PART I: SPECIAL ISSUE

Oregon Collaborative for Excellence in the Preparation of Teachers

PART II: REGULAR JOURNAL FEATURES

Virginia Mathematics and Science Coalition
The Journal of Mathematics and Science:
COLLABORATIVE EXPLORATIONS

Editor
P N Raychowdhury
Virginia Commonwealth University

Associate Editors
J Boyd
St. Christopher's School
J Colbert
Virginia Tech
N Dávila
University of Puerto Rico
R Farley
Virginia Commonwealth University
L Fathe
Occidental College
K Finer
Kent State University
B Freeouf
Brooklyn College
S Garfunkel
COMAP
J Garofalo
University of Virginia
W Haver
Virginia Commonwealth University
W Hawkins
Mathematical Association of America
R Howard
University of Tulsa
M Leiva
U of North Carolina at Charlotte
Shin-R Lin
New York Institute of Technology
J Lohmann
Georgia Institute of Technology
P McNeil
Norfolk State University
G Miller
Nassau Community College
L Pitt
University of Virginia
S Rodi
Austin Community College
D Shillady
Virginia Commonwealth University
S Solomon
Drexel University
M Spikell
George Mason University
C Stanitski
University of Central Arkansas
D Sterling
George Mason University
U Treisman
University of Texas
B Williams
College of William and Mary
S Wyckoff
Arizona State University
Volume 6  Fall 2003

PART I: SPECIAL ISSUE

Oregon Collaborative for Excellence in the Preparation of Teachers

PART II: REGULAR JOURNAL FEATURES

Virginia Mathematics and Science Coalition
The Journal of Mathematics and Science: COLLABORATIVE EXPLORATIONS

Volume 6 Fall 2003

PART I: SPECIAL ISSUE
Oregon Collaborative for Excellence in the Preparation of Teachers

Virginia Mathematics and Science Coalition
Introduction

The Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT), funded in 1997 by the National Science Foundation, was created to improve the mathematics and science preparation of future teachers in Oregon and to increase the diversity of the population of students preparing to be teachers. In pursuit of these goals, OCEPT has directly involved well over 200 science, technology, engineering and mathematics (STEM) and education faculty, administrators, and academic advisors from virtually all of the 34 institutions of higher education in the state, as well as K-12 teachers from numerous school districts.

Background

The OCEPT project was fortunate to begin in an environment with many positive features. Oregon, in general, has very high standards for teacher preparation. All teachers have to pass national exams in their teaching fields, and the passing standards for Oregon’s teachers are some of the highest in the nation. In addition, most secondary teachers earn majors in their teaching discipline.

However, there was general consensus that several areas needed attention. Mathematics and science courses for majors provided excellent content background for secondary teachers, but the courses often did not model the pedagogy reflected in the national standards or current research on teaching and learning [1]. While most of the state universities and community colleges offered a somewhat agreed-upon mathematics sequence for elementary teachers, it was not offered at every university with a teacher education program. Science requirements for future elementary teachers varied greatly among the different institutions, and often were inappropriate as the only science experiences for these elementary teachers. Few institutions
offered additional mathematics or science courses or programs designed especially for upper elementary and middle school teachers. The proportion of teachers of color was very small compared to the proportion of K-12 students of color, and the state was producing very few teachers from underrepresented groups.

In addition to courses and teaching, the other systemic issue that needed attention was the chasm that seemed to exist on many of the state's campuses between the undergraduate STEM programs and the (often graduate) teacher education programs. There was little communication among faculty or advisors in the two programs and no shared vision that both programs are essential in the preparation of teachers. Neither community colleges nor universities were fully aware of the magnitude of the role played by community colleges in the preparation of teachers. Although STEM faculty often knew colleagues in their discipline on other campuses or in other disciplines on their own campus, few had opportunities to develop close ties with them or to work together on issues related to mathematics or science education.

What We Did

Given the identified needs, professional development for university and community college faculty was the first major focus of OCEPT. Intensive three-week summer institutes engaged Faculty Fellows in shared experiences in learning new mathematics and science content. Faculty participated in varied types of learning activities that reflected current research, became better acquainted with teacher licensure procedures in the state, collaborated with education faculty from their own institution, and became familiar with the national Standards documents from NCTM, NRC, and AAAS [2-4]. Disciplinary and special interest groups were formed to facilitate continued communication and collaborative work across institutional and disciplinary lines. Experienced classroom teachers were integrated into the summer institutes, and some also held visiting teacher-in-residence positions at several campuses. They served as members of the disciplinary and special interest groups and as mentors to college faculty.

