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Making a difference in secondary science education

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Abstract

There is empirical research and scholarly debate about what constitutes effective learning. Students have offered perspectives on describing good teaching, which mainly focuses on teachers' interpersonal qualities and subject expertise. Teachers want to make a difference to students' lives, yet little research has been conducted to determine science teaching practices that may have an impact on students' lives. This qualitative study analyses responses from 167 adults (preservice teachers; 26% males and 74% females) aged between 19 and 51 about their memories of positive and negative secondary science education experiences, and high-impact science lessons that had an influence on them. Apart from obtaining demographic information, the questionnaire requested these adults to reflect on their secondary science education experiences, for example: (1) As a secondary student, was secondary school science a positive experience? Why or why not? (2) State one secondary science experience and the effect this had on you. Results indicated 52 adults claimed science as a positive experience, 56 deemed science to be a negative experience, and 59 were split in their decisions (stating both positive and negative experiences). All responses on making a difference in secondary science experiences fell within nine categories, that is: teacher's role, hands-on experiences, group work, useful and practical science, purposes articulated clearly, interactivity with life, clear explanations of abstract concepts, involvement in field work, and the topic selection choice. Some adults responded with more than one practice (e.g., group work and excursions). The most controversial science activity in the secondary school was the dissection of a small animal (e.g., toad, frog, rat) or parts of a larger animal (e.g., cow's heart, bull's eye). This act had an impact on these adults, as they remembered distinctly dissecting a creature. The feelings were divided between disgust and repulsion to delight and enlightenment. There were those who objectively dissected a creature and those who found the experience indelibly sickening. To illustrate one participant said, "Cutting a toad up made me leave the room and made me sick, I couldn't see the point, why not work with diagrams?" Low or negative impact practices involved: disengaging activities such as sensory-repulsive tasks, unclear reasons for learning science, teacher's lack of enthusiasm, chalk and talk or copying teacher's work, and denigrating students' personal ideas. Although teaching approaches can vary between different educational levels, and an individual's preferred learning style may change with age and experience, high-impact teaching practices noted in this study were predominantly student-centred or could be adapted to suit individual styles. Indeed, exemplary primary, secondary and tertiary teaching practices may be interchangeable and relevant to effective teaching practices regardless of the level of study. Implementing science lessons with one or more elements of high-impact teaching may lead towards making a difference, particularly if these teaching practices produce in students positive long-term memories about their science education.

Over the last few decades, there has been exponential growth in scientific applications as well as an increased understanding of basic science ideas and ways of thinking scientifically (Sjøberg, 2001). However, many researchers, like Sjøberg, claim that the international enrolment trend into the sciences for both secondary school and tertiary settings is falling "or at least not developing as fast as expected or planned" (p. 2). At a recent Global Science Forum conducted by the Organisation for Economic Co-operation and Development (OECD), one of the objectives was "to identify the underlying factors that affect students' choices" (OECD, 2006, p. 3) in order to address declining student enrolments in the sciences. The findings and recommendations from the forum indicated a need for science curricula reformation. The declining enrolments of students in the sciences is often attributed to the "uninteresting … content of science courses" (OECD, 2006, p. 9).

Osborne and Collins (2001) conducted interviews with 16-year-old English students in relation to their views and beliefs of school science. These students reported that their diminishing interest was due to being overloaded with content and not generally related to working life, the lack of discussion of topics of interest, the absence of creative expression opportunities, the alienation of science from society, and the prevalence of isolated science subjects. Indeed, these students were dissatisfied with science contexts that did not meet the students' interests. Students themselves describe school science to be "dull, authoritarian, abstract and theoretical. The curriculum is often overcrowded with unfamiliar concepts and laws. It leaves little room for enjoyment, curiosity and a search of meaning. It seldom treats the contemporary issues" (Sjøberg, 2001, p. 3). It seems science in schools is of low interest to students. The curriculum may not be engaging and the students are not motivated to continue learning science beyond the compulsory years. Starting points to address declining enrolments and interests are science classrooms and accompanying teachers.

