THE PENN SCIENCE TEACHER INSTITUTE: A PROVEN MODEL

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Abstract

The University of Pennsylvania's Master of Chemistry Education (MCE) program graduated five cohorts of approximately twenty teachers between 2002 and 2006. One year after the teachers in the last cohort earned their degrees, the Penn Science Teacher Institute (Penn STI) initiated a follow-up study to ascertain if the goals of the MCE program had been sustained. For example, were the teachers incorporating updated content knowledge into their lessons and were their students learning more chemistry? A total of seventy-four of the eighty-two graduates participated in some aspect of this study. Because baseline data were not available for the MCE teachers and their students, baseline data from a comparable group of chemistry teachers enrolled in the first cohort of the Penn STI program and their students were used in some analyses. Among other findings, the data indicate that MCE met its goals: 1) to improve the chemistry content knowledge of its teacher participants; 2) to increase the use of research-based instruction in their classrooms; and, 3) to improve student achievement in chemistry (students of MCE graduates scored significantly higher than the comparison group).

Introduction

The University of Pennsylvania's Penn Science Teacher Institute *(*Penn STI*)*, a National Science Foundation-funded Mathematics and Science Partnership Teacher Institute for the 21st Century, commenced in 2004 and was based on the Penn Department of Chemistry's Master of Chemistry Education (MCE) program. Although the MCE program began in 1999 and continues today as part of the Penn STI, a follow-up study of graduates of the first five cohorts was conducted only recently [1].   The resulting evidence demonstrates the success of professional development that is sustained, rigorous, and content based. Figures and tables within this paper come directly from the *MCE Follow-up Report*.   As a result, most conclusions, summaries, and discussions are also from the *Follow-up Report.* This article presents both an overview of the Penn STI and a summary of results of the *MCE Follow-up Report* that will be of interest to

scientists, science educators, and science teachers, especially those who have been involved with NSF's Teacher Institutes.

Overview of Penn STI

The fundamental hypothesis the Penn STI carried forward from the MCE program is that increasing the content knowledge of science teachers, while simultaneously helping them change their classroom practice to a more research-based approach, will increase student learning of and interest in science. This hypothesis drives the Institute structure and evaluation.

The Penn STI structure for increasing science teacher content knowledge is based upon two, 10-course master's degree programs, The Master of Integrated Science Education Program for teachers of middle school science and The Master of Chemistry Education Program for high school science teachers. Both of these programs have common features, such as: 1) cohorts of twenty teachers; 2) eight science/chemistry content courses and two science/chemistry pedagogy courses; and, 3) courses taught over three consecutive summers and during the two intervening academic years. In addition, teacher participants in both programs take two courses during the academic year and in the summer. The specific placement of the two pedagogy courses during the academic years, when teachers are in their classrooms, is also common to both programs. The sixteen content courses were specifically designed by the Penn instructors to meet the needs of in-service science teachers. This is *not* an audience with which a Penn science instructor is familiar. As a result, each course has undergone several iterations before finding the appropriate combination of content depth and breadth.

The placement of the pedagogy courses during the academic year is an important part of the structure that enables the Penn STI to help teacher participants transform their classroom practice. Another strategy used by the STI to affect change in classroom practice is for Penn instructors to utilize instructional approaches in STI science content courses that they do not regularly use in their undergraduate/graduate science courses. To facilitate this change, each program's instructor team meets monthly during the academic year with STI staff and evaluation personnel. In these meetings, the instructors learn about reform-based classroom practices through reading and discussing journal articles, as well as through sharing experiences. This practice results in instructors iterating instructional approaches in their STI courses as they become more cognizant of, and comfortable with, reform-based teaching practices. However, some instructors are more open to using the new instructional practices than others.

The evaluation of the Penn STI is a complex one, collecting baseline, annual, and post-program data on each aspect of its fundamental foci: teacher content knowledge, including teacher understanding of the nature of science; teacher classroom practice; student attitudes toward science; and, student content knowledge. Although similar data were not available for the first five MCE cohorts, instruments used in the external evaluation of the Penn STI were appropriate for the MCE follow-up study.   For this reason, Ohio's Evaluation and Assessment Center for Mathematics and Science Education (E & A Center), which conducts the Penn STI external evaluations, was selected to do the post-hoc evaluation of the MCE program.

Methods

The MCE follow-up study employed a mixed methods approach utilizing two instruments developed by the E & A Center and currently used in its evaluation of the Penn STI. The E & A Center's Teacher Questionnaire provided quantitative data on teachers' views of their own classroom practices, while the Student Questionnaire provided data on students' views of those practices. The Penn STI had developed a high school student chemistry concept test for the STI evaluation, and that test provided data on student learning. The program director and internal evaluators at Penn developed an on-line survey for the MCE follow-up study that provided demographic data and, through open-response questions, was a rich source of qualitative data. The on-line survey also provided information concerning teacher content knowledge; that is, teacher perceived benefits of the MCE courses and the use of new content knowledge in their teaching. The survey also provided insights into teacher leadership and collegial collaboration.