Building on existing networks, such as the long established broad-based policy organization Oregon Mathematics Education Council and the more informal Teachers of Teachers of Mathematics, companion science organizations (Oregon Science Education Council and Teachers of Teachers of Science) were created in order to sustain activity beyond the end of the grant. The councils have broad representation from business, industry, private and public
universities and community colleges, and K-12 teachers and administrators. They provide advice and counsel to: the Oregon Board of Higher Education; the Oregon Department of Education; the Teachers Standards and Practices Commission (the state’s teacher licensing agency); and, the state’s educational institutions and their STEM and education programs. Collaborative activities were also instituted with other existing science and mathematics professional organizations, such as Oregon Science Teachers Association and Oregon Council of Teachers of Mathematics, Oregon Chapter of American Association of Physics Teachers, and Oregon Academy of Science.

Although identification and advising of pre-teacher education students was not originally a major component of the project, it emerged as an important focus. In particular, the early identification (at the high school level or during the first two years of collegiate work) of students interested in becoming teachers appeared as a critical issue early in the OCEPT project. Institutions offering licensure through graduate “fifth year” teacher education programs had no undergraduate “education” degree or other means by which to identify students. Community college education programs were usually designed for early childhood education, and sometimes students interested in secondary teaching were misplaced into such programs. An OCEPT “Student Goals and Interests Survey” form was developed to help identify future teachers [5]. Institutions were encouraged and supported to 1) provide early advising on selection of appropriate courses and major; 2) get pre-teacher education students involved in future teachers organizations; and, 3) engage students in early field experiences with children in the community and peer teaching experiences on campus. Future teachers clubs were started on several campuses and very successful Future Teachers Conferences held at Linn-Benton Community College and Portland Community College—each attracting more than 200 participants—which involved undergraduate students from several institutions in planning and organizing the conferences.

With Oregon’s population approximately 85% Caucasian and only approximately 4% of the teaching force from underrepresented groups, achieving diversity in the education profession has been a challenge. To build an infrastructure to support increased diversity, 31 cooperative group learning courses were developed at eleven institutions to support retention and success in key mathematics, biology, chemistry, and physics courses. Many of the programs were modeled on Uri Treisman’s Emerging Scholars Program, first developed at the University of California, Berkeley. These were often called Math Excel, Chem Excel, etc. Others were modeled on the
Peer-Led Team Learning (PLTL) model first developed as part of the NSF-funded Workshop Chemistry project based at City University of New York.

When the OCEPT staff realized that many STEM faculty were not experienced in writing about teaching issues and curriculum changes, and often were unfamiliar with journals that published such papers, WRITE ON! writing retreats were created. These retreats were designed to support faculty dissemination efforts about their work with OCEPT. To our surprise and pleasure, faculty also praised them as one of the best professional development experiences they had experienced.

What Was Accomplished

As a result of OCEPT, more than fifty courses and programs were developed and over 175 courses revised at more than 25 institutions. Faculty have reported: 1) using more variety in their teaching and assessment strategies; 2) adopting standards-based instructional techniques; and, 3) promoting opportunities for student teaching and tutoring experiences in K-12 schools. OCEPT-influenced classrooms are more interactive, have a greater use of instructional technology, and emphasize conceptual development with a focus on scientific inquiry and/or mathematics problem solving.

Mathematics programs for middle school teachers were developed at Western Oregon University and Southern Oregon University to complement Portland State University's existing program. Since many middle school teachers of mathematics and science were originally prepared as elementary teachers, the challenge now is to extend these programs to serve these practicing middle school teachers in all regions of the state in order to strengthen their mathematics content knowledge and understanding.

Linn-Benton, Chemeketa, Treasure Valley, Blue Mountain, Central Oregon, and Portland Community Colleges, along with Oregon State, Western Oregon, Eastern Oregon, and Portland State Universities, and the Universities of Oregon and Portland, have all made progress in building science programs especially designed for students aimed at the elementary/middle level licensure. A guide describing many of these programs and their courses, currently in development, will serve as a resource for other science faculty and departments.
The University of Oregon has developed a new science-oriented Pathways program and Pacific University has implemented a new undergraduate major for elementary teachers that strengthens their content preparation. Most of the universities with graduate teacher education programs are now exploring or developing similar programs.

