Investigating the Role of Physics Departments in the Preparation of K-12 Teachers

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My experience at the University of Maryland extends over an eight-year period during which I, with the help of others, designed an introductory physics course for preservice elementary teachers. The course was modeled after the AAPT Powerful Ideas in Physical Science.[1] This became part of the course and program changes associated with the Maryland Collaborative for Teacher Preparation and NSF-sponsored program.[2]

The Nature of the Course

The nature of a physics or physical-science course appropriate for elementary teachers is revealed in some of the statements shared with the students in the course syllabus.

Laboratories

The laboratory activities are the key to the course. Most of the concepts that we deal with will be encountered first in the guise of laboratory activities. Along with your lab group you will observe physical systems, predict their behavior, test your predictions and draw your own conclusions based on your laboratory experiences. You and your lab partners will be the world's most knowledgeable persons in this enterprise and the negotiators of our final understanding of each concept. Your teachers are resources, but they cannot do the understanding for you, nor simply tell you of theirs.

Labgroups

Labgroups will consist of three students, and should become a stable group during the third week. This modest learning community will share much of the responsibility for the personal understanding of all of its members.

Examinations

There will be two two-hour examinations and one final exam. Each will have a written portion as well as a laboratory-activity component, and be worth 150 points.

Exams will be conceptual in nature, comprised largely of essay questions that will require you to draw from your personal laboratory experiences as you articulate and support your understanding of physical concepts. When you are asked to solve a quantitative problem you will also be asked to provide a conceptual explanation. Each examination will contain a laboratory experience to be completed with your own lab group.

You may use your notebook during the exams.

Journals

You will be asked to respond informally to activities, discussions and questions in a journal. This is the place for personal comments, questions and thoughts to be shared with the class, or in a personal interchange with your teachers. The journal can be a critical feature in our learning process. We will offer credit for journal submissions, and evaluate each using a rubric to be described later. Submissions will be electronically supplied on the PHYS 117 listserv, or sent to the instructor.

Written Assignments

Assignments will be given with due dates for each. There will be a combination of laboratory and homework assignments, both of which will contribute to your semester's overall score.

PHYS 117A
SKILLS DISCUSSION
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A number of skills will be developed within our PHYS 117 learning community, for which you have a personal responsibility. From time to time we will relate these to the National Science Education Standards, so you will have a context for your work.

Observation

We will be able to demonstrate with laboratory activities most of the concepts or ideas that we will be dealing with in this introductory physical-science course. The first skill you will need to develop is that of making personal predictions and describing in your own words what you personally observe as activities are carried out. This will sometimes mean utilizing diagrams in support of your words, and using words that are already a natural part of your vocabulary. As our work progresses, you will begin making the transition to words that arise from within the science community, a community within which you are now a full participant.

Scholarly Response

On examinations and in your written work, the first stage of a scholarly response will be your personal skill in describing in your own words your predictions or conjectures, what you have observed, followed by words and explanations that may have been provided by you, your labmates, the professor, the TA, the text or lab guide.

Evidence

The best evidence you can offer is the statement "**I saw it**," not "the book said so" or "Dr. Layman said." This ability becomes your personal responsibility, and our task is to optimize your chance to do this skillfully. One caveat, however, is the statement that may become more clear as the semester progresses, "If I hadn't believed it, I wouldn't have seen it."

Explanations

Explanations for things observed, offered by you, your labmates, your TA, the teacher, the text and from other sources must always be greeted with some skepticism. Our observations on the other hand are more reliable and can always be verified by repeating the observation. We must, however, recognize that although we may all be "observing the same event," we may not all "see" the same thing. When explanations for what we observe involve second-hand information or inferences from the observations, however correct they may turn out to be, we will occasionally use the term "rumor has it," to indicate that we may not yet have full understanding of a concept.

Welcome

Welcome aboard. We will have a grand time honing your personal skills and understandings, and your ability to watch yourself learn. We (meaning you and the instructors) will also learn much from our interactions. All members of a successful learning community participate in "learning."

Note: Students enrolled in a course should have access to the rational behind the course and have an indication that the teaching/learning procedures employed arise from best practice as described or defined in national reports. The remainder of this section of the syllabus is made up of quotations from one national document.

SHAPING THE FUTURE[3]

New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology

A Report on its Review of Undergraduate Education
by
the Advisory Committee to the National Science Foundation
Directorate for Education and Human Resources

Too many students leave Science, Mathematics, Education & Technology (SME&T) courses because they find them dull and unwelcoming. Too many new teachers enter school systems underprepared, without really understanding what science and mathematics are, and lacking the excitement of discovery and the confidence and ability to help children engage SME&T knowledge. Too many graduates go out into the workforce ill prepared to solve real problems in a cooperative way, lacking the skills and motivation to continue learning.[4]

We recommend that[5]:

SME&T faculty: Believe and affirm that every student can learn, and model good practices that increase learning; start with the student's experience, but have high expectations within a supportive climate; and build inquiry, a sense of wonder and the excitement of discovery, plus communication and teamwork, critical thinking and life-long learning skills into learning experiences.