Although baseline data on classroom practices and student achievement were not available for the five MCE cohorts, a proxy was available in the baseline data from the first three cohorts of high school teachers in the Penn STI MCE Program (MCEP), a group of teachers with similar demographics to those of the MCE Cohorts I-V. Penn had contact information for eighty-one of the eighty-two MCE graduates. Sixty graduates returned the Teacher Questionnaire and 57 completed the on-line survey. Overall, seventy-four of the eighty-two graduates participated in some aspect of the data collected for the follow-up study.

Findings—Classroom Practice

Proxy baseline data were gathered utilizing the E & A Center's Teacher Questionnaire, administered pre-participation to MCEP participants and post-participation to MCE Cohorts I-V graduates. The two figures below show items from the teaching/learning subscales where there were significant differences using *t*-test comparisons.
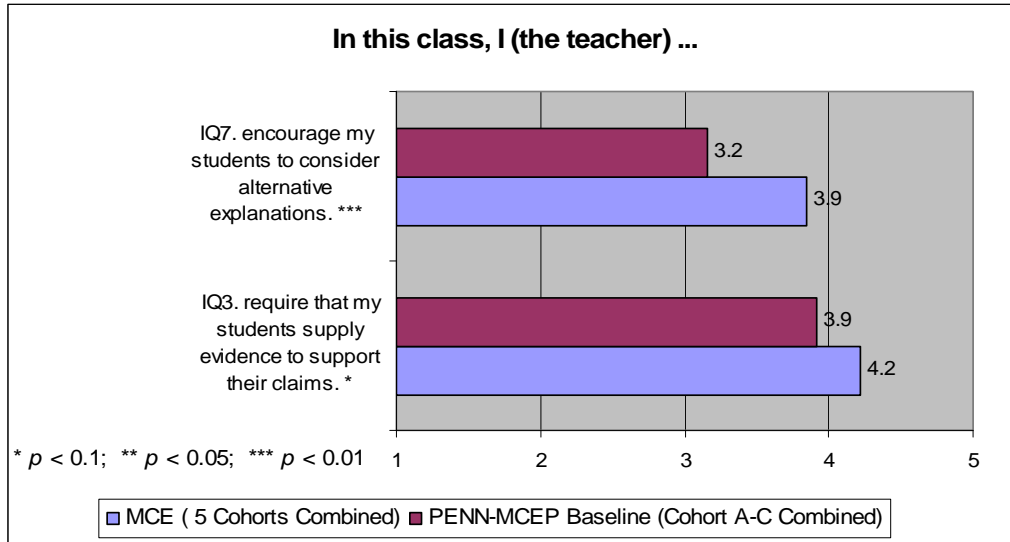
Figure 1. Mean scores for teachers' responses on teacher classroom behaviors subscale: MCE follow-up and MCEP baseline data [1].
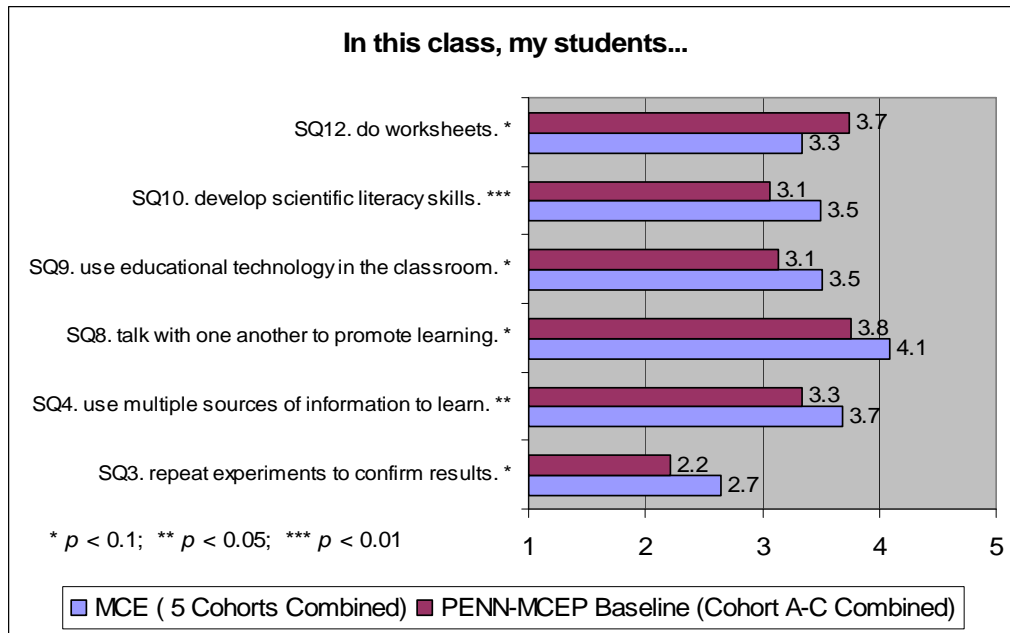

Figure 2. Mean scores for teachers' responses on student classroom behaviors subscale: MCE follow-up and MCEP baseline data [1].

