SENCERizing Preservice K–8 Teacher Education: The Role of Scientific Practices

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Abstract

Recent policy reports are calling for curriculum reforms to address problems about a lack of relevance and an avoidance of the core scientific practices in science courses K–16. One important cohort is K–8 teacher candidates who need courses in which they learn core ideas in science and participate in science practices. One promising approach is infusing SENCER courses into the science course sequence for future teachers. We report a review of select SENCER courses using an Evidence-Explanation framework to assess the type and levels of science practices introduced. Results on 'Differences in Courses', 'Common Themes Among Courses', and 'Demographic Patterns' are reported.

Introduction

Recent US.. policy reports express a growing concern for the supply of scientists, science workers and science teachers; c.f., National Research Council 2006 report *Raising Above the Gathering Storm* and the National Center on Education and the Economy 2007 report *Tough Choices Tough Times*. The STEM (Science Technology Engineering Mathematics) teacher and workforce shortages have two components (1) declines in attracting and retaining individuals into science/science education programs of study and (2) into places of employment. These recent reports show that uptake of STEM courses and careers are waning. Then there is the documented evidence that the development of youth attitudes toward science, both negative and positive, begins in and around middle school grades (ADEEWR, 2008). Thus, much of the focus for addressing the problems is on schools and schooling K–16.

Consensus review reports (Carnegie Corporation of New York, 2009) are placing much of the blame on the curriculum models citing a lack of relevance and an avoidance of the core scientific practices that frame science as a way of knowing; e.g., critiquing and communicating evidence and explanations. The NRC K–8 science education synthesis research study *Taking Science to School* (Duschl, Schweingruber & Shouse, 2007) is another consensus report that makes recommendations about the reform of science curriculum, instruction and assessment. The *TSTS* report concludes that K–8 science education should be grounded in (1) learning and using core knowledge, (2) building and refining models and (3) participating in discourse practices that promote argumentation and explanation. The report also concludes that a very different model of teacher education must be put into place. That raises an important set of issues. Where in the undergraduate curriculum do future K–8 teachers engage in and learn to use the core knowledge, building and refining models and argumentation and explanation practices?

The typical introductory survey science courses taken by non-science majors and elementary education candidates focus more on the 'what we know' of science and less on the 'how we know' and the 'why we believe' dynamics and practices of science. Determining the level and degree of scientific practices in science courses is essential for shaping and understanding pre-service/inservice teachers' engagement and confidence in doing science when planning and leading science lessons in their own classroom. Science courses that focus exclusively on teaching what we know in science are inappropriate for future teachers.

Teacher candidates need courses in which they participate in science practices. One promising approach we have been considering is infusing SENCER courses into the science course sequence for future teachers (e.g., subject matter, SENCER, science teaching methods). Science Education for New Civic Engagements and Responsibilities (SENCER) course frameworks offer a potential solution to both engagement in and understanding of science practices. The SENCER commitment is to situate science learning in civic or social problems to increase relevance, engagement and achievement in science content knowledge and inquiry practices. This article reports on an analysis of a subset of SENCER courses that take up environmental problems as the civic engagement issue.

The study investigates how the design of SENCER courses provides opportunities to practice science as inquiry. The premise is that teachers gaining experience in science practices are more likely to use these practices in their own elementary school classrooms. In turn, these teachers will be in a better position to understand and hopefully address the *Taking Science To School* recommendation that K–8 science education be coordinated around the 4 Strands of Proficiency:

is this quoted materail? from Duscl et al 2007?

Students who understand science:

1. Know, use and interpret scientific explanations of the natural world.
2. Generate and evaluate scientific evidence and explanations.
3. Understand the nature and development of scientific knowledge.
4. Participate productively in scientific practices and discourse.