Inquiry—although there is disagreement about the meaning of the term "science literacy" and doubt about whether agreement is possible on a list of facts everyone should know. There is no disagreement that every student should be presented an opportunity to understand what science is, and is not, and to be involved in some way in scientific inquiry, not just a "hands-on" experience.

VII. SME&T faculty[6]

A. Believe and affirm that every student can learn; recognize that different students may learn in different ways and with differing levels of ability; and create an environment in each class that both challenges and supports.
B. Be familiar with and use the results of professional scholarship on learning and teaching.
C. Build into every course inquiry the processes of science (or mathematics or engineering), a knowledge of what SME&T practitioners do and the excitement of cutting-edge research.
D. Devise and use pedagogy that develops skills for communication, teamwork, critical thinking and lifelong learning in each student.

E. Make methods of assessing student performance consistent with the goals and content of the course.
F. Start with the student's experience; understand that the student may come with significantly incorrect notions; and relate the subject matter to things the student already knows.
G. Build bridges to other departments, seeking ways to reinforce and integrate learning, rather than maintaining artificial barriers.
H. Develop partnerships and collaborations with colleagues in education, in the K–12 sector and, in the business world, to improve the preparation of teachers and principals.
I. Model good practices that increase student learning.
J. Take seriously academic advising that helps students have as much flexibility as possible and is linked to career development services of the institution.

There is no textbook for the course. The inquiry activities are designed to provide student-derived understandings of the concepts and scientific procedures. Students may refer to texts, but soon recognize that they can arrive at a better understanding through their own inquiry activities.

The course utilizes a learning cycle and the success of each student depends on each student sharing the responsibility for learning, the success of the student's laboratory group and at times the whole class, with the professor taking the role of one whose obligation is to skillfully orchestrate the whole process.

Brooks and Brooks[7] have provided a set of conditions that should be present in any setting in which inquiry learning is taking place. This can serve as a metric when monitoring the course for preservice elementary teachers.

Inquiry-Centered Instruction

Inquiry-centered instruction may be described in terms of a set of characteristics shared by teachers adopting this approach.[7]

Such teachers:

- encourage and accept student autonomy and initiative;
- use raw data and primary sources, along with manipulative, interactive and physical materials;
- when framing tasks, use cognitive terminology such as classify, analyze, predict and create;
- allow student responses to drive lessons, shift instructional strategies and alter content;
- familiarize themselves with students' understandings of concepts before sharing their own understandings of those concepts;

- encourage students to engage in dialogue, both with the teacher and with one another;
- encourage student inquiry by posing thoughtful, open-ended questions and asking students to question each other;
- seek elaboration of students' initial responses;
- engage students in experiences that pose contradictions to their initial hypotheses and then encourage discussion;
- allow time after posing questions; and
- provide time for students to construct relationships and create metaphors; and nurture students' natural curiosity.

The Role of Technology in the Course

The laboratory for this course was the first one in the department to use laboratory interfacing as a regular part of a course. Macintosh computers with laboratory interfacing equipment are at each of ten laboratory tables. The Microcomputer-Based Laboratories (MBL) utilize motion detectors to study position and velocity and to build their graphing skills. They use the curve fitting programs to study functions that describe motion: linear, quadratic and trigonomic. They compare the computer-generated results to their own personal calculations and determination of linear equations. One of the goals of the course is to integrate the use of mathematics with the science, so they are perceived as common elements of the language needed to describe the experiments and the physics in a general manner.

The four elements emphasized in the course are experiments, stories, graphs and equations. Students learn to work among these representations of the science and recognize that different students feel at home with different representations, but they, as teachers, need to feel at home with each and skillfully work across these elements. The MBL activities provide high-quality graphs, quick turnaround for experiments that need to be re-run and the ability to analyze the graphs to support the students' verbal or written explanations for the physics involved.