Figures 1 and 2 illustrate that the frequency of use of reform-based teaching/learning strategies was higher for the MCE graduates when compared to a comparable group of teachers before their participation in the MCEP. This analysis suggests that the MCE program transformed teaching/learning strategies employed by its graduates toward ones commonly accepted to enhance student learning in science [1].

Because the Teacher Questionnaire provides self-reported data, the E & A Center's Student Questionnaire was used to assess for self-report bias. The classroom behaviors subscale of the Student Questionnaire contains items paralleling those on the teaching/learning subscale of the Teacher Questionnaire. Statistical analysis was not done on the paired items because different questionnaires were used; however, for the purpose of comparison, the means of similar items are shown in Figures 3 through 5. In each Figure, the wording following the item number is from the Teacher Questionnaire while the wording in parentheses is from the Student Questionnaire [1].
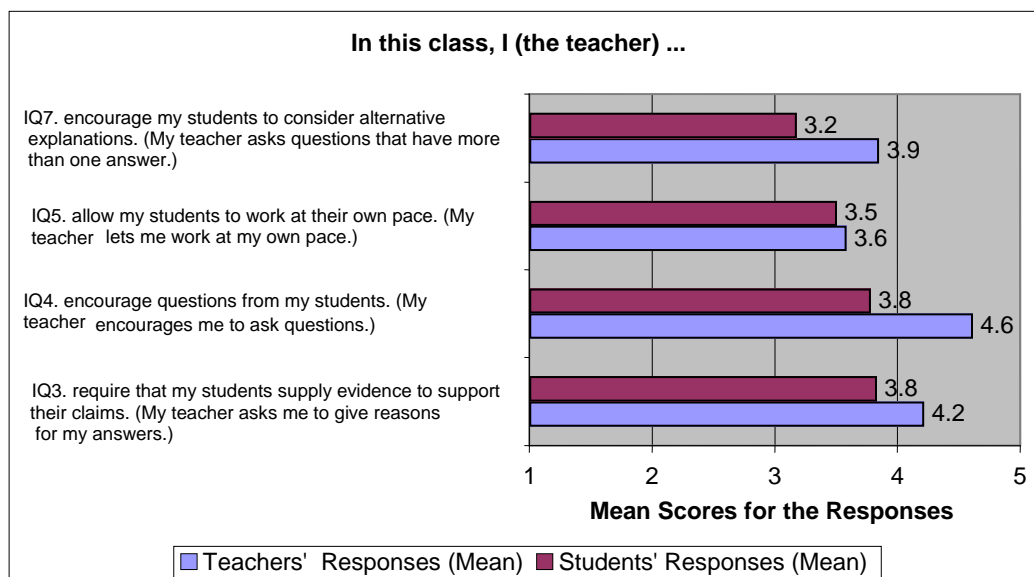
In this class, I (the teacher) ...

IQ7. encourage my students to consider alternative explanations. (My teacher asks questions that have more than one answer.)
- Students' Responses (Mean): 3.2
- Teachers' Responses (Mean): 3.9

IQ5. allow my students to work at their own pace. (My teacher lets me work at my own pace.)
- Students' Responses (Mean): 3.5
- Teachers' Responses (Mean): 3.6

IQ4. encourage questions from my students. (My teacher encourages me to ask questions.)
- Students' Responses (Mean): 3.8
- Teachers' Responses (Mean): 4.6

IQ3. require that my students supply evidence to support their claims. (My teacher asks me to give reasons for my answers.)
- Students' Responses (Mean): 3.8
- Teachers' Responses (Mean): 4.2

Mean Scores for the Responses

☐ Teachers' Responses (Mean) ■ Students' Responses (Mean)