One of the three *TSTS* recommendations for teacher professional development speaks directly to the issue:

> Recommendation 7: University-based science courses for teacher candidates and teachers' ongoing opportunities to learn science in-service should mirror the opportunities they will need to provide for their students, that is, incorporating practices in all four strands and giving sustained attention to the core ideas in the discipline. The topics of study should be aligned with central topics in the K–8 curriculum so that teachers come to appreciate the development of concepts and practices that appear across all grades. (Duschl et al, 2007, p 350)

Review of Literature and Analytical Frameworks

With respect to changing how and what science is taught, one important cohort of science students is pre-service elementary (K–8) teachers who have low self-efficacy when it comes to science (Watters & Ginns, 2000). The K–8 education cohort's lack of confidence and experience within the science experiences they had contributes to maintaining a cycle in which the students they teach lose interest and confidence in learning science due to poor teaching strategies, misdirected curriculum and weak teacher knowledge. (Wenner, 1993). Sadler (2009) has found that socio-scientific issues (SSI) affect learners' interest and motivation, content knowledge, nature of science, higher order thinking and community of practice. Thus, it is not a surprise that SENCER courses have successfully demonstrated increases in student enthusiasm (Weston, Seymour & Thiry, 2006). However, more information is needed to determine how SENCER courses impact student achievement in core knowledge of science and with science practices that involve model-building and revision. The first step toward conducting research on the impact of SENCER courses on learning is to ascertain which SENCER courses are implementing scientific practices; e.g., raising research questioning, planning measurements and observations, collecting data, deciding evidence, locating patterns and building models, and proposing explanations. The driving question is can SENCER courses when placed between science courses and science teaching methods courses effect teacher thinking and practices.

Co-designed courses represent another model that brings science and science methods courses together. The co-designed courses are planned and taught by both science and science education faculty. Zembal-Saul (2009, 687) has found that co-designed courses that adopt a framework for teaching science as argument to preservice elementary teachers served "as a powerful scaffold for preservice teachers' developing thinking and practice . . . [as well as] attention to classroom discourse and the role of the teacher in monitoring and assessing childrens' thinking." Schwartz (2009) found similar positive effects on preservice teachers' principled reasoning and practices after using an instructional framework focusing on modeling-centered inquiry coupled with using reform-based criteria from Project 2061 to analyze and modify curriculum materials. What these two studies demonstrate and the SENCER model supports is the effectiveness coherently aligned courses can have on students' engagement and learning. Such shifts in undergraduate courses and teaching frameworks will contribute to breaking the cycle that perpetuates low interest and high anxiety in the sciences at all levels of education, K–16.

Research shows that pre-service elementary school teachers tend to enter the profession with inadequate knowledge of scientific content and practice. Pre-service elementary teachers answer only 50 percent of questions correctly on a General Science Test Level II (Wenner, 1993). Stevens and Wenner's (1996) surveys of upper level undergraduate elementary education majors are consistent with other research that 43 percent of practicing teachers had completed no more than one year of science course work in college (Manning, Esler, & Baird, 1982; Eisneberg, 1977). The lack of courses and experiences in science reflected the low self-efficacy in science among pre-service elementary school teachers (Stevens & Wenner, 1996; Wenner, 1993).

If no changes are made to current coursework required of pre-service elementary school teachers, they will continue to have low self-efficacy in science and therefore avoid teaching this subject (Stevens & Wenner, 1996). Thus, teachers are unlikely to use inquiry within their science lessons with the result that students are not exposed to scientific practices. The cycle of negative experiences with science does not have to be accepted as an educational norm; as the studies by Zembal-Saul and by Schwartz demonstrate. Changes can be made that coherently align science courses with methods courses.

SENCER courses can serve as a bridge to connect real-world issues and scientific knowledge with the positive impact of raising motivation and engagement among non-majors' and pre-service elementary teaches' to learn science (SENCER, 2009). Evidence shows that learning science within the context of a current social problem helps to motivate pre-service teachers and enables them to form goals that include learning scientific concepts and practices (Watters and Ginns, 2000; Sadler, 2009). Pre-service elementary teachers who experience scientific practices and do investigations that build and refine scientific evidence and explanations can more informed decision makers about science and the teaching of science.

Evidence-Explanation Continuum Framework

While it is important that SENCER courses successfully motivate pre-service elementary teachers to learn about science content, it is also essential that science courses provide opportunities to use scientific knowledge and practices. The targeted science practices for this review of SENCER courses are from the Evidence-Explanation (E-E) continuum (Duschl, 2003, 2008). The E-E continuum represents a step-wise framework of data gathering and analyzing practices. The appeal to adopting the E-E continuum as a framework for designing science education curriculum, instruction and assessment models is that it helps work out the details of the critiquing and communicating discourse processes inherent in TSTS Strand 4—Participate productively in scientific practices and discourse. The E-E continuum recognizes how cognitive structures and social practices guide judgments about scientific data texts. It does so by formatting into the instructional sequence select junctures of reasoning, e.g., data texts transformations. At each of these junctures or transformations, instruction pauses to allow students to make and report judgments. Then students are encouraged to engage in rhetoric/argument, representation/communication and modeling/theorizing practices. The critical transformations or judgments in the E-E continuum include:

1. Selecting or generating data to become evidence,
2. Using evidence to ascertain patterns of evidence and models.
3. Employing the models and patterns to propose explanations.