In their study of heat and the conservation of energy, temperature probes are used to study heating, cooling, freezing and melting processes and to recognize some of the properties of ice and water that illustrate so nicely the conservation of energy. Students are asked to design an experiment to determine "how much ice water can melt." After obtaining approval of their plan, students can place a temperature probe in water to which ice is being added. Students notice that the graph of the temperature of the mixture first falls rather swiftly, then begins leveling off at a temperature near $0^{o}C$ and that at that point the ice has stopped melting. Careful discussion within the laboratory group leads the students to recognize that a finite amount of water can melt only a finite amount of ice. Laboratory groups create a wide variety of experiments some of which cannot provide an answer to the question. Only when students present their results to the rest of the class do they discover the flaws in their designs, pointed out by the other students, not the professor. One common approach is to simply put a finite amount of ice in water and determine that it has melted. This begs the question of "how much."

The ability to design an experiment, carry out the experiment, make measurements and observations, and then present conclusions based on all of these aspects is a skill that can contribute to the students developing personal confidence that they can do science. This is critical to a willingness to let their own students encounter science in the same way and honors the recommendations of the National Science Education Standards (NSES).[8]

The Context for the Course within a Large Research Department

A large research department has the luxury of offering a variety of introductory courses to different sets of students. This course arose from a one-semester lecture/lab course. A single section was allowed to move entirely into the laboratory, meet two hours at a time, three days a week and have no formal lectures. It was eventually granted its own course identity, was initially taught by John Layman and then was broadened to two sections. Sarah Eno, an assistant professor within the High Energy group who had spent a semester interning with John Layman, taught the second section. She stepped into this course with the blessing of her research group. It has also been taught by a second High Energy assistant professor, a senior member of the faculty and a post-doctoral student.

There is little in the preparation of the average physics professor empowering them to teach in the manner required in this course. It is student centered, activity centered and spends much time guaranteeing student understanding of the limited number of concepts dealt with. There must be recognition that telling what we know in a manner that we think is "clear" does not enhance the understanding of many of the students. Because of what they bring to class and the modeling of successful learning that they experience in class, students can exit with deep understanding of a limited number of concepts, and some of the context within which the learning took place. If students have successfully designed experiments, carried them out and reached conclusions due to their personal skills they will begin to understand the nature of science and how to learn it.

The Conditions for the Course Creation and Transformation

At Maryland I began teaching PHYS 117, the one-semester introductory course, for those seeking only one semester, and used it as the stepping stone for the evolution of PHYS 115, the course for preservice elementary students. We had become part of the Maryland Collaborative for Teacher Preparation, the NSF program designed to improve the preparation of K–8 teachers throughout the state.

PHYS 117 served as one of the model sites where inquiry approaches were instituted. The physics department gained credit for supporting this transformation, and the department continues to support two sections per semester, serving over 100 students per year. Those who have now taught the course are two assistant professors, two full professors, one associate professor and one post-doctoral faculty member.

Relationship to the College of Education

The reputation of the course and the skills of the students are monitored when students take their science methods courses. Both full professors are familiar with the physics course. One has brought elementary students and their teachers to the PHYS 115 laboratory to work with the motion detectors so that the present students can see the value of MBL work even for elementary students. The second professor has carried out the formal research on the MCTP program and has funding to continue the research beyond the close of the grant.

These professors find that students arriving from the inquiry-centered physics course are clearly differentiable from other students. They understand inquiry, assume responsibility for their own learning, do not expect to be told everything, and are willing to carry out more open ended and thought provoking activities. They eagerly describe the activities and approaches that enabled them to understand physics. These skills and attitudes coincide with the expectations of the NSES. More will be said about this in the research section of this chapter.

When sections of the course were modified by one senior faculty member bringing them back to a more classical approach, the science-education professors could detect this change when they found the students less excited about their work, and not able to relate their introductory science courses to the skills and understandings expected by the NSES.

Faculty Preparation, Three Approaches

The most successful approach to faculty preparation for teaching in an inquiry fashion was the internship that Sarah Eno participated in. This is best described by her own essay provided in the Appendix.

A second approach was to have one of Sarah's colleagues down the hall brought in. He paid one or two visits to class and then began teaching. He consulted regularly with Sarah and John, and was able to learn the inquiry- and student-centered approach within two semesters.

The third approach was to have a full professor, who had originated the laboratory program for the PHYS 117 class, teach the course. It was he who moved the course more toward a classical approach with more providing information for the students and a somewhat reduced inquiry approach.

The syllabus and laboratory guide are structured to support an inquiry approach, with concern for the merging of the science and mathematics. The character of the software associated with the computer activities also compliments students' development of an understanding of the relationship between graphs, equations and the capacity of an instrument to acquire the data. All of this in support of the student constructing a deep understanding of the concepts and processes of science.

Gaining Departmental Support

In an ideal world, physics departments would recognize their role in providing introductory courses for preservice elementary teachers. If this cannot be done in a separate course, then one of the introductory courses serving this population should be modified. Many of these changes will be of benefit to all students in the course. If there is collaboration between those teaching and monitoring this course and their colleagues in science education, courses at both points in the students' program will be viewed as complimentary and all part of a university-wide teacher-preparation effort. Students should find common expectations across courses and programs.