Figure 3. Mean scores for teachers' and students' responses on teacher classroom behaviors subscale [1].
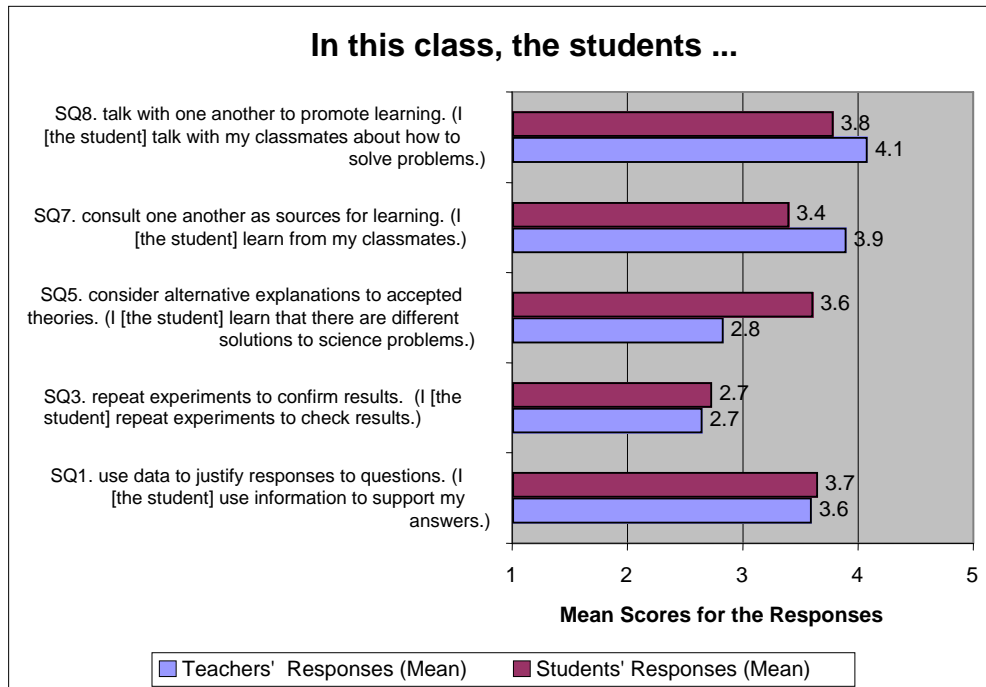
**Figure 4. Comparison of scores for teachers' and students' responses
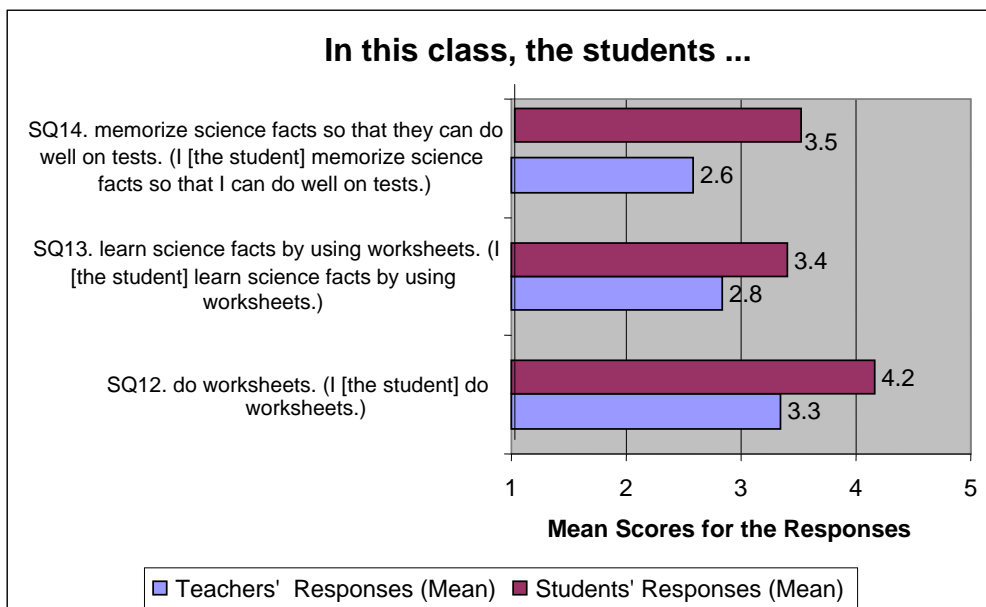on student classroom behaviors subscale (inquiry-based learning activities) [1].**

**Figure 5. Comparison of scores for teachers' and students'
responses on student classroom behaviors subscale (traditional learning activities) [1].**

For both subscales, teacher and student views differed for several items. However, on the teacher classroom behaviors subscale (see Figure 3), both students and teachers generally agreed that MCE graduates allowed their students to work at their own pace and required their students to support claims with evidence. On the inquiry-based learning activities subscale (see Figure 4), agreement between students and teachers indicated that, in classrooms of MCE graduates, students consulted one another to help their learning, repeated experiments to confirm results, and used data to justify responses to questions [1]. As expected, students, compared with teachers, responded that they experienced more use of traditional activities (memorization and worksheets) as shown in Figure 5.

