My Science is Better than Your Science: Conceptual Change as a Goal in Teaching Science Majors Interested in Teaching Careers about Education

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Abstract

We argue, based on a multi-year collaboration to develop a pedagogy course for physics majors by experts in physics, education, and the science of learning, that the process of teaching science majors about education and the science of learning, and evidence-based teaching methods in particular, requires conceptual change analogous to that encountered by students in introductory physics classes. Similar to students learning many natural science concepts, science majors default to naïve theories of learning based on their own experiences and preferences, even when in conflict with educational research. Their demonstrated ability to analyze research on teaching and learning in the framework of the scientific method ultimately does not translate into acceptance of the outcomes as valid. We suggest a number of contributing factors. Recognizing the need to target conceptual change is critical in informing how we educate science students who are interested in teaching, whether as a profession or in a shorter-term capacity such as a graduate teaching assistant. It also suggests that an approach different from the way we typically teach science-education students is needed.

Conceptual change is a familiar concept in the teaching of science literature (e.g., Driver, Squires, Rushworth, and Wood-Robinson, 1994; Vosniadou, 2002). It remains a challenge to encourage the sort of learning that truly transforms student misconceptions and prior beliefs into conceptions more aligned with scientific theory and data. These early beliefs tend to resist change for a number of reasons (Chi, 2005; Chi, 1992) and, because they tend to be "good enough" explanations for the day-to-day experiences of most students, they tend to guide behavior despite student access to more accurate or appropriate alternatives.

While we commonly attend to such issues around the conceptual changes of K–12 students and non-science-majors in natural science teaching and learning, we are unaware of discussions of the role of conceptual change for science majors as they learn in other domains such as the science of learning. Similarly, naïve notions of learning based on biased views of personal experiences are frequently extrapolated to beliefs about the nature of learning itself. In addition to students who pursue a career in secondary education teaching, many science majors will play some role in the teaching of other science students should they pursue graduate school and ultimately find themselves in an academic department teaching courses within their discipline.

Over the past several years, an interdisciplinary team of physicists, a learning scientist, and a science educator have been delivering a class on teaching and learning aimed at sophomore-level physics majors interested in careers as educators as part of a project funded by Physics Teacher Education Coalition (PhysTEC). Given that the academic experience of physics students is firmly rooted in the natural sciences, we sought to leverage a scientific perspective by organizing the class around educational research and scientific findings in the study of teaching and learning (the Science of Learning). In short, this was an introductory class on the science and evidence-based practices of learning appropriate for science majors. The underlying assumption behind the design and teaching of this course was that students rooted in the natural sciences would easily transfer a perspective they had already developed on the nature of scientific knowledge (i.e., the scientific method) to the nature of the science of learning. For example, these students have demonstrated proficiency in engaging in the processes of science to address scientific hypotheses through deep engagement in the practice of science. We would think that students fluent in the scientific method with respect to physics would resonate with a similar approach to teaching and learning.

Will physics majors transfer their perspectives on the nature and process for developing scientific knowledge to the science of learning?

Just as students in natural science courses tend to differentiate course knowledge from the constructs which they habitually use to explain their world, physics students in our class on education tended to separate the class material from their personal theories of how people learn. While being able to tell us, for example, that the scientific basis for learning styles is relatively weak according to multiple primary sources that were assigned as required readings, they would follow up with statements that indicated that they clearly believed in the theory just discredited by data. Support for such a belief was rooted in egocentric evidence manifested by comments such as, “This is how I best learn the material,” or “They just need to do it this way,” referring to the strategies that particular students tended to use in their own lives.

After our first semester teaching this course and obtaining little movement in getting students to formulate data-based opinions of learning, we hypothesized that we needed to emphasize the science aspects of the course and explicitly map these onto terminology and processes in physics research with which the students were already familiar. We asked students how they would test the validity of learning styles and determined a potential experiment as a class. We then shared an article from the literature that had already carried out this experiment. We asked them to identify dependent and independent variables in the learning literature, comment on design, and even construct alternative tests of the same hypotheses, just as they would for physics experiments. Our students fully engaged in this process in class and in assignments.