Sustaining the Teaching/Learning Conditions over Faculty Changes

A special effort must be made within a department to preserve the special character of such a course. It must not be viewed as watered down physics, but as a course that deals with a much broader set of learning/teaching skills and for this reason deals with fewer concepts and deals with these concepts under fundamentally different teaching/learning conditions. Its laboratory-centered approach must be viewed as a special contribution of the department even though faculty could deal with more students at a time in another setting.

Examples of Changes that Can Occur that May Change the Character of the Course

Normally students are asked to read the syllabus and on the first day of class jump right into activities such as using the motion detector without preliminary explanations or detailed instructions. As student understanding develops within the laboratory groups, class discussion refines these understandings. If one chooses electricity as the first activity, students would immediately be asked to use one battery, one lamp and one wire to make the lamp light.

Modifications can occur with a change in teachers. Present to the students a more formal description of What is Inquiry, Teacher Characteristics and Goals for the Laboratory. Adding an Introductory section prior to any physics conceptual work, discussing the Cosmic Voyage, Dealing with Big and Small Numbers, The Metric System, Metric Prefixes, Making Measurements, Conversion of Units and

The Greek Alphabet are all helpful. Following this introductory material the first set of physics concepts deal with Electricity and Magnetism. But instead of giving the students a wire, a battery and a lamp, they are asked to first read about How We Know about Electrons. The assumption is that students need more direction instead of allowing students to make conjectures, try things, describe them in their own terms and slowly make a natural transformation to the way we physicists would describe things.

Preserving the character of an inquiry course may be a major challenge within a major department. The course must be viewed as belonging to the department, not the professor assigned to teach it. We are in the early stages of working on this at Maryland.

Research Results, Accounting for Course Influence and Value

Randy McGinnis of the Science Teaching Center at the University of Maryland carried out the formal research of the Maryland Collaborative for Teacher Preparation. He taught some of the sections of the science-methods courses for the preservice elementary teachers and made comparisons of the skills and views of MCTP vs. non-MCTP students enrolled in the methods block.

The research work that I will utilize in describing the relationship that should exist between introductory science and math courses taught in ways that model good inquiry instruction and the science-methods courses preservice elementary students take in the last stages of their programs will be that of Randy McGinnis and Amy Roth-McDuffie. The study, An Action Research Perspective of Making Connections Between Science and Mathematics in a Science Methods Course, focused on six teacher candidates participating in a National Science Foundation-funded undergraduate teacher-preparation program designed to produce specialist mathematics and science upper-elementary/middle-level teachers and on three elementary-education majors with concentrations in mathematics or science. Discussion focuses on the researchers' reflections as prompted by a comparison of the performance of the special teacher candidates and the other teacher candidate participants.

As a result of the teacher candidates' participation in the MCTP reform-based science and mathematics courses, the following research questions were investigated:

1. Are the MCTP teacher candidates distinguished from the non-MCTP teacher candidates in the science content knowledge they bring to their science methods class?
2. Are the MCTP teacher candidates distinguished from the non-MCTP teacher candidates in the beliefs and perceptions they bring to their science methods class concerning:
   a. preparedness to teach science content to elementary students?

b. an appropriate science learning environment for elementary students?
c. the structure of mathematics and science?
d. the rationale for and intent to make connections between science and mathematics in elementary teaching?
e. the role of science methods in their teacher preparation program?

3. Are the MCTP teacher candidates distinguished from the non-MCTP teacher candidates in the beliefs and perceptions upon completion of the science methods course concerning:
   a. an appropriate science learning environment for elementary students?
   b. the extent to which their science methods professor modeled good teaching of science?
   c. the extent to which they observed their science methods professor making connections to mathematics in his teaching?
   d. the rationale for and intent to make connections between science and mathematics in elementary teaching?

For our work here in Nebraska, I shall report some of the results of just research questions dealing with content knowledge and beliefs and perceptions brought to the methods class that arose from their inquiry-oriented introductory science and mathematics courses.

For research question one, are the MCTP teacher candidates distinguished from the non-MCTP teacher candidates in the science-content knowledge they bring to their science-methods class? We find that the MCTP students had less confidence in their science than the non-MCTP students who had classical courses in science but the MCTP students had higher scores on the science diagnostic instrument. Unfortunately there were no differences in the physical-science portion of the test. This may indicate that the MCTP students retained the skepticism associated with inquiry in making their preliminary judgments.