The time students spend in school and classrooms is considerable, yet the majority of students report poor satisfaction with schools (Lahelma, 2002), and individual subjects – especially the sciences (Osborne & Collins, 2001). It is interesting to note, that studies that investigate students' perceptions of school whilst still at school (Osborne & Collins, 2001; Gordon, Holland, & Lehelma, 2000) rarely report responses reflecting enjoyment or pleasure. However, longitudinal studies that revisit students after completing school often report "memories were rather positive in most cases. While positive emotions were almost completely absent from the stories ….. by students who were still attending secondary school, memories afterwards often reflected enjoyment" (Lahelma, 2002, p .372). Lahelma's ethnographic study probed her participants' memories of their schooling. One question asked the participants to recall something important they had learned at school. Most could not answer the question. When rephrased to something they liked at school, most mentioned specific subjects such as science. In science, respondents mentioned science lessons in which they learned through experiencing, giving presentations and teamwork on projects.

The influence of the classroom teacher has been a key research topic for many years. Several researchers document the importance of the science teacher's role in stimulating interest in science. To illustrate, Wright and Hounshell (1981) found that teachers were the greatest influence in stimulating interest in science. "The mythical scientifically literate citizen who has positive feelings about science, science teaching, and science teachers may be just a matter of teaching strategy!" (Shymansky & Penick, 1981, p. 421). More recently, Meece (2003) discussed the vital role teachers had on learning, where students' motivation and academic engagement was enhanced when the teacher was caring, respectful, and provided learning experiences that targeted the students' needs. Science teachers are critical in meeting educational goals as they influence what and how a student is taught, however, "it is not enough to acknowledge that teachers play a critical role" (McNeill & Krajcik, 2007, p. 2). The teacher's role and how the teacher influences learning needs to be further analysed to more clearly identify effective teaching. There is some evidence that the quality of the teacher can make a difference to a student's education (Vogt, 2002; Wong, Britton, & Ganser, 2005). A teacher's affective domain can be used to motivate students to their fullest potential (Knobloch, 2002; Noddings, 2001). Long term learning in science education cannot be assumed by teacher characteristics alone. Indeed, long-term learning may be linked to adults' memories of their science education, which may also aid towards identifying high-impact teaching practices (Hudson, 2007).

This study sought to explore the perceptions of secondary school science from people across the adult age range. Did they remember and regard their secondary science experiences positively or negatively? What did they remember? Following the analysis of a questionnaire, the study hoped to determine what were the remembered high-impact teaching practices for secondary science education?

Research methods

In this qualitative study, 167 adults aged between 19 and 51 responded to a questionnaire that focused on their positive and negative secondary science education experiences, high-impact science lessons, and teaching practices that impacted on their learning. Apart from obtaining demographic information, the questionnaire requested these adults reflect on their secondary science education experiences: (1) As a secondary student, was secondary school science a positive experience? Why or why not? (2) State one secondary science experience and the effect this had on you. This questionnaire was administered at the beginning of the first lecture for learning about teaching science. The respondents were therefore all preservice teachers undertaking studies to become primary school teachers. Responses were recorded and coded for commonalities (Hittleman & Simon, 2006). The purpose of this research was to identify high-impact teaching practices for secondary school science and, in particular, analyse these preservice teachers' memories of their secondary science lessons, the impact of secondary science education, and teaching practices that appeared to have long-term effects. This research is based on a similar study conducted for primary science education (Hudson, 2007). Data were collated into themes as they emerged.