Another important judgment is, of course, deciding what data to obtain and what observations or measurements are needed (Lehrer & Schauble, 2006; Petrosino, Lehrer & Schauble, 2003). The development of measurement to launch the E-E continuum is critically important. Such decisions and judgments are critical entities for explicitly teaching students about the nature of science (Duschl, 2000; Kuhn & Reiser, 2004; Kenyon and Reiser, 2004). How raw data are selected and analyzed to be evidence, how evidence is selected and analyzed to generate patterns and models, and how the patterns and models are used for scientific explanations are important 'transitional' practices in doing science. Each transition involves data texts and making epistemic judgments about 'what counts.'

In a full-inquiry or a guided-inquiry, students formulate scientific questions, plan methods, collect data, decide which data to use as evidence, and create patterns and explanations from the selected evidence (Duschl, 2003). Science engagement becomes more of a cognitive and social dialectical process as groups and group members discuss why they differed in data selected to be evidence and varied in the evidence used for explanations (Olson & Loucks-Horsley, 2000). Students' participating in these interactions tend to build new knowledge and/or to correct previous misconceptions about a scientific concept (Olson & Loucks-Horsley, 2000).

Research Context and Methods

The research question asks to what extent do SENCER courses model and use scientific practices that are linked to obtaining and using evidence to develop explanations? SENCER courses were selected from the SENCER website and examined to determine the opportunities provided to engage in scientific practices. Only SENCER courses designed around environmental topics (e.g., water, earth, soil, rocks) were selected because these courses offer up integrated science opportunities. Next, course syllabi, projects and activities were reviewed to ascertain students use, or the potential for use, of data-driven E-E scientific practices.

SENCER courses were considered to emphasize planning and asking questions if students asked their own research question, designed their own experiment, or designed an engineering project. A course that stressed data collection showed that students went into the field and collected soil, water, or air, or they took measurements of samples. A SENCER course provided students practice in evidence if they decided which data to keep as inferred by students representing data or creating graphs. Practice in evidence was also inferred if students analyzed data later. Students could not complete this activity without deciding which evidence to use. A course gave students experience in patterns if students determined how the evidence was modeled as seen by analysis of evidence or running statistics on evidence. Lastly, a course allowed students to practice using explanation if students connected their project to previous research or theories as seen in library searches, if they made predictions for another phenomenon based off of their results, or if they discussed recommendations. Courses that included scientific content but focused on practices used in the humanities such as research and communication with another culture and were left out of this study. A summary of the criteria for evaluating the courses appears in Table 1,below.

The names of the courses located on the SENCER website appear in Table 2. Each scientific practice identified was worth one point on the scale. A scale from 1–5 was created to effectively compare scientific practices identified in each of the course modules. A score of 1 indicated that the course module only incorporated one portion of scientific practice, and a score of 5 indicated that the course emphasized all five portions of scientific practice within the E-E continuum. Therefore, a course with a score of 1 did not emphasize scientific practice whereas a course receiving a score of 5 heavily emphasizes scientific practice.

TABLE 1. Criteria for Evaluating SENCER Courses

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E-E Continuum Component	SENCER Course Criteria for Inclusion of E-E Continuum Component
Asking questions and planning	Students: ask their own research question(s), design their own experiment. or design engineering project
Data collection	Field Work: Soil, water, air collection, or sample measurements
Evidence	Students decide evidence to keep; inferred from data representations or graphs or later data analysis in the pattern component of the E-E continuum
Patterns	Students determine how evidence is modeled; inferred from analysis of evidence or running statistics on evidence
Explanation	Connection of project to previous research; library searches; predictions for another phenomenon based off of results; or discuss recommendations