To answer our second research question ("Are the MCTP teacher candidates distinguished from the non-MCTP teacher candidates in the beliefs and perceptions they bring to their science methods course concerning [a spectrum of areas]"), we analyzed the data we collected from the beginning of the semester teacher-candidate interview. What follows are assertions we generated from a careful reading and comparison of all the participants' responses to the interview questions. These assertions are presented in the order of the sub-sections of the second research question. Included in each are exemplar comments from the participants that support the claims made by our assertions.

a. Content preparedness to teach elementary students. **The MCTP teacher candidates were distinguished from the other teacher candidates by expressing that preparedness to teach young students science content required their**

being taught content in a manner that modeled good practices. However, as a result of being taught science content by MCTP faculty in a constructivist manner, which they recognized required a high level of comfort with science content, the MCTP teacher candidates tended to express they felt less prepared as compared with the non-MCTP teacher candidates who were taught content in a lecture-based manner. The non-MCTP teacher candidates expressed a somewhat naive confidence of their content preparedness.

MCTP Teacher Candidate Beliefs and Perceptions. **The distinguishable feature of the MCTP teacher candidates' comments on content preparedness was that they believed their MCTP professors taught content in a manner that modeled good pedagogy, and they could emulate this approach with young learners. They believed this approach promoted lifelong retention of content.**

> Jennifer:
> I think, especially the MCTP classes, we have seen the type of instruction and we have gotten to experience firsthand the way that we want to teach math and science, so that it is not the boring memorization, you know, do that problem ten times, or just memorize the biology and whatever. And I think that we have had a stronger base of the content because it has been taught that way; I think I have learned it more.... I mean, it was more of a displaying of that type of teaching method. Real methods were not taught, you know, about how to teach the subject, but I think more of a display of that type of teaching. (Interview, September)

> Aubrey:
> I think absolutely, totally my Physics 117 was incredible. I think to this day I still have a pretty good knowledge base of what happened in that class and can explain things with some, you know, some level of knowledge and confidence. But I just finished [non-MCTP] chemistry this summer, two sessions, and I probably could not pass any of the exams if they were given to me right now, and that was only about a month ago. (Interview, September)

Non- MCTP Teacher Candidate Beliefs and Perceptions. **A distinguishable feature of the non-MCTP teacher candidates' comments on content was a perception that while they believed that they had gained a sufficient body of science-content knowledge, it had been learned in isolation from a good model of how to teach young students.**

> Patty:

> Science, I would say I am pretty prepared for the elementary level, yes. Middle school, the courses I took are enough—enough I think to probably prepare for middle school. I do not know how much I have retained to be able to just go in there right now. I mean, I would definitely have to review. (Interview, September)

> Kevin:
> I had always felt that we had gone through and learned the science content, but that I was never taught how to teach until I got into these classes [method block]. Now I feel quite assured that I will know strategies and ways to deal with teaching that I had felt was really not touched on at all in previous content courses. (Interview, September)

b. A vision of an appropriate science-learning environment for elementary students. **The MCTP teacher candidates expressed a vision of an elementary science-learning environment in alignment with the reform movement (student-centered and problem-based, with an emphasis on students' prior knowledge) that they believed was modeled by their MCTP science content professors. They also could contrast this reform-based vision with a traditional lecture and textbook-based science-content environment. The non-MCTP teacher candidates expressed dissatisfaction with a traditional learning environment based on teacher lecture, but could not express an alternative vision of good teaching for elementary science students except for the increased use of labs involving equipment and manipulatives. Moreover, when they referred to using equipment and manipulatives, the non-MCTP teacher candidates did not indicate that they had developed a vision for how they would use these things or for what purpose.**

MCTP Teacher Candidate Beliefs and Perceptions. **Drawing on their recent undergraduate experience learning science content in MCTP classes, the MCTP teacher candidates expressed a well-developed vision of an elementary science-learning environment that included inquiry, cooperative learning, a concern for students' prior knowledge, the teacher as a facilitator and a commitment to achieving equity between males and females. Furthermore, they indicated they had developed personal theories/rationales for why these modes of learning are appropriate for young learners.**

> Karen:
> I guess I kind of imagine a classroom setting with the students in groups of four of five; lots of manipulatives at least in the beginning part of the lesson, like an introduction to geometry with the cubes or something like

that. And what I have learned, and am finding more and more important, is the discussion taking part in mathematics and science. That it helps the kids understand the concepts more clearly, and it also gives the teacher a chance to assess that way rather than as a quiz with multiplication tables and that kind of stuff. You can hear what they are talking about and see what kind of level they are at, so I definitely would like to emphasize discussion. "How did you get that answer?" Or if two people got the same answer but they did it differently, "Show how you did it," you know, more like a process than just having the right answer. (Interview, September)