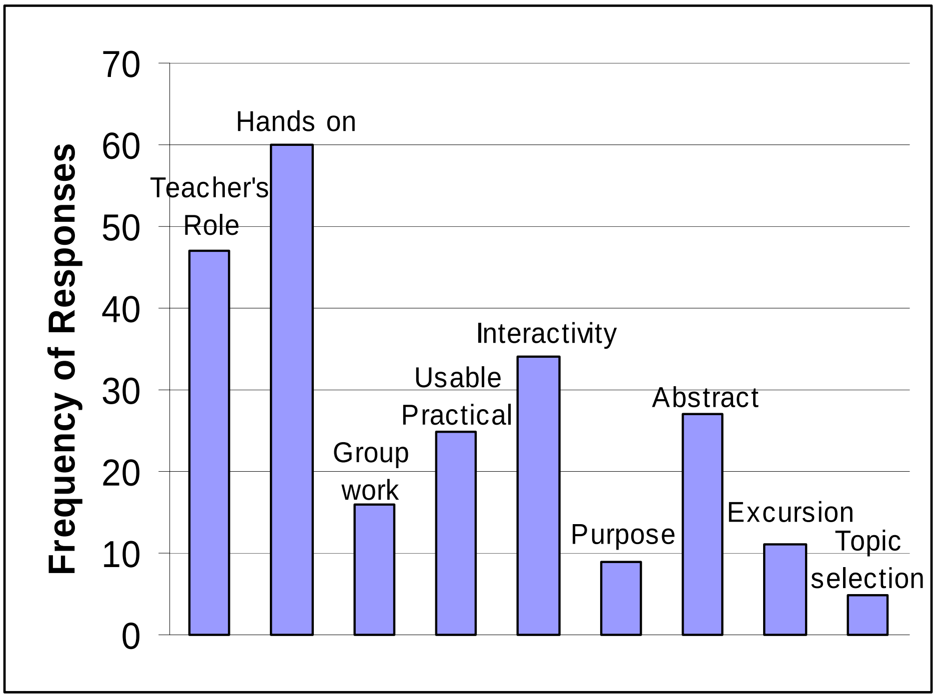
Context

This study comprised of 26% males and 74% females (n=167). Thirty-two percent of these adults entered preservice teacher education straight from high school, however, as this was the second year of preservice teacher education for most participants, their ages varied considerably, that is: 43% were between 19 and 22 years of age, 31% between 23 and 29, 17% between 30 and 39, and 9% were over 40 years of age. Consequently, all these participants were at least one and half years away from their Year 12 secondary science class with the majority of participants five or more years from their last high school days. All these participants attended the same metropolitan university within the same Bachelor of Education degree and were involved in the same core science education unit.

Results and discussion

Results about secondary school science being a positive experience were divided as follows: 52 claimed science to be a positive experience, 56 indicated science as a negative experience, and 59 were split in their decisions (indicating a mixture of positive and negative experiences). All responses relating to the impact of teaching practices in the secondary science classroom fell within nine categories, that is: teacher's role, hands-on experiences, group work, useful and practical science, purposes articulated clearly, interactivity with life, clear explanations of abstract concepts, involvement in field work, and the topic selection choice. Some adults responded with more than one practice (e.g., Group work and Excursions). Graph 1 shows the frequency of responses from these preservice teachers (*n*=167). Preservice teachers' negative responses about their own learning of science will also be discussed in this section.

Graph 1
Frequency of responses for each of the high-impact teaching practices



The above graph highlights that hands-on experiences and the teacher's role played were significant in remembering high school science activities; however, there were other considerations that may have had a high impact on these adults. The results and discussion will occur under these subheadings: teacher's role (affective domain and content expertise), hands-on experiences, group work, useful and practical science, purposes articulated clearly, interactivity with life, clear explanations of abstract concepts, involvement in field work (i.e., excursions for understanding science), and the topic selection choice.

Teacher's role (affective domain and expertise)
The quality of the teacher made a difference to 47 of the adults in this study. Responses about teachers' impact on their lives were mainly concerned with the teacher's affective domain and content knowledge expertise. Reflecting on their positive science education experience, these adults used words such as "fantastic", "wonderful", "great", and "magical" to describe their science teachers' personalities. One adult's love of science emerged "because I had an awesome teacher" (Participant 10). There was little doubt that their enjoyment and success in science was related to the teacher's infectious enthusiasm. "Secondary school science was one of my better subjects. I always had good teachers who seemed to really enjoy science themselves" (Participant 7). Another described a teacher's passion for science, which was also contagious. "I loved science. My grade 8 teacher was passionate about science and made me

want to learn more" (Participant 24). Indeed, the teacher's affective domain and strategies for learning can directly influence a student's enjoyment of science: "Because of my teachers, I enjoyed biology but could not stand chemistry and physics" (Participant 59), and "My memory of secondary science was dependent on the teacher who took the class. Some years were great because the teacher was able to communicate the content in interesting and clear ways" (Participant 130).

Conversely, the results indicated that a teacher's disagreeable personality, thoughtless strategising for stimulating students' interest in science, poor classroom management, and inability to make science fun can hamper a student's love of science and science education. The findings showed that science teachers have key roles for making lessons enjoyable in order to stimulate learning. "I did not enjoy it, therefore did not put much thought into it" (Participant 81). Classroom management needed to be part of the teacher's role in order to teach science. Students may lose interest when classroom management is not apparent. For example, "I had a teacher who had zero control over the class. This made the subject seem totally pointless" (Participant 146).