The on-line survey provides additional insights on changes in classroom practices through a series of questions on the use of instructional strategies before and after participation in the MCE program. In the following three figures, the instructional strategies from the on-line survey have been grouped for ease of interpretation: strategies recommended by the *National Science Education Standards* (see Figure 6), traditional teaching strategies (see Figure 7), and strategies that did not change (see Figure 8) [2]. Each figure illustrates the number of teachers reporting use of the strategy before and after MCE participation. Although fifty-seven teachers responded to the on-line survey, not all answered each question, resulting in variations in the numbers of responses.
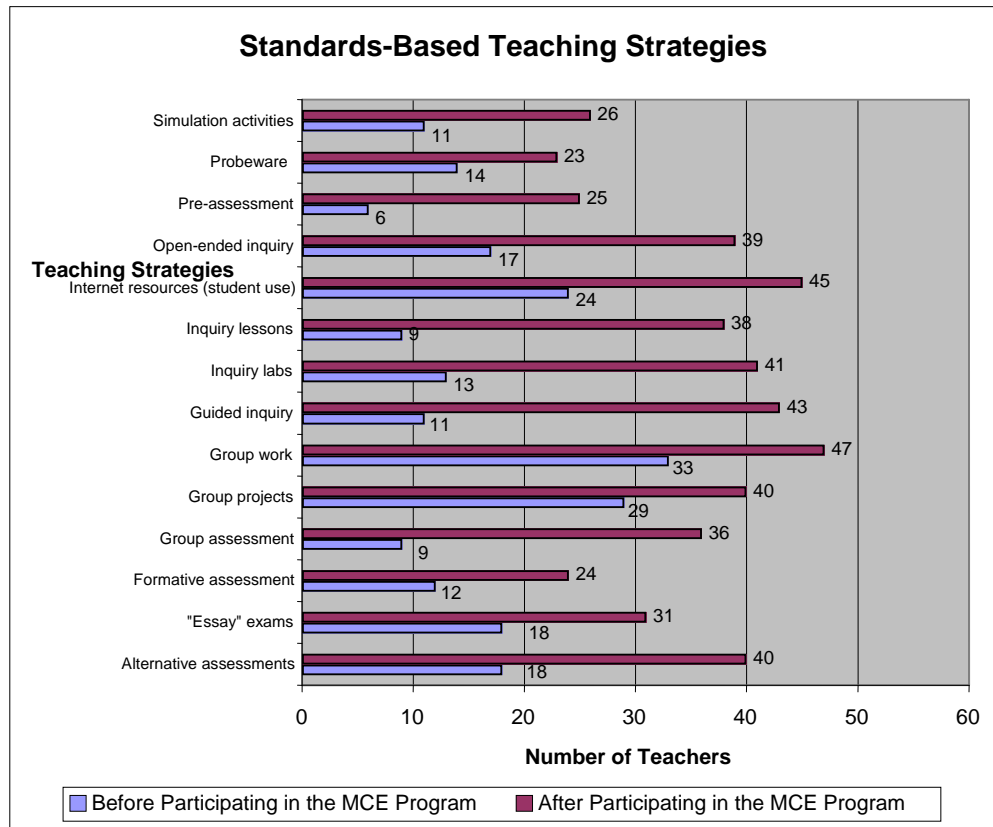
**Figure 6. Use of standards-based teaching strategies
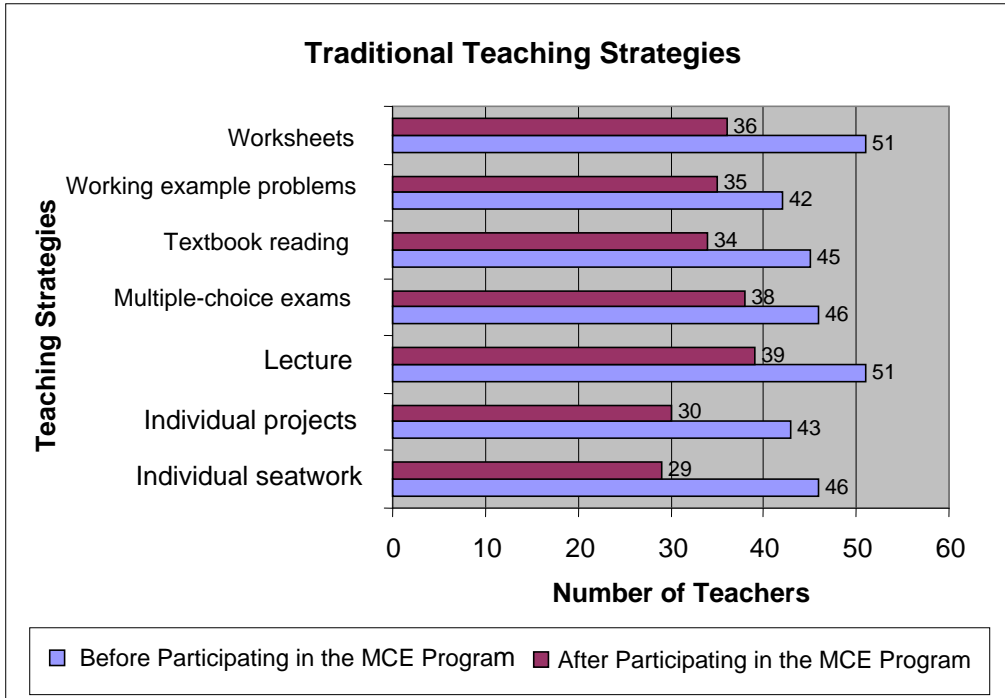before and after participating in the MCE program [1].**