made singular

deleted "licensure"—you receive license, not major in it

standardized time units

TABLE 2. Selected SENCER Courses

Course Title/Civic Problem*	Institution	Classification	Class Size†	Student Year	Major	Class Time‡
Introduction to Statistics with Community-based Project. No specific focus; students choose topic	Metropolitan State University, Saint Paul, MN	Public university, urban	32	Nontraditional students (working)	Applied math; biology; management; nursing; social work; math teaching	3.3 hrs
Ordinary Differential Equations in Real-World Situations: No specific focus; various data sets given to solve	Bryn Mawr College, Bryn Mawr, PA	Women's liberal arts college	15–20	Junior, senior	Math	1.3 hrs, twice
The Power of Water. Create the most efficient turbine to power small rural community	Longwood University, Farmville, VA	State institution	60–90, lecture 24, lab	Sophomore	General education	3-hr lecture; 2-hr lab
Science on the Connecticut Coast: Investigations of an Urbanized Shoreline: Determine human impact in local marshes/beaches	Southern Connecticut State University, New Haven, CT	State institution	20	Freshman, sophomore	Non-majors	2-hr lecture/ lab; 3-hr field
Renewable Environment: Transforming Urban Neighborhoods: Determine impact of urbanization on environment	Saint Mary's College of California, Moraga, CA	Christian Brothers College	n/a	n/a	n/a	3-hr × 2
Riverscape (five courses): Determine human impact on water quality	Hampton University, Hampton, VA	Private university	5–25	Sophomore, graduate student	Undergrad and graduate pre-service teachers	1 time
Chemistry and Policy: A Course Intersection: Determine human impact on soil quality and learn how to communicate results to general public	Vassar College, Poughkeepsie, NY	Liberal arts college	n/a	n/a	Chemistry, non-majors interested in policy	1-hr lecture × 3; 4-hr lab
Environment and Disease: Determine if connection exists between human impact on environment and widespread disease	Bard College, Annandale-on-Hudson, NY	Liberal arts and sciences college	n/a	Freshman	n/a	1.3-hr lecture × 2; 2.5-hr lab
Energy and the Environment: Topic varies, but students study some aspect of water quality	New York University, New York City, NY	Private university (14 schools)	120–30, lecture 20, lab	n/a	n/a	1.25-hr lecture; 1.67-hr lab
Geology and the Development of Modern Africa: Investigate the best location to conduct mining in Africa, using geological techniques	Hamilton College, Clinton, NY	Private liberal arts college	n/a	n/a	n/a	4 hr
Chemistry and the Environment: Create questions related to environmental quality around campus	Santa Clara University, Santa Clara, CA	Jesuit Catholic university	n/a	n/a	n/a	n/a
Science, Society, Global Catastrophe: No particular research question; students practicing steps of scientific process	University of Wisconsin, Marathon, Wausau, WI	Public university, freshman sophomore	25	Freshman, sophomore	n/a	n/a

Reworded classification—this IS a public university, correct?

* Looking at, e.g., water quality; for some, do they even have a SENCER focus?

† Students per class.

‡ Per week.

Course demographics were also investigated from the SENCER website. Information researched included type of institution, class size, student year, major and class time (Table 3). Demographic information was then used to interpret any differences seen in level of scientific practice among SENCER course modules.

Results and Findings

The results and findings are reported in 3 sections: Differences in Courses, Common Themes Among Courses, and Demographic Patterns.

Differences in Courses

Differences in courses are presented from the highest emphasis on scientific practices (5) to lowest emphasis of scientific practices (1). Two courses, "The Power of Water" and "Chemistry and the Environment," received a 5 because they provided students with practice in each aspect of scientific inquiry (Table 3). However, they approached various aspects of inquiry differently due to the nature of the problem being solved. "The Power of Water" took an engineering method in which students designed the most efficient micro-hydropower turbine for a hypothetical small rural village whereas "Chemistry and the Environment" students formulated their own question to research about some environmental chemistry issue on their campus.