Hands-on experiences

Science appeared to be enjoyable wherever hands-on experiences were mentioned by these adults. Indeed, hands-on experiences had the highest frequency as noted in Graph 1. The combination of effective teaching, content, and hands-on practices boosted students' enjoyment of the subject: "I particularly enjoyed Biology because I had a good teacher and found the subject matter interesting and we did helpful experiments" (Participant 5). The variety of hands-on experiences and related equipment usages also seemed attractive, "A lot more exciting than primary, more materials available to use: microscopes, slides, dye and dissecting" (Participant 27). Importantly, hands-on experiences provided these students with a way to understand scientific concepts "Much more positive. I loved the laboratory experiments and field research- practicals were much easier to absorb!" (Participant 62). However, this study found that a lack of hands-on experiences can produce negative feelings about science education. Copying a teacher's work from the whiteboard or facts from a textbook severely reduced the enjoyment of secondary science. "I found it a lot more like a lecture. I couldn't find things out myself, it was just all facts from a textbook" (Participant 23).

Group work

Sixteen specifically mentioned group work as the most memorable aspect of their high school science. "We were allowed to work in groups and discuss ideas more" (Participant 61). It also appeared that greater ownership of learning occurred when groups were formed. Participant 8 found secondary science as a positive experience particularly as groups were "given some freedom in our choice of experiments". Group work not only created more interest but also lead towards using scientific knowledge in assessment pieces, for example, "Through a number of experiments we learnt how to think and act like a detective. Later we used our knowledge in an assignment to work out different 'murder case' scenarios" (Participant 164). Generally, students considered group work favourable and desirable as it provided greater autonomy and targeted their needs for completing assessment tasks.

Usable and practical knowledge

The results showed that usable and practical knowledge was valued by 25 of these adults when they were secondary students. "We learnt about science that was relevant to us. First aid, energy, toys/motor skill development etc., which made it interesting to learn" (Participant 74). A few adults indicated their delight in having practical science knowledge at their fingertips in the secondary school setting, for example, "vast amount of information readily available" (Participant 31). The balance between theory and practice appeared to be lacking in many high school settings. For example, 6 of these adults indicated that hands-on practicals were valuable and aided in understanding the theory, yet, understandings were severely short-sheeted when theories were presented without hands-on practicals. "I was a verbal and pictorial understander rather than a reader. So when the theory kicked in I didn't understand very much" (Participant 3). Many adults in this study found secondary science to be boring because of the excessive theory and note taking. "Boring because it was almost all theory and note taking" (Participant 15).

Interactivity with flora and fauna: Real-life connections

Real-life interactivity with fauna and or flora provided stronger focuses for learning, as students appeared genuinely interested in living things. Overwhelmingly, interactivity with life played a significant role in these adults' memories of their secondary science: "genetics and the animal and human body were great" (Participant 9), and "I took up biology to continue my fascinations of animals and plants" (Participant 145). Indications that science based around life was a positive experience even though the accuracy of science experiments was compromised, "I didn't enjoy several of the junior units like electricity or chemistry. Biology was great, though at times I was still fudging prac results" (Participant 21). Indeed, biology was considered very favourable among these adults as a way that changed their attitudes towards science, "I did not find science positive until biology. I could relate biology to real life experience" (Participant 29). Physics and chemistry on the other hand were given negative status by many adults with only seven specifically stating that these strands were positive experiences. Yet, there were less than 20% in this cohort who had studied Year 11 and 12 chemistry and/or physics, and most of the participants studied either biology or multi-strand science. This was also a reason for the higher frequencies related to biology, that is, 34 adults indicated memorable experiences related to interactivity with flora and fauna.

The most controversial science activity in the secondary school was dissection of a small animal (e.g., toad, frog, rat) or parts of a larger animal (e.g., cow's heart, bull's eye). This act had an enormous impact on these adults, as they remembered distinctly dissecting a creature. The feelings were divided between disgust and repulsion to delight and enlightenment. It was the point of separating those who could objectively dissect a creature from those who would find the experience indelibly sickening. To illustrate, "Cutting a toad up made me leave the room and made me sick, I couldn't see the point, why not work with diagrams?" (Participant 32). Some participants did not articulate whether their science experiences were positive or negative, rather they made statements that emphasised the memorable nature of the science activity: "Watching a sheep be castrated in Agriculture- can't really forget it!" (Participant 59).