Traditional Teaching Strategies

Teaching Strategies	Before	After
Worksheets	51	36
Working example problems	42	35
Textbook reading	45	34
Multiple-choice exams	46	38
Lecture	51	39
Individual projects	43	30
Individual seatwork	46	29

Number of Teachers

☐ Before Participating in the MCE Program   ■ After Participating in the MCE Program

**Figure 7. Use of traditional teaching strategies before
and after participating in the MCE program [1].**

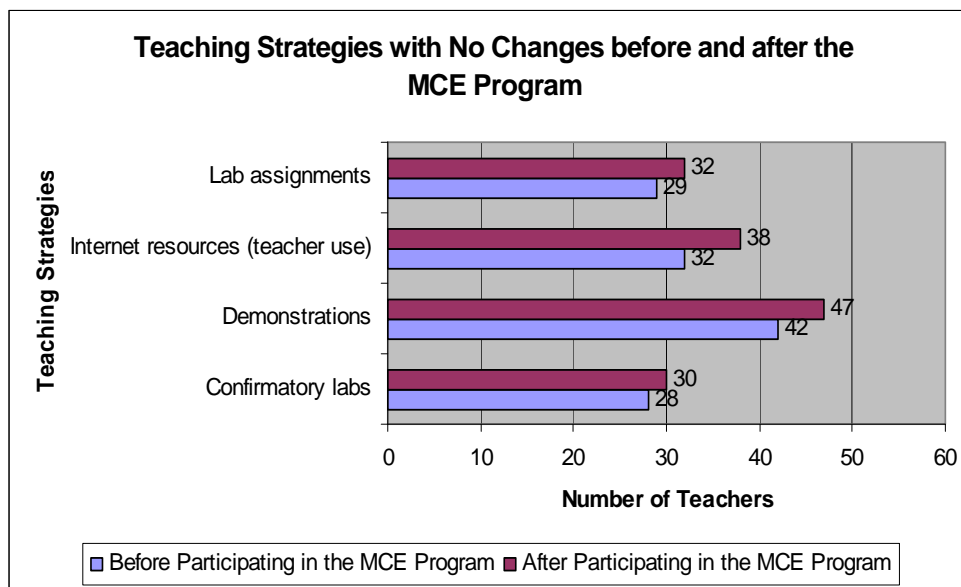**Teaching Strategies with No Changes before and after the MCE Program**

**Figure 8. Teaching strategies with little or
no changes before and after participating in the MCE program [1].**

Figures 6 and 7 taken together indicate teachers believe that, after MCE participation, they have dramatically increased their use of inquiry, group activities, technology, and non-traditional assessment strategies while decreasing their reliance on many traditional instructional and assessment strategies.   In Figure 8, where less dramatic changes are seen, strategies are those that are commonly associated with laboratory science classrooms, and therefore would be less likely to change given the nature of high school chemistry curricula [1].

The open-ended response sections of the on-line survey provided additional insights into pedagogical knowledge gained through the MCE program. Eighteen percent of respondents listed the "importance of small groups" while "PIM's," "POGIL's" and "various forms of inquiry" were reported by 16%, 11% and 5%, respectively. The "Penn Inquiry Model" (PIM) is an inquiry teaching-learning model developed for the Master of Chemistry Program in 1999. It is based on how research scientists carry out their research, and was developed for the purpose of helping Penn instructors understand the meaning of "inquiry" as used in science education [3]. The acronym "POGIL" is used to describe "Process Oriented Guided Inquiry Learning" [4]. Both small group collaboration and inquiry teaching and learning strategies are stressed in all

MCE content and pedagogy courses. Pedagogy gained through MCE and reported in tables F7 and F8 in the *Follow-up Report* as being implemented in their classrooms included: "use of inquiry" (32%), "group work" (26%), "the three levels of representation" (14%), and "new assessment tools" (12%) [1].

