) as they worked to explain the concept of fitness. Similarly, STCs employed questions to both prompt Jennifer's thinking through a specific example, and to also check for Jennifer's conceptual understanding. Future studies should closely examine the types of scientific examples STCs employ in discussion of natural selection concepts, and particularly from what source(s) STCs draw these examples.

These types of inquiry best define the role of this current study and of simulations more broadly. Clinical simulations serve as an emerging core pedagogy (Dotger 2015), but also serve as performance and diagnostic assessments in infancy, with potential to measure how teacher candidates engage within distinct professional challenges (Dotger 2013; Dotger 2015). Performance is indicative of professional knowledge and reasoning, but also an indicator of each STC's skill in synthesizing her/his knowledge and reasoning in such a manner as to effectively combat student misconceptions. It does matter what our STCs know about, and how they reason with, natural selection. However, instructor knowledge and reasoning are not the only factors that contribute to effective science teaching. Per the scope of this particular study, what also matters is how STCs translate what they know and understand about natural selection into accessible, accurate, and logically sequenced instruction on natural selection for the benefit of their own students. By authentically illuminating what STCs know and can do, simulations help teacher educators ascertain conceptual and pedagogical successes and mistakes. Simulations as an approximation—that faculty can mediate and that STCs can actively engage in—serve as both a pedagogy and a diagnostic tool to advance effective science teaching.

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References

Dotger, B. (2010). "I had no idea": Developing dispositional awareness and sensitivity through a cross-professional pedagogy. *Teaching and Teacher Education, 26*, 805–812.

Dotger, B. (2013). "*I had no idea!*"*: Clinical Simulations for Teacher Development*. Charlotte, NC: Information Age Publishing.

Dotger, B. (2015). Core pedagogy: Individual uncertainty, shared practice, formative ethos. *Journal of Teacher Education, 66*(3), 215–226.

Dotger, B. & Smith, M (2009). 'Where's the line?' – Negotiating simulated experiences to define teacher identity. *The New Educator, 5*(2), 161–180.

Dotger, S., Dotger, B., & Tillotson, J. (2010). Examining how preservice science teachers navigate simulated parent-teacher conversations on evolution and intelligent design. *Science Education, 94*(3), 552–570.

Dotger, B., Masingila, J., Bearkland, M., & Dotger, S. (2015). Exploring iconic interpretation and mathematics teacher development through clinical simulations. *Journal of Mathematics Teacher Education, 18*, 577–601.

Ball, D., Sleep, L., Boerst, T., & Bass, H. (2009). Combining the development of practice and the practice of development in teacher education. *The Elementary School Journal, 109*(5), 458–474.

Barrows, H. S. (1987). *Simulated (standardized) patients and other human simulations: a comprehensive guide to their training and use in teaching and evaluation*. Chapel Hill: Health Sciences Consortium.

Barrows, H. S. (1993). An overview of the uses of standardized patients for teaching and evaluating clinical skills. *Academic Medicine, 68*(6), 443–453.

Barrows, H. S. (2000). *Problem-based learning applied to medical education*. Springfield: Southern Illinois University Press.

Barrows, H. S., & Abrahmson, S. (1964). The programmed patient: a technique for appraising student performance in clinical neurology. *Journal of Medical Education, 39*, 802–805.

Bogdan, R. C., & Biklen, S. K. (2003). *Qualitative research for education: an introduction to theories and methods* (4th ed.). Boston: Allyn & Bacon.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Research, 18*(1), 32–42.

Clermont, C., Krajcik, J., & Borko, H. (1993). The influence of an intensive in-service workshop on pedagogical content knowledge growth among novice chemical demonstrators. *Journal of Research in Science Teaching, 30*(1), 21–43.

Demastes, S. S., Settlage, J., & Good, R. (1995). Students' conceptions of natural selection and its role in evolution: cases of replication and comparison. *Journal of Research in Science Teaching, 32*(5), 535–550.

Forzani, F. M. (2014). Understanding "core practices" and "practice-based" teacher education: learning from the past. *Journal of Teacher Education, 65*(4), 357–368.

Futuyma, D. J. (1998). *Evolutionary biology* (3rd ed.). Sunderland: Sinauer Associates.

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

Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., & Williamson, P. (2009). Teaching practice: a cross-professional perspective. *Teachers College Record, 111*(9), 2055–2100.

Hatch, T., & Grossman, P. (2009). Learning to look beyond the boundaries of representation: using technology to examine teaching. *Journal of Teacher Education, 60*(1), 70–85.

Korthagen, F. A., & Kessels, J. P. (1999). Linking theory and practice: changing the pedagogy of teacher education. *Educational Research, 28*(4), 4–17.

Lampert, M. (2005). *Preparing teachers for ambitious instructional practice: learning to listen and to construct an appropriate response*. Montreal: Paper presented at the annual meeting of the American Education Research Association.

Lead States, N. G. S. S. (2013). *Next generation science standards: for states, by states*. Washington, DC: The National Academies Press.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *PCK and science education* (pp. 95–132). Norwell: Klewer Academic Publishers.

Mayr, E. (2001). *What evolution is*. New York: Basic Books.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: an expanded sourcebook* (2nd ed.). Thousand Oaks: Sage Publications.

Moore, R., Mitchell, G., Bally, R., Inglis, M., Day, J., & Jacobs, D. (2002). Undergraduates' understanding of evolution: ascriptions of agency as a problem for student learning. *Journal of Biological Education, 36*, 65–71.

National Academy of Sciences. (1998). *Teaching about evolution and the nature of science*. Washington, DC: National Academy Press.

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. (2007). Does increasing biology teacher knowledge of evolution and the nature of science lead to greater preference for the teaching of evolution in schools? *Journal of Science Teacher Education, 18*, 699–723.

Putnam, R., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Research, 29*(1), 4–15.

Settlage, J. (1994). Conceptions of natural selection: a snapshot of the sense-making process. *Journal of Research in Science Teaching, 31*(5), 449–457.

Stein, M. K., Engle, R. A., Smith, M. A., & Hughes, E. K. (2009). Orchestrating productive mathematical discussions: five practices for helping teachers move beyond show and tell. *Mathematical Thinking and Learning, 10*(4), 313–340. doi:10.1080/10986060802229675.

Zeichner, K. (2013). The turn once again toward practice-based teacher education. *Journal of Teacher Education, 63*(5), 376–382.