Purposes clearly articulated

Discovering reasons for science knowledge seemed to assist students' learning, as indicated by nine of these adults. "Learning about Newton's laws of motion and tropisms were really eye opening. I found out that there are reasons things happen like a sunflower following the sun" (Participant 58). However, when the purpose for involvement in science was not clearly articulated then students can feel disillusioned. “I didn’t know how it fitted with the real world” (Participant 12). Some adults claimed they only followed teachers’ directions without knowing reasons why they were doing what they were doing: “We were mainly in the lab and I didn’t understand what was actually happening in the beakers. Just followed instructions” (Participant 22), and “Having to measure momentum and the differences between objects of various weights. I found this activity hard to relate to, and questioned the point of the exercise” (Participant 28). Enjoyment in science alone seems to be limiting if purposes are not clearly articulated, “Science lost its relevance for me as it wasn’t in worldly terms. I didn’t feel much or any continuity so I lost interest” (Participant 49).

Abstract science concepts were clearly explained
Secondary science is embodied in many abstract concepts or concepts that are more difficult to demonstrate through hands-on experiences. Teacher explanations of science concepts become crucial to the student’s understanding of such concepts. Surprisingly, 27 of these adults made claims around the abstract nature of science concepts. Concepts need to be explained that make sense to the learner, otherwise, students’ understandings will be limited, for example, “I found secondary science as a negative experience because it was never explained in a way that made sense to me” (Participant 20). Insufficient and uninformative explanations can turn a student off science for life, particularly if a teacher only reads from a textbook, “Secondary science was bad. I had one teacher who couldn’t communicate, another was a Dr. and he just read us information and didn’t explain properly--therefore I didn’t continue with science” (Participant 37). Participant 3 emphasised the need to have difficult concepts explained in more simplified terms: “In physics our teacher read a chapter from the text book. It was some sort of gibberish. When he finished, my friend and I called him over and asked him to reduce everything he had just said and put into simple terms that a primary school student would understand”. Science teachers need to look for other ways to explain difficult to grasp concepts so students do not feel like failures in science: “I remember learning about atoms, protons, electrons etc. and feeling really dumb because no matter how much the teacher explained things I couldn’t understand” (Participant 64).

Excursions for developing science understandings
Eleven adults in this study had strong memories of their science excursions when they attended secondary schools. These excursions mainly focused on topics in biology and were recognised as enjoyable: “Going to Heron Island for biology excursion. It was a great experience because we directly get in to the see and analysed the environment” (Participant 26). Similarly, “The Green Island trip allowed us to map the movement of the coral cay- fun!” (Participant 21). Excursions with a strong focus on developing science understandings can provide students with memorable science investigations. There were several adults who remembered camping in bushlands to investigate flora and fauna. Some of these excursions provided overnight camps that allowed for scientific interactions with the environment: “Stradbroke Island camping, travelling and exploring mud flats, beaches, forests and identifying trends in environments gave me a more scientific view of how things work and live” (Participant 163).

Topic selection
This study provided insight into adults’ memories of their science topics. Five of these adults appreciated the broad topic selection. Participant 74 explained that effective teaching requires the teacher to “select interesting science topics that motivated me to learn”. Some topics suggested as favourable by participants in this study included: forensic science, “My forensic science semester was highly memorable. It fascinated me about how science can uncover

information, prints, evidence that has been hidden or supposedly wiped clean" (Participant 135); light and optics, "We did photography in grade 12, which I really enjoyed. I learnt to appreciate the art of photography and the little details involved which science makes it work" (Participant 7); and topics where equipment was accessible at school, "We built a Van der Graaf generator. Harnessing the power of electricity was awesome" (Participant 12). Addressing students' needs aims to target Vygotsky's (1986) zone of proximal development, which must involve students' interests and needs. On selecting motivating topics, Participant 1's response resounded frequently throughout the 167 responses: "I found that from grade 8-10 I enjoyed it, as it was interesting however when I started multi-strand I found many of the topics pointless and boring". In science education, students' needs are varied, which requires careful thought on providing a range of suitable science topics. Yet, state syllabus documents and examination requirements impact on topic selection to address specific students' needs in secondary science.