These selected quotes from the MCE *Follow-up Report* further illustrate the pedagogical learning experienced by teachers:

- "Professor A and Professor B used the Penn model for group instruction and discussion. The small group environment was beneficial because it allowed for several responses to the same question… The small group discussion, for me, reduced my misconceptions and improved my development of a concept." [Teacher #16; Cohort II]
- "Many of the professors modeled pedagogy. Inorganic was low-tech in the demonstration examples. Organic showed me how to use concept maps critically and also elicit feedback from students. Incorporation of technology needed not only to be shown, but practiced, and I do this with my students as well." [Teacher #38; Cohort V]
- "Inquiry has been the biggest influence. It is a heavy part of the way I teach—through labs… students almost always develop their own procedures and decide on appropriate data collection…" [Teacher #6; Cohort IV]

Findings—Timing of Change in Classroom Practice

The on-line survey also questioned the timeline during which teacher graduates implemented changes in their classrooms. Most teachers (30%) reported that they began to implement change in their classroom practices during the first school year after their initial summer of MCE coursework, some within the first semester (21%). Quotes from this survey provide additional insights into the implementation timeline:

- "I started to use more inquiry and group work after my first summer of the program." [Teacher #35; Cohort III]
- "It started after the first summer of courses, but was most significant after the conclusion of the courses when there was more time for implementation." [Teacher #60; Cohort II]

Findings—Student Achievement

Because MCE Cohorts I-V had not been asked to provide baseline data on student achievement in chemistry, proxy data from students of the first three cohorts of high school teachers in the Penn STI Program (MCEP) were used. These data were gathered from the students of MCEP teachers prior to the teachers starting the Penn STI, and they were drawn from responses to the Penn STI-developed chemistry concepts assessment. This assessment also was

administered to students of volunteer graduates of MCE teacher Cohorts I-V. The analysis of student achievement scores is shown in Table 1.

Table 1
Mean Percentage for Achievement: MCE and MCEP Students

Project	N	Mean	Std. Dev.	df	*t*-value	*p*-value
MCE	328	41.37	19.38	600	5.65	<0.001
MCEP Baseline Data	342	33.92	14.28			

* Table from the MCE *Follow-up Report*.

As the MCE *Follow-up Report* states: "It must be noted that the [student] groups may not be comparable. However, there is a significant difference in favor of the MCE [graduates] group, suggesting that participation in the MCE program can enhance the chemistry achievement of students of participating teachers" [1].

Teacher Content Knowledge

Teacher participants in MCE Cohorts I-V were not administered a pre-/post-program chemistry content knowledge examination, as is now done in the MCE Program (MCEP) of the Penn STI. As a result, no quantitative data were available on teacher chemistry content knowledge for the follow-up study. However, teachers were queried through the on-line survey on what they perceived as the benefits of their new content knowledge and how they utilized it in their classrooms.

Both "Greater in-depth knowledge of concepts" and "Broader understanding of concepts" were listed by 21% of respondents as shown in Table F3 of the *Follow-up Report*; this was followed by "Expanded general knowledge of concepts" (12%) as benefits of their MCE participation [1]. Teacher classroom use of specific knowledge gained in MCE included "light concepts using spectroscopy" (21%), "environmental science concepts, including global warming" (18%), "periodic table concepts" (14%), and both "orbitals" and "Lewis structures" (12%).   Again, quotes from teacher respondents like the following support the finding of enhanced content knowledge by graduates of the MCE program:

- "I feel like I have a better appreciation of how all of it fits together. I also have a better understanding of chemical research that I can convey to my students." [Teacher #60; Cohort II]

- "Being able to understand the background of many of the chemical concepts that I teach has enabled me to have a sense of a 'bigger' picture. This helps me to frame responses to students' questions." [Teacher #50; Cohort IV]
- "I was able to give my advanced students a more detailed description of orbital/quantum theory and my average students more accurate analogies of the theory. I used biochem applications in a food chem. unit with my lower students." [Teacher #9; Cohort III]

Leadership and Collegial Collaboration

One expected outcome of the MCE program, as well as the current Penn STI programs, is that graduates will become Teacher Leaders in their schools and/or districts, working collaboratively with their colleagues to share their new pedagogical and content learning. The on-line survey included questions on leadership activities and such collegial collaborations.