Stephanie:
My first class [in the MCTP] was hands-on with Dr. Layman [introductory physics]. That format is so different, but I feel like that class kind of prepared me for how I want to teach. (Interview, September)

Jessica:
I think learning content has to be non-threatening. I think the group work is good with a lot of hands-on materials. I think it should be something that it seems like it is a situation that is fair to both males and females.... My vision of my ideal science classroom, I would have lots of living things all around the class—animals, fish, plants, just all kinds of stuff all over the walls. I would have all kinds of different areas that students can move to and explore and learn things, books that they can look at, things that they can look at, things that they are interested in, lab tables, lots of equipment—a student-centered, really nice environment where they would be learning by doing things hands-on. Group work—manipulatives, experimenting, finding things out on their own. (Interview, September)

Non-MCTP Teacher Candidate Beliefs and Perceptions. **In the context of their recent undergraduate experiences of learning content in a lecture-based manner that they believed was inappropriate for young learners, the non-MCTP teacher candidates' alternative vision of good pedagogy for young learners was one based on instances of good teaching in their own K–12 educational histories or on brief field-based education experiences observing young students. These alternative visions were not thoroughly developed.**

Anna:
As an elementary student, I always liked the practical experiments. Like, when I was in second through fourth grade I did not speak much English, and with the experiments and laboratory work, I would learn through observing the lab, the experiment, the actual experiment. I could not read or

understand, so I only learned through observation. (Interview, September)

Patty:
I think in the elementary level, I think manipulatives are real effective. [pause] I have done a lot of one-on-one with kids. Most of my experience [as a parent volunteer in an elementary school] has been with second grade, and I have done a lot of one-on-one or working in small groups, and it seems like it is much easier to show them using something than to just try and tell them, so definitely manipulatives is an effective way. (Interview, September)

c. The structure of mathematics and science. **The MCTP teacher candidates brought to their science methods a shared vision of the structure of the disciplines of the science that was characterized by being in alignment with current philosophical thought on the structure of the disciplines. The non-MCTP teacher candidates expressed a limited vision of the structure of science and mathematics that in many ways conflicted with current philosophical thoughts on the disciplines.**

MCTP Teacher Candidate Beliefs and Perceptions. **The MCTP teacher candidates expressed a shared perception that mathematics and science were similar structurally. The similarities included: intellectual pursuits based on curiosity, ways to better understand logical systems and the physical universe, with the primary aim to improve the quality of life through solving problems. They perceived the disciplines as different with science more limited by a tentativeness nature of knowledge and with mathematics more structured and static that led to more conclusive answers.**

Bob:
They are both problem solvers. Both of them are used in solving problems, in trying to improve the quality of life, or to understand our world. I think...I...I seem to think math is more structured than science, just more rules governing math than science. (Interview, September)

Karen:
Both mathematics and science solve mysteries. And with math it seems like there is always an answer, sometimes in science there is not. There might be, like, a theory. It seems like math doesn't change that much. (Interview, September)

Aubrey:

> I think they both tend to be inquiry based. I think there is a lot that can be done with that as far as building on the student's prior knowledge and just working into their questions and their desires for what they want to learn. I think that the focus can be more on the terms and the ways of using, you know, the knowledge. I think they are both very similar in how you can use them to discover things and hands-on activities. (Interview, September)
> Jennifer:
> I think in both math and science, there are a lot of things that we don't know... science seems to almost not work without having math as part of it.... I would think that, also, a true scientist would have to have some mathematical background to be able to do some of the experiments and that is how I see a true scientist as an experimenter.… I think that a true mathematician might be able to, you know, work in his profession without a whole lot of science background. (Interview, September)

Non-MCTP Teacher Candidate Beliefs and Perceptions. **The non-MCTP teacher candidates indicated they held the perception that mathematics was distinguished from science by mathematics being a static discipline concerned with finding conclusive answers to algorithm-based problems. Science was perceived as a growing area of knowledge based on inquiry. There were some claims of similarity of the disciplines as both being based on formal reasoning skills.**

> Anna:
> What similarities do I see? They both have some research. Both science and math you usually hypothesize. Math is straightforward. It is a one-answer, one-solution problem. (Interview, September)

> Patty:
> I am thinking that science is much broader [than mathematics] because it is always changing. I know there has been a lot of new math that has come up over the last ten or 15 years, but the basis of math is one plus one is always two. It is always going to be, and always has been.... I want to say formal reasoning for both. (Interview, September)