Early field experiences in K-12 classrooms have become part of some mathematics and science courses, and been used both to give STEM students experience with the content in another setting and to encourage STEM students to consider teaching as a career. A handbook for faculty on strategies for incorporating early field experiences into mathematics and science classes was developed to assist faculty in providing such opportunities.

The success of the Excel and PLTL programs led to the institutionalization of many of them. It also led to changes within other science and mathematics courses as faculty recognized the positive effects of strategies employed in these programs. Peer teaching experiences through the PLTL and Excel programs developed on several campuses have changed the character of lower division courses on those campuses. They have also proved to be a valuable method of inciting student interest in teaching.

Advising and support for students interested in becoming teachers has been improved. A mathematics and science Advising Guide, created by OCEPT Co-P.I. Camille Wainwright, provides important information about all the teacher education programs, including their mathematics, science, and technology requirements. It has proved useful to academic advisors and to pre-teacher education students alike. Similar advising guides were subsequently developed in the areas of language arts and the social sciences. Information from these guides has been incorporated into a state Advising Guide available on the website of the Oregon University System [6].

Articulation of pre-teacher education programs among institutions has been strengthened. While all of Oregon's community colleges and public universities already had transfer articulation agreements in place when OCEPT started, several institutions have extended their transfer agreements to accommodate the special needs of pre-teacher education students. In addition, several community colleges and universities now have co-admission agreements, by which students are admitted simultaneously to both a community college and a university, with student advising and program planning becoming a joint responsibility of the two institutions. Some
community colleges have also developed articulation agreements with private universities. Cooperation with the annual University/Community College Articulation and Transfer Conference, sponsored by the Oregon University System, and special OCEPT pre-teacher education advising workshops have greatly strengthened advising and articulation for pre-teacher education students.

The Oregon Science Education Council and Oregon Mathematics Education Council have both produced and disseminated “Recommendations for the Science/Mathematics Preparation of Teachers” for Oregon, based on national and state standards [7,8].

WRITE ON! retreats have now been instituted by some other projects and also some institutions, and they have also been offered specifically for experienced and beginning K-12 teachers of mathematics or science. The Oregon Council of Teachers of Mathematics and the Oregon Science Teachers Association are now exploring ways of incorporating this model into their annual “leaders institutes,” each of which brings together approximately 150 teacher leaders and early career teachers with leadership potential. Elaine Jane Cole, OCEPT Project Manager, has been the organizer and leader of the WRITE ON! retreats.

A Mentor Advocacy Partnership, described by many as an unusual collaboration of representatives of school boards, school administrators, teachers union, Department of Education, teacher licensing agency, and higher education was formed to promote the development of mentoring programs for beginning teachers and to obtain legislative support for these programs. Based on the Early Career Mentor Program piloted by OCEPT, the Oregon Council of Teachers of Mathematics and the Oregon Science Teachers Association are now committed to provide more mentoring and professional development for beginning teachers.

To assess the project and its impact, OCEPT commissioned case studies of institutional change at six institutions that have actively participated in OCEPT. It also conducted an annual survey of students entering teacher education programs who plan to be elementary or secondary mathematics or science teachers. OCEPT has also instituted the Outcomes Research Study to look deeply at the mathematics and science background and teaching practices of newly prepared teachers and of STEM faculty who taught them. The Outcomes Research Study is described in Camille Wainwright’s article for this journal, “The Development of Instruments for Assessment
of Instructional Practices in Standards-Based Teaching” and the Study will continue for the next three years through the new OCEPT II grant under her direction at Pacific University.

Aspects that Contributed to OCEPT Success

The entire project modeled cooperative group learning. Nearly all the institutes and workshops were planned and conducted by the participants themselves. Leadership of discipline and special interest groups emerged from within the groups. The project itself was managed by dedicated volunteers and staff representing a variety of institutions and disciplinary interests.

K-12 classroom teachers were recognized as full partners and colleagues. They were participants and leaders throughout the project. Their role was invaluable in helping college and university faculty develop or revise courses and implement new teaching strategies.