Most of the courses scored a 4 (Table 3), these included "Introduction to Statistics with Community-based Project," "Chemistry and Policy", "Renewable Environment: Transforming Urban Neighborhoods," "Riverscape," "Environment and Disease," "Energy and the Environment," and "Geology and the Development of Modern Africa." These six courses differed from "The Power of Water" and "Chemistry and the Environment" because they did not allow students to explain their patterns or models. Two courses that received a 4 did expose students to explanation, but left out some other aspect of scientific practices in inquiry. Students in "Chemistry and Policy" did not create their own scientific question to study, and "Riverscape" did not provide students with practice in creating create patterns. The "Riverscape" course is a major source of interest because it was designed specifically for preservice elementary school teachers in the attempt to gain appeal in science and learn scientific practices.

Two courses provided students with the opportunity to use 3 out of 5 practices within scientific inquiry, giving them a score of 3. "Renewable Environment: Transforming Urban Neighborhoods" and "Science in the Connecticut Coast," allowed students to collect data, provide evidence, and create patterns or models. However, students did not practice the planning and explanation stages of scientific inquiry.

Two courses that gave students experience in the fewest scientific practices scored a 2. There were no courses that scored a 1. "Science, Society, and Global Catastrophe" and "Math Modeling" differed in the inclusion of scientific practices. "Science, Society, Global Catastrophe" gave students training in finding evidence and creating patterns and models but not in the remainder of scientific practices. "Math Modeling" enabled students to practice finding evidence and creating explanations, but the course provided students with the remaining portions of scientific inquiry.

Common Themes Among Courses

SENCER courses with differing levels of scientific practices tended to have common themes for practicing scientific inquiry. One major theme was the use of collaboration as seen through group work on a scientific project. Most course modules shown on the SENCER website specifically state that students work in groups for their projects. Others such as "Riverscape" and "Chemistry and Policy" do not directly state that students do group work, although collaboration is emphasized within the course. The only course that did not emphasize collaboration was "Renewable Environment: Transforming Urban Neighborhoods," although this information may have been left off of the SENCER website. While not specifically stated within the E-E continuum, collaboration plays an important role within inquiry. Students who are able to discuss scientific concepts with one another can articulate ideas and argue enabling them to reconstruct their own ideas of scientific meaning (Olson & Loucks-Horsley, 2000).

Another common theme among high practice SENCER courses was that students communicated their results with one another in various formats. Most courses incorporated formal presentations at the end of the project for the rest of the class. Others used formal presentations, although they were created for different audiences such as the general public or for a buyer of potential land for diamond extraction. Other course modules such as "Science in the Connecticut Coast" and "Environment and Disease" based communication more on discussion of scientific concepts. Despite differences in the means of presenting ideas in class, communication of results is an important skill essential to inquiry-based learning.

Demographic Patterns

The SENCER courses differed in demographic information. The total number of students participating in class was widespread between 5 and 130 students (Table 3). Laboratories decreased class size to roughly 20 students. However, more

TABLE 3. Scored Courses

pls. clarify meaning of "X" in these five columns; should empty cells be "n/a" or "no result"?

Course	Total Score	Planning	Data Collection	Evidence	Patterns and Models	Explanation
Introduction to Statistics with Community-Based Project	4	X: come up with own question- write proposal	X: gather data	X: represent data	X: run stats and interpret data	
Math Modeling	2				X: find patterns	X: predictions; make questions from patterns/models
The Power of Water	5	X: create design of turbine	X: gather data	X: made graphs	X: interpret graphs	X: library research
Science in the Connecticut Coast	5	X: plan how they gather data	X: gather lots of data	X: inference because says that students analyze data later	X: analyze data	X: discuss results at conferences with other scientists
Renewable Environment: Transforming Urban Neighborhoods	3		X: gather data	X: inference because learning to interpret	X: learn to interpret	
Riverscape	4	X: question plus their own experiment	X: gather data	X: report results in proper format		X: search scientific literature; inference that attempting to explain
Chemistry and Policy	4		X: spectroscopy, chromatography, and electrochemistry; learn the importance of adequate sampling	X: inferring chose which data to use if communicating results	X: communicate results to those with less knowledge	X: discuss recommendations
Environment and Disease	3		X: learn challenge of collecting data	X: inference, analyze results	X: analyze data and interpret data- use of models	
Energy and the Environment	4	X: create own question to study and design experiments	X: collect H_2O sample	X: plot into graphs on excel spreadsheet	X: generate their own scientific conclusion- present to peers	
Geology and the Development of Modern Africa	4	X: planning how to implement surveys	X: collect data and gather samples	X: inferring yes because analyzing data	X: analyze data to present to investors	
Chemistry and the Environment	5	X: develop hypothesis and make experiment	X: varied water/air samples	X: inferring yes if making recommendations	X: inferring yes if make recommendations	X: make recommendations
Science, Society, Global Catastrophe	2			X: choosing which data to use in activities	X: math and statistical modeling exercises/ interpretation of data	