> Kevin:
> They share logic skills. Science can be hands-on, real life and then math is really just a bunch of symbols when it comes down to it. (Interview, September)

d. Rationale for and intent to make connections between science and mathematics in elementary teaching. **The MCTP teacher candidates evidenced considerable reflection based on the firsthand MCTP experience of learning science and mathematics in a connected manner for a rationale making connections between science and mathematics. They intended to make extensive connections between the disciplines in their future practices. The non-MCTP teacher candidates were characterized by not having reflected on a rationale for making connections between the disciplines nor having experienced learning the disciplines in that manner except in cases where mathematics was used as a tool in science. They expressed a willingness to make connections between mathematics and science but based that connection solely on the use of mathematics as a tool.**

MCTP Teacher Candidate Beliefs and Perceptions. **The MCTP teacher candidates brought to their science-methods course the ability to articulate a rationale for making connections between science and mathematics based on extensive prior experience of learning the disciplines in that manner. Through their MCTP experiences, they perceived mathematics and science to be so intrinsically connected that they had difficulty conceiving teaching them as separate subjects. Their rationale included the belief that both disciplines could contribute, and in the case of mathematics, assist the other, in developing a better holistic understanding of an area of interest.** They professed a shared intent to make extensive connections between the two disciplines in their future teaching practices.

Stephanie:
Well, I pretty much think that mathematics and science are interconnected. I mean, if you think about the formulas in science, you are learning all that in math, also.

Jessica:
I think that one of the reasons Stephanie might think that and that I might think that, too, is just because we have been learning it that way, for the past four years (I know I have anyway). And so I say, "Oh yeah, math just fits in with science, and science just fits in with math naturally. How would they not?" And maybe some people do not see that and do not emphasize it. I do not know if it is something that we have to emphasize so much and try and make a point of doing it because we are just so used to doing it anyway, and it is just going to naturally kind of fit in.

Karen:

> Making connections keeps things as a whole, and you know, learning parts, and parts, and parts, and parts that is just a bunch of parts, but if you make connections all across the board, especially with math and science, because they relate so much, it just keeps everything like a nice package all wrapped up.

> Jessica:
> I think you can make connections between mathematics and science using calculators, graphing, all sorts of graphs, all kinds of graphs that you could do for different things in science. Doing different trials, and making graphs of your findings type things. I mean, math naturally comes out in science that way. For math activities, you could give them activities, too. An activity I had in an MCTP math class comes back to my mind. It was about learning about shadow lengths and how we could determine how the people in the past could determine that the earth was round and the distance around the earth by a change in shadows. I mean, that is an example of a way that would relate science and math together, and you could do it in a math class, and kids might not think they were learning science, but they would be learning science just by measuring shadows and that sort of thing.

> Aubrey:
> I think mathematics and science can be connected largely by not calling it a math lesson or a science lesson. I think dealing with the topics and letting them flow into the different subjects sort of leads to an integration without forcing it. And questioning, open-ended questions, and probing questions that would lead them to kind of make those discoveries in their minds and draw their experiences from both together. I want to set up things so, like, if my units are more interdisciplinary, so then the connections, hopefully, become obvious at least in a way that the kids are going to feel like they can go home and say, “Mom, I did this today. This was math, but you know what? It was also science and it was really fun and important.”

> Stephanie:
> You do not have to say, “Look, there is a interconnection between these two subjects.” It is going to come out naturally.

Non-MCTP Teacher Candidate Beliefs and Perceptions. **The non-MCTP teacher candidates brought to the science-methods course a restricted rationale for making connections between mathematics and science. While they voiced a**

willingness toward attempting to make connections between science and mathematics, they based the connection fundamentally between science and mathematics on mathematics use as a tool in science.

> Patty:
> Oh, this one I will have to think about...I am sure I could come up with lots of ways to tie them together, I just cannot think of any right now.
>
> Kevin:
> I think it is important to make connections between mathematics and science. . There is quite a large connection between the two of them. You can always figure out science properties by doing the experiment, but then it
> is usually the math that is used to prove them.... Hopefully I will learn how to connect mathematics and science this semester [during the methods block].
>
> Anna:
> Usually, when you collect data from science, you are actually doing the math, because most of the experiments want you to find the average.
>
> Kelly:
> Well, I think it would be easier to show the connections going from science to math for me. To show that how—I cannot think of an example—but when they have done an experiment and they had to, like, say write the results down, and they have made a graph or something and then you can connect that to the math.

e. The role of science methods in their teacher preparation program. **The MCTP teacher candidates brought to the science methods class an inclusive vision of teacher preparation program composed of a seamless linkage between their undergraduate content courses and their science methods course. As a result of being taught content in a manner that modeled good pedagogy, they had a vision of how they wanted to teach. However, they recognized that the science methods course was essential to teach them the skills and knowledge base to enact that vision of teaching. The non-MCTP teacher candidates brought to science methods a vision of content classes taught in a manner they believed was inappropriate for young learners. They saw the science methods as their first opportunity to gain skills in teaching science appropriately.**

MCTP Teacher Candidate Beliefs and Perceptions. **The MCTP teacher candidates held the vision of science methods as performing an important next step role in their teacher preparation program by assisting them in enacting their vision of teaching content to young learners appropriately. They believed the primary purpose of science methods was to give them the opportunity to develop the strategies and knowledge necessary to adapt what they previously observed their professors doing in science content classes to lessons for young learners.**

Stephanie:
I am hoping to actually learn how to tie everything together.…We are going to be learning about the different methods of teaching. That is what I am hoping to gain from it.