Twenty-one percent of the MCE graduate respondents reported that they were "involved in curriculum discussions/revisions in order to meet state standards," with 12% reporting that they "mentored new teachers or student teachers" and 9% reporting that they "shared teaching, writing, and reading strategies with faculty." Additionally, 33% reported the "sharing of content, curriculum, and/or activities with other teachers" (see Tables F10 and F11 in the *Follow-up Report*) [1]. Examples of leadership activities are described in the following quotations from the *Follow-up Report*:

- "I was asked to chair the Professional Development Committee during 2004-5… to co-teach and model lessons… [and] prepare workshops for non-tenured teachers…" [Teacher #5; Cohort I]
- "I was asked to help rewrite the biology and chemistry curriculums for the high school." [Teacher #37; Cohort III]
- "I find other teachers are willing to try new strategies like POGIL and PIM because of the MCE program and my involvement." [Teacher #59; Cohort V]
- "The members of my department who know that I completed MCE will often ask me content-based questions that they think I will be able to answer with more insight than they have into certain areas of chemistry. I also let members of my department know that I can be used as a resource for developing their curriculum as well. Younger teachers in my department will often come to me with questions about curriculum and classroom management." [Teacher #32; Cohort II]

Conclusion

Data gathered for the *Follow-up Report* provide strong indications that the Penn STI program model is effective in changing classroom practices toward more frequent use of research-based strategies and that those changes begin *during* a teacher's involvement in the program. The program structure places pedagogical courses during the school year, following a summer in which teacher participants have experienced inquiry strategies as *students,* often discovering that those strategies enhance their own learning. In all, the Penn STI and its precursor provide an effective model of initiating timely change in classroom practice. Further data from the *Follow-up Report* provide initial evidence that student learning may be increased as a result of a teacher's participation in sustained, rigorous, content-based professional development, the model used in the MCE and STI programs at the University of Pennsylvania.

Changes in teacher content knowledge in the *Follow-up Report* are self-reported and largely qualitative. However, the evaluation report (*University of Pennsylvania Science Teacher Institutes—Year 4*) provides quantitative data of pre-/post-program increase in teacher chemistry content knowledge [5]. These data confirm significant content gains by teacher participants over the twenty-six months of participation. In addition, the examples provided by on-line survey respondents on their level of leadership and collegial collaboration suggest that the Penn STI model meets its goal of graduating Teacher Leaders for schools and districts.

Lessons Learned—Future Plans

The Penn STI, which is based on the MCE program, has added several new structures as a result of "lessons learned" from its precursor, the MCE program. The extensive quantitative data included in the STI external evaluation are the most significant examples. The Penn STI Year 4 evaluation report contains substantial evidence that the Penn STI is successful in attaining positive outcomes, such as increasing teacher content knowledge, changing classroom practices to more research-based ones, and increasing student interest in and knowledge of science [5].

It is the intention of the Penn STI to make further use of the MCE *Follow-up Report* data, only part of which has been summarized here, as well as to seek further funding to continue the longitudinal study of both groups of teachers (chemistry and middle school science) in the Penn STI. Only through rigorous, multi-year studies that include both quantitative and qualitative data can we hope to understand adequately the wide range of teacher needs, teaching situations, and career trajectories. This will help determine appropriate and necessary program structures that

will enhance learning of science for all students. Certainly gaining this knowledge is also a goal of the National Science Foundation, and specifically, their Teacher Institutes for the 21st Century.

Acknowledgments

References

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OREGON MATHEMATICS LEADERSHIP INSTITUTE PROJECT: EVALUATION RESULTS ON TEACHER CONTENT KNOWLEDGE, IMPLEMENTATION FIDELITY, AND STUDENT ACHIEVEMENT

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Abstract

The Oregon Mathematics Leadership Institute (OMLI) National Science Foundation Mathematics and Science Partnership project partners are Oregon State University, Portland State University, Teachers Development Group, and ten Oregon school districts. The primary activities of the project were a sequence of three intensive three-week residential institutes emphasizing mathematics content knowledge for teaching, collegial leadership, and the building of Professional Learning Communities. Teachers at all levels of grades K-12 participated together in the mathematics content courses. By the conclusion of the third Summer Institute, teachers had shown significant improvements in mathematical content knowledge for teaching. Analysis of student achievement data in participating schools was initially inconclusive. However, once implementation fidelity traits were taken into account, a positive relationship between project participation and student achievement emerged. The degree to which schools implement the practices promoted by the OMLI project is a significant positive predictor of student performance above and beyond what can be explained by the socioeconomic factor as indicated by the percentage of students who qualify for the free and reduced lunch program. This relationship is particularly acute at secondary levels, but additional factors appear to be at play at elementary grade levels.

Introduction

The Oregon Mathematics Leadership Institute (OMLI) is a five-year project funded by the National Science Foundation under the Mathematics and Science Partnership program with additional federal funding provided through the Oregon Department of Education. The OMLI is a partnership between Oregon State University, Portland State University, Teachers Development Group, and ten Oregon school districts: Beaverton, Bend-LaPine, Crook County, Molalla River, North Clackamas, Redmond, Reynolds, Roseburg, South Lane, and Woodburn. These school districts include both rural and urban settings, a wide range of socio-economic student backgrounds, and one district with a majority of students classified as English Language Learners