information is needed for "The Power of Water" laboratory class size. Student year ranged from freshmen to graduate students within the course. Student type varied greatly from non-majors and pre-service elementary school teachers to math or chemistry majors. Total class time differed among the courses in addition to the way the time spent was scheduled (Table 3).

None of the demographic information influenced the degree to which students gained practice in using science. Although class size is variable among courses, it had no impact on amount of scientific practices emphasized. Courses with large class sizes such as "The Power of Water" and "Energy and the Environment" provided students with similar practice in using science to smaller classes such as "Riverscape."

Additionally, student major had little impact on scientific practices emphasized within SENCER courses. Majors used a varying number of scientific practices among the courses studied. Math students in "Introduction to Statistics with Community-Based Project" used more areas of scientific practice than math majors in "Math Modeling" as seen in Table 3. Majors also did not use any more scientific practices than non-majors in these courses. "The Power of Water" allowed students to use all 5 elements of scientific practice in inquiry whereas majors in "Math Modeling" were only given the opportunity to practice 2 aspects.

Class year also did not affect the ability to expose students to use scientific practices. As expected, SENCER courses enabled upperclassmen and graduate students to gain practice in conducting science as seen in "Riverscape." However, many SENCER classes also provided underclassmen with a rich experience in practicing science. For example, "The Power of Water," consisting of sophomores, provided students with practice in every area of scientific inquiry.

Lastly, class time did not affect student exposure to using scientific practices. Courses that received the same scores consisted of a wide variety of time scheduled. "Chemistry and Policy" devoted much more time toward class time than "Environment and Disease," but students experienced the same number of scientific practices.

Conclusions

Distinctions in SENCER course characteristics have led to varying opportunities for students to gain experience in doing scientific practice as seen in this study's scores. Those with the highest scores allow students to have the greatest amount of ownership over their own work. Courses with a score of 5 provide students with the ultimate source of ownership in allowing them to choose their own question to study. Modules with scores of 3 and 4 may not allow students to ask their own questions to study, but they do provide students with responsibility over the remainder of scientific practices in the E-E continuum. Courses with the lowest scores provide students with the least amount of ownership over their own work. Students are given a piece of someone else's project and continue a small portion of that project. For example, students are given another project's data set that they are expected to analyze. Future SENCER courses should consider giving students as much ownership over their work as possible to encourage student experience in using scientific practices.

The nature of data collection also had an impact on the level of scientific practices used within course modules. Courses in which there was easy access to collect soil or water samples of interest along with equipment to measure samples showed a higher level of scientific practices within the E-E continuum. Courses such as "Math Modeling" and "Science, Society, and Global Catastrophe" may not have allowed for easy access to gather water or soil samples. Therefore, the course was unable to provide students with the opportunity to gain practice in data collection. "Geology and the Development of Africa" found a loophole that enabled students to gather their own data by using a computer simulation. Students did not actually collect rock samples in this class, but were able to collect data from their computer simulation. Perhaps computer simulations could be used in other courses that do not have easy access to take samples from the environment.

While these characteristics provide critical information to increase a SENCER course's use of scientific practices, traits that have no effect on level of scientific practices also offer great insight to increase student experience in performing science.

It is reassuring that SENCER courses can be flexible enough in incorporating inquiry for small as well as large class sizes. Future courses using the SENCER approach may be designed knowing that students can successfully learn scientific practices within a large classroom size. SENCER courses may cater to majors and especially to non-majors who have little experience in scientific practices. It is appropriate to use SENCER not only for upper level courses, but it is also critical to apply these modules to lower level classes.

SENCER courses provide a way to incorporate scientific practices within student learning. The integration of social issues with science builds pre-service teacher interest in scientific practices. As these students gain experience in using scientific tools, they become more confident in incorporating science into their future elementary classroom. Perhaps our future teachers' greater enthusiasm for science will spark student interest in the sciences.

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