Negative responses

The aim of the questionnaire was to determine memorable, positive experiences in secondary science education to uncover possible high-impact teaching strategies; however about a third of these preservice teachers remembered science as negative experience (Table 1). Apart from negative responses indicated within sub-headings above, data suggested that inclusive practices needed to be facilitated by teachers. In summary, high-impact teaching for secondary science appears to include the teacher's personal attributes (i.e., enthusiasm for teaching the subject). Importantly, group involvement provides the basis for sharing understandings of scientific concepts with usable and practical science lessons. Hands-on experiences were also highlighted by these participants, which further included interactivity with life and active participation on science-based excursions. Participants claimed that teachers who articulated clear purposes for conducting science activities motivated student involvement. Conversely, teachers' lack of enthusiasm, being uninformed on students' interests, presenting disengaging activities that assail the senses, lack of hands-on experiences with considerable "chalk and talk", and denigrating students' ideas appeared as low or negative impact teaching (Table 1).

Table 1

High-Impact and Low or Negative-Impact Practices for Secondary Science Teaching

High-Impact Teaching for Science	**Low or Negative Impact**
Teacher's role and affective domain	Uninformed on student interests
Group work	Teachers' lack of enthusiasm
Usable and practical scientific knowledge	Reasons not articulated
Hands-on experiences	Chalk and talk; copy from OHT
Interactivity with flora and fauna	Personal ideas denigrated
Clearly articulated purposes	Disengaging activities
Abstract concepts clearly explained	
Excursions for science understandings	
Selection of topics	

Surprisingly, there were some practices highlighted as effective in the literature that were not found within the 167 participant responses on secondary science education. For example, targeting students' misconceptions about scientific concepts, which is advocated by many educators (e.g., see California Journal of Science Education**,** 2005, which devotes Volume 5 Issue 2 to "Dealing with science misconceptions"; Ünal & Coştu, 2005) was not rated by these participants as a way to create memorable learning experiences in secondary science. Targeting misconceptions may be a teaching strategy to challenge students' current knowledge but may not contribute to long-term positive impacts for secondary science; yet targeting misconceptions in primary science appears to have an impact in primary science (e.g., see Hudson, 2007).

Conclusion

This study investigated 167 adults' responses about their memories of positive (and negative) secondary science education experiences that may lead towards developing high-impact science lessons. There were strong connections in this study to constructivism, authentic learning, and problem-based learning. There were also connections to discovery and interactive approaches for learning science concepts. The results indicated high-impact teaching for science included: the teacher's role, hands-on experiences, group work, useful and practical science, purposes articulated clearly, interactivity with life, clear explanations of abstract concepts, involvement in field work, and the breadth of topic selection. Low or negative-impact practices were also expressed by participants that involved: disengaging activities with sensory-repulsive tasks, unclear reasons for learning science, teacher's lack of enthusiasm, chalk and talk or copying teacher's work, and denigrating students' personal ideas. Implementing science lessons with one or more high-impact science teaching practices may "make a difference" towards influencing students' positive long-term memories about science and their science education. Conversely, avoiding negative practices may also assist in facilitating positive long-term memories.

Although teaching approaches can vary between different educational levels, and an individual's preferred learning style may change with age and experience, these high-impact teaching practices have a student-centred focus that may be adapted to suit individual styles. Indeed, exemplary primary, secondary and tertiary teaching practices may be interchangeable and relevant to effective teaching practices regardless of the level of study. The high-impact teaching for science indicated in this study can have relevance at all levels of education. For example, presenting practical, hands-on activities that have group work and purpose are applicable to secondary science as much as tertiary science courses. Preservice teacher education courses need to embed in their course designs high-impact teaching strategies and present negative practices as a way to avoid such practices. Considerations of positive and negative teaching practices can assist teachers and preservice teachers to plan for high-impact science lessons as a potential way for making a lifelong difference. It is proposed that knowledge of positive high-impact teaching practices may assist preservice teachers and teachers. Conversely, it is proposed that knowledge of negative high-impact teaching strategies can be disseminated and avoided by both preservice teachers and teachers. Identifying positive high-impact teaching practices in the sciences may lead to arresting the decline in science enrolments.

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