OCEPT raised the awareness of the scholarship of teaching among STEM faculty. By fostering scholarly work by mathematics and science faculty which focused on their own teaching, more of them now consider this sort of reflection and investigation a regular part of their role as a faculty member.

Working through existing professional organizations and agencies enabled participants to see OCEPT goals and activities as a part of their shared responsibility, increasing the interest in issues relating to the preparation of future teachers, and thus providing venues for continued efforts.

In summary, the OCEPT project initially targeted individual Faculty Fellows in college mathematics and science departments. OCEPT contributed to the increased number of new teachers in mathematics and the sciences, and helped start programs which over time will increase the diversity of the teaching force. However, its major focus throughout the project has been to improve the quality of preparation of new teachers of mathematics and science. Perhaps the greatest indicator of the effect of OCEPT is a noticeable change in perspectives of faculty and academic advisors throughout the state. Their circle of “colleagues and friends” now includes people on many different campuses and in different disciplines. Their “interests” include thinking about how things are taught as well as what is being taught; recognizing the importance of learning subject matter knowledge in conjunction with learning about teaching the subject; and, actively encouraging good students to become teachers. These informal networks and
personal changes of mathematics, science, and education faculty and advisors that were
developed during the project may prove to be one of the most long-lasting and significant
contributions of OCEPT.

In addition to these changes at a personal level, we believe that the education systems
have also been influenced in a positive way. For example, in an independent review of the
seventeen teacher education programs in the state, they all, without prompting, mentioned that the
progress they were making in improving their programs had been significantly increased by the
impact of OCEPT on their campus. Thus, OCEPT became a catalyst for systemic change
throughout the state, influencing not only individuals, but also agencies, organizations and
institutions, providing momentum at all levels for the continued improvement of teacher
preparation in Oregon.

We hope that you enjoy this special issue, in which OCEPT participants share various
aspects of OCEPT from their own perspectives.

Bio

Dr. Marjorie Enneking is Professor of Mathematics at Portland State University, and
Principal Investigator of the Oregon Collaborative for Excellence in the Preparation of Teachers.

References


2000.


[4] Benchmarks for Science Literacy, American Association for the Advancement of Science: Project 2061,

[5] Student Goals and Interests Survey, Portland State University website, Internet:
http://mth.pdx.edu/ocept/evaluation.htm


Abstract

Peer-Led Team Learning has been in use in Introductory Biology and Introductory Chemistry since Fall 1999 at the University of Portland. Its effect on improved conceptual understanding, retention of students, and improvement in study skills will be discussed. An ancillary, but no less important benefit in the development of interest in science teaching among the peer leaders, is also addressed.

Introduction

An ongoing concern among science educators has been the promotion of conceptual understanding in large lecture classes and the improved retention of beginning students in these courses [1-4]. In April, 2001, R. Pendarvis reported that the attrition rate in introductory science courses is on average 40%, with some open enrollment institutions reporting losses as high as 70%. Student-centered learning approaches are one way of increasing the retention of students and if needed, of improving student study skills to the college level. They have also been shown to improve students’ conceptual understanding. Another concern, both nationally and locally, is the scarcity of well-prepared teachers of high school science and the shortage of students in the pipeline considering science teaching as a career. Peer-Led Team Learning is helpful in remedying these concerns [5,6]. For several years, the Departments of Biology and Chemistry at the University of Portland have been focusing their efforts on improving and increasing the success of their first-semester freshmen in Introductory Biology and Introductory Chemistry. The University of Portland is a private, primarily residential university in the city of Portland, Oregon with an enrollment of about 2,600 students. The number of students who declare science,
primarily biology, as a major has steadily increased with a corresponding increase in the SATs and high school grade point averages. For incoming first-time freshmen in Fall 2000, the average SAT score was 1132 and the average high school GPA was 3.54 out of a possible 4.00. Although more academically superior students are being admitted, the success of these students in passing first-semester *Introductory Biology* and *Chemistry* was not increasing. The study skills students needed to succeed were weak or non-existent. Freshmen who graduated from high school with high grade point averages reported that they never had to study to do well in science in high school. They were finding out that this was not the case in college, but too late to recover academically.