However, when it came time to discuss the findings in the context of their own teaching, our students consistently reverted to pre-existing personal theories of learning. We quickly found that physics students did not apply their scientific perspectives to educational issues, reverting to or maintaining evidence-contrary and personal perspectives on learning. In fact, they would commonly parse the issues at hand to reflect their understanding of the abstract concept while leaving their prior theories intact: "I know learning styles don't exist. But, I learn better visually." We did not expect to deal with persistent resistance to the idea of applying scientific thinking to an area in which they already possessed, rather confidently, misconceptions or egocentric conclusions about learning. However, personal opinions and experiences around learning frequently overrode discordant conclusions based on data.

This strong resistance to the idea of applying scientific thinking to the science of learning generated the following essential question around the learning trajectory of these students. We began to suspect that the presenting issue was not one of transfer but conceptual change.

Are we pursuing conceptual change of pre-existing conceptions of learning?

Every person has a theory for how people learn, and it is usually a theory of how they themselves learn. Just as the student early in his or her introductory planetary motion course typically attributes the reason for the Earth's seasons to the distance from the Sun at various locations in the revolution of Earth based on their personal experience with light and heat sources, our students attributed their learning trajectories to their own personal theories of how they learn. Thus, assimilating the science and evidence-based practices of learning into their future work as educators was met with barriers commonly associated with the assimilation of ideas about the natural sciences. To date, however, there is a paucity of work on the process of conceptual change in natural science students for concepts relevant to teaching and learning.

McDevitt and Ormrod (2008) offer insight into this process for pre-service teachers and their prior beliefs about child development. With the aim of promoting understanding of concepts in child development, and thus the transfer of this learning to the teaching and learning of young children, McDevitt and Ormrod (2008) identified three major barriers: (1) tenacity of prior beliefs; (2) cognitive biases; and (3) personal epistemologies. Just as in McDevitt and Ormrod (2008), these three barriers inhibited the learning outcomes associated with this course on science teaching and learning. While each student would perform well on exams, papers, and focused discussions, our students tended to revert to their prior theories in broader discussions and microteaching demonstrations.

Each student in the class possessed a personal story describing his or her pathway to the university and the selection of his or her undergraduate major. This pathway is both personal and value-laden, documenting specific experiences, individuals, and outcomes that, cumulatively, make up the individual's tacit knowledge about the teaching and learning of science. As noted by Keil and Silberstein (1996) and Strike and Posner (1992), this tacit knowledge is not easily accessible to the individual and is often overlooked or simply not considered relevant. This, in turn, exacerbates the tenacity of each individual's prior beliefs because, in the end, these experiences worked for the individual, leading them to the university and to a particular major with the end justifying the means. That is, the students believe that since it worked for them, it should work for everybody else. A specific example of this appeared when students presented their microteaching demonstrations and were questioned about a particular approach or example they chose to use in the demonstration. Common responses suggested that not only could students not draw from course content focused on evidence-based practices, but students could also not see the need for a different approach, as their approach was the one that should lead to understanding. In spite of exams, papers, and focused discussions, the students regressed to their personal beliefs when put into the context of microteaching demonstrations.

Similarly, our students demonstrated several cognitive biases during the course, mainly confirmation bias and belief perseverance (e.g., Chinn and Brewer, 1993; Kuhn, Amsel, and O'Loughlin, 1988). Course materials, including readings from a textbook as well as primary sources, exams, and papers provided multiple opportunities for students to actively engage with the research on the science of learning. Through focused discussions, students were encouraged to process this information, and through Socratic questioning, make meaning of the information. Furthermore, outside assignments were designed for students to make connections rather than simply summarize or regurgitate the information or content. Time and again, students would actively engage in the material in two very specific ways: (1) focus on information that resonates with their beliefs (confirmation bias) or (2) skepticism (belief perseverance). In the first situation, students would only highlight, reference, or make connections to course materials that could be used to confirm their prior beliefs. Rarely accompanied by a related story, this situation was instead followed with an air of confidence that the conflicting information is somehow not credible or valid. In the second situation, students would discuss, respond to questioning, and make specific connections by providing counter arguments to the finding or outcomes presented in the course materials. This often was accompanied with an overgeneralization about one specific example or an anecdote that was in direct contradiction to the nature of science, something in which these students have already demonstrated proficiency. This leads to the third major barrier.