Jessica:
I was thinking I would learn in science methods how I am going to use what
I learned, take it to a classroom and fill up the day teaching what I know. What I will actually have to do to get across the things that I need to get across to the students without having to tell them these things directly.

Karen:
Learn how to do lesson plans.... I am concerned about day-to-day, what do you do? I mean, how far in advance are you prepared? You know, I have this
image, that 10-year veteran teachers have their whole year planned out, but how much can I possibly get done in just this semester to even prepare myself for the 12 weeks of teaching should I have? That is kind of one of the things I am hoping to get out of methods is that I will feel ready to go in and student teach.

Bob:
It is the preparation, getting lesson plans together, knowing where you are going to go with it. I am hoping to learn all of that.... I guess in methods I am hoping to learn planning and organization, and how to present the material and all of that lesson plan type thing. That is where we are stuck.

Non-MCTP Teacher Candidate Beliefs and Perceptions. **The non-MCTP teacher candidates saw the science-methods course as their first opportunity in their undergraduate program to focus on the teaching of science to young learners in an effective and appropriate manner. They expressed interest in learning**

the strategies to teach science as if they were content [independent].

Kelly:
Oh, what I hope to gain in science methods is knowledge of the strategies to teach. This is the first time that they have come up.

Anna:
How to come up with questions to ask, because if I was just to give a lesson right now, I would not go too deep with the details to ask how would they get that. So I guess so far I have learned I need more to learn.

Kevin:
Just the different strategies, the different ways of looking at certain topics that are associated with difficulties for children to learn certain topics. How to get around them, how to set them up with different features and things like that.

Additional Characteristics

Let me turn to two key characteristics of an inquiry-based introductory course for preservice teachers, journaling and summarizing.

Journaling

Journaling can play a key role in providing students an opportunity to metacognate on their personal progress in learning. It is an opportunity to look at the big picture and summarize their thoughts and feelings about their own progress in the course. Here are examples from PHYS 117.

Dear PHYS 117 listserv members. Almost all of you have signed on to our listserv and I want to welcome each of you to our communication venture.

Journal #1

Our First Journal is: In PHYS 117 we are trying to create a "learning community." If we are successful, what obligations do you have as a student, and what obligations do we have as instructors?

The response is to be one page or less. This can mean about one page of computer screen response or one page of printout had you done this. Be sure that you identify your response in terms of which Journal response yours is (this is Journal #1), the date and your name.

Good luck. Remember you may submit your response to me personally at jl15@umail.umd.edu, but it would be nice to share it with the other members of our learning community as well.

PHYS 117A Journal #2

We have almost completed our study of heat and the conservation of energy in which we tried to create an equation or formula for making calculations or predictions of mixing experiments that eventually included mixing of different substances. Some managed to find a rule or equation, while others said that they “did not do equations.” Others said that they had no difficulty in using an equation once someone gave it to them.

What is your present view of our work with equations, whether recognized or borrowed, and the role they play in your understanding of heat energy measurement?

PHYS 117A Journal #3

We design and carry out experiments and make skilled observations of their results in our class regularly. What is your view of experiments and do you feel at home with experiments?

Summarizing

The second feature is the mechanism of bringing closure to a particular broad concept. After students have carried out a small series of interrelated laboratory activities they are asked to summarize their observations and understandings. Example from motion activities with a Fan Cart in PHYS 117.

Activities with a Fan Cart.
M3.1: Visual Observations and Telling a Story
M3.2: Monitoring the Fan Cart with a Motion Detector
M3.3: Learning More from Velocity Time Graphs
M3.4: Curve Fit II

M3: Summary

You have now observed, told a story about, recorded, equationed and curve-fitted a new kind of motion. What are the special features of this motion?

What would you need to do if you were to walk in front of the motion detector to produce the same kind of graph?

Closing Comment

The expectations of the NSES speak to all elements of our community. Colleges and universities have an obligation to prepare teachers able to meet the standards, and departments have their role to play. The physics community is one of the most successful in terms of studying teaching and learning. We should