To remedy these concerns, the lead instructors in *Introductory Biology* and *Chemistry* adopted and adapted the Peer-Led Team Learning approach in their first-semester courses in Fall 1999. This model is an active and interactive learning experience for students. It creates a leadership role for undergraduate mentors in weekly workshops and engages faculty in new dimensions in teaching. This approach is based upon an NSF-supported initiative developed by David K. Gosser, et al. in 1991 at City College of New York [7]. Now in the dissemination phase, it is being extended to biology and physics, as well as chemistry. It is an especially flexible and versatile model, having already been implemented at a variety of educational settings as diverse as City College of New York, the University of Rochester, St. Xavier University, and the University of Portland.

In assessing the critical components for successful implementation of the Peer-Led Team Learning model since its inception, Gafney [8] has found the following criteria to be key:

- Peer-Led Team Learning must be integral to the course and coordinated with all of the elements of the course.
- The instructor must be centrally involved in the workshops.
- Undergraduate workshop leaders must be trained in facilitating group work—they do not function as lecturers or discussion leaders, but as mentors leading the group to find its solutions.
- Workshop materials must be challenging and interactive, meeting the needs of both the slower and the more advanced students by incorporating diverse methodologies to meet diverse learning styles.
- Institutional support must be present.
In adapting this model at the University of Portland, the following conclusions were reached concerning logistical arrangements:

- Group sizes of eight/room/leader were optimal.
- Weekly workshops of two-hour blocks functioned best.
- Scheduling workshops around the same class lecture was highly desirable.
- Group hopping was disruptive; the groups that functioned best were those whose members formed a cohesive unit, and this team cohesion deepened as the semester progressed.

In both the biology and chemistry courses, the group leaders met weekly with the instructors to discuss the upcoming workshop and to troubleshoot past workshops. The peer leaders also kept weekly journals reflecting their groups’ progress. These journals became an encouraging record of each peer leader’s growth and confidence as the semester progressed. From 1999-2002, there were on average 100 students enrolled in workshop chemistry each fall with ten peer leaders each responsible for one workshop. In the biology course, there were on average 145 students enrolled during this time with fourteen workshops and nine peer leaders. Some peer leaders in biology were responsible for two or more workshops. There were on average eighty students taking both workshop chemistry and workshop biology each semester. Both the biology and chemistry workshop leaders participated in a common training session prior to the start of the workshops in the fall. The training session focused on how to facilitate group work, how to respond to differing learning styles, how to handle sensitive issues that might arise in workshops, and how to provide an opportunity for new mentors to practice leading a group. This training session was reinforced during the year by hour-long sessions held weekly with the instructor assessing and troubleshooting problems that developed within a group. The peer leaders were selected by the instructor based upon their successful completion of the course and their demonstrated ability to work well in a group setting. Many of them were sophomores.

This peer-led model is, however, quite flexible. At the University of Portland, the biology and chemistry instructors differed in how Peer-Led Team Learning was implemented. The biggest difference was that in the chemistry course, attendance at workshops was required; whereas in biology, students were encouraged to attend workshop biology. Another difference was that the peer leaders for the chemistry course attended the “lecture,” and their groups were encouraged to sit near one another in the lecture hall so that they could facilitate group work during class. This inclusion of peer leaders in the lecture had been introduced by the chemistry
instructor in 1998; however, those peer leaders, although upper division chemistry majors, were not skilled in facilitating discussions and sometimes gave incorrect information. In addition, their attendance in the lecture classes was sporadic and uneven. Formalizing the peer mentor program eliminated all of these problems.

In both chemistry and biology, the workshops used various approaches from model building to “jeopardy” games to involve the students in the workshop topics. Workshops began with a self-graded quiz since freshmen, in particular, are less skilled in formative self-assessment [9]. The quiz questions often were repeated in the midterm examinations reinforcing the importance of workshop participation. Workshop leaders were trained to emphasize active learning techniques that utilized different learning styles each week.

The most frequently used approach in chemistry, for example, involved workshops consisting of several problem sets. These sets were developed by the instructor from the workshop project, past examination questions, and/or textbook problems [10]. Students worked in pairs on a problem and each pair put its work on the board. After a suitable time, everyone would compare and contrast each pair’s solution. If the pair had difficulty solving the problem, another similar one would be assigned. If the pair had no difficulty, a problem involving new concepts would be introduced later. Students proceeded through the workshop at their own pace.