Personal epistemologies based upon their own experiences and successes seemed to dominate in our classroom. Majors in the natural sciences, occasionally spurred on by some of their professors, believe that they are at the top of the intellectual food chain, in possession of concrete knowledge and skills beyond the grasp of students in other majors. Indeed, it was not uncommon for our students in the natural sciences to believe that psychology or education are not sciences. We heard this from our students time and again. This may contribute to their resistance to consider learning strategies other than the ones they personally use, as well as the consideration that data from other fields is valid when it conflicts with their own beliefs. Indeed, we were surprised at how often our students would proudly comment that strategies other than the ones they personally deploy were "dumb," and the students who use them were flawed in their thinking and ability to learn science: "They just don't get it." Students in our class were often asked to discuss challenges they encountered in the teaching and learning of science through their work as laboratory, teaching, and learning assistants. In many situations, our students gave up and attributed the apparent lack of understanding of physics to personal attributes of the learner and not the teacher. This personal reaction may have led the students to discount the scientific aspects of course content, especially when at odds with their idiosyncratic theories, with a sense of self-righteousness we do not typically see in students in the social sciences.

The course has changed. It is less ambitious with respect to the science of learning, and more hands-on with the core content. We focus less on the scientific aspects of teaching and more on the practice. In that sense, it is more "fluffy." Student satisfaction has skyrocketed, as has enthusiasm for the profession of teaching, which was our core mission in this course intended as a first exposure to science pedagogy. In fact, in the last few years we have had a drastic increase in physics majors pursuing licensure through our fifth-year Master's program after over a decade without a single graduate from the program. Yet, we note that the students generally have not loosened their grips on their preconceptions regarding teaching and learning and, importantly, physics students seem unwilling to transfer their knowledge of critical thinking and the scientific method to the science and practice of learning in the classroom. In other words, we have yet to figure out effective strategies to encourage conceptual change of preconceived notions of the learner. Rather, we have worked around them by targeting how to teach secondary science instead of changing their beliefs about how people learn. This is perhaps particularly ironic for physics majors who have grappled with a subject with well-identified hurdles requiring conceptual change and understand well the nature of the scientific method.

We still believe that if our students embraced pedagogy as a learning science, they would benefit greatly by going beyond their idiosyncratic notions of learning to focus on effective, research-based strategies. However, we also note the change in perspective for us as instructors of this course; namely, we recognize the value of exposure to activities designed to engage students in teaching and providing opportunities for them to simply take on and enjoy the role of teacher, perhaps deferring conceptual change to a later course. We recognize, though, that the core mission of enthusiasm for the profession of teaching cannot ultimately be the only desired outcome.

Conclusion

If there had been more work available discussing the necessity of conceptual change as a component of training science majors to become fluid with concepts of teaching and learning, our path would have been much clearer. The absence of attention to science majors as they learn in other domains, like education or the science of learning, seems misguided. Enthusiastic teachers without an understanding of the science and evidence-based practice of learning likely leads to teaching based on the tenacity of prior beliefs, cognitive biases, and personal epistemologies: in other words, teaching to the way they believe people learn and not based upon the science of how we learn. We are writing this to make others who develop similar courses aware of the lessons we have learned. While there is a clear role for generating enthusiasm, our curriculum must eventually target conceptual change. If we are going to offer science majors the opportunity to develop their skill sets in the teaching and learning of science, this may require an approach that is very different from the traditional trajectory of students interested in education and self-selected to pursue teaching science.

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