**Chemistry Results**

In order to assess the impact of the workshop approach on the students’ grasp of introductory chemistry, grade and exam results from a previous non-workshop class were compared to the results of those sections that had workshop chemistry. The Fall 1992 class was selected for this comparison because its composition of major, average GPA/SAT, and enrollment was most similar to the workshop classes and the instructor was the same. The text was different, but of similar rigor, and the class content was the same. In the first-semester Chm 207: Introductory Chemistry I, there was a significant increase in the percentage of students earning A’s and B’s compared to similar classes in the past without workshop chemistry. This is summarized in Table 1.
Table 1

<table>
<thead>
<tr>
<th>Chm 207: General Chemistry I</th>
<th>Fall</th>
<th>92(^1)</th>
<th>99(^2)</th>
<th>00(^3)</th>
<th>00(^3)</th>
<th>01(^2)</th>
<th>01(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% A + B’s</td>
<td>44</td>
<td>73</td>
<td>57</td>
<td>71</td>
<td>60</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>% D, F, W’s</td>
<td>16</td>
<td>13</td>
<td>26</td>
<td>8</td>
<td>19</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

1. No Workshop
2. With Workshop
3. Data renormalized to include only those students who attended workshops.

Clearly, retention and final semester grades improved with the workshop approach. Higher final grades did not necessarily prove that students achieved greater conceptual understanding, but they are suggestive of this, especially since all the exams were concept-based and comparable in scope and emphasis.

Biology Results

There was a similar positive correlation between participation in workshop biology, which was optional, and the final grades in *Introductory Biology*. Figure 1 shows the grade distribution and the number of workshops attended for Fall 1999 and Fall 2000 in *Bio 205: General Biology*. 
Workshops Attended 1999/2000

Figure 1. Mean number of workshops attended in each grade category for Bio 205: General Biology.

A regression analysis comparing the percentage grade in the course versus the number of workshops attended showed a correlation between workshop attendance and higher grades in the course (p<0.005).

Students also showed a statistically significant increase in median scores on the comprehensive final exam in biology as shown in Table 2.

Table 2
Mean Percentage on Final Exam in Introductory Biology

<table>
<thead>
<tr>
<th></th>
<th>Fall 98$^1$</th>
<th>Fall 99$^2$</th>
<th>Fall 00$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>76.8</td>
<td>79.5</td>
<td>80.3</td>
</tr>
</tbody>
</table>

1. No workshop
2. With workshop
Participation in workshop biology also seems to have had a positive correlation to female students’ final grades in the course. Female students had a 0.521 positive correlation between the number of workshops attended and final class grades. Male students had a 0.238 correlation. This correlation is significant at the 0.01 level (2-tailed). This gender benefit to female students with peer learning was found in chemistry as well. While participation in workshop chemistry and biology was beneficial to both male and female students, it was even more beneficial to female students.

**Results Common to Workshop Chemistry and Workshop Biology**

Students in both chemistry and biology responded favorably when surveyed on their experiences with workshop chemistry and biology.

**Table 3**

| Student Responses: Percentage of Students Agreeing or Strongly Agreeing to the Following Items |
|-----------------------------------------------|-----------------|-----------------|-----------------|
| 1. Interacting with the workshop leader increases my understanding of chemistry/biology. | F99 85 | F01 100 | F02 92 |
| 2. Interacting with other group members increases my understanding of chemistry/biology. | F99 87 | F01 89 | F02 86 |
| 3. I would recommend workshop courses to other students. | F99 86 | F01 93 | F02 85 |

A strong majority of those students who were enrolled simultaneously in workshop biology and chemistry agreed with the statement that “having a workshop in both chemistry and biology helps me.” The peer leaders were also asked to assess the value of the workshop approach in learning chemistry and biology. In every assessment, there was unanimous agreement that they would recommend a workshop course.
Benefits to Peer Leaders

Our original goals in introducing Peer-Led Team Learning into Introductory Biology and Chemistry had been to improve conceptual understanding of biology and chemistry, increase students’ success in first-semester courses, and retain students in their desired field of study. Our preliminary data are very encouraging that these goals are being met, but there was a parallel and unexpected bonus in this student-centered learning approach: namely the involvement of undergraduate peer leaders as mentors who formed a bridge improving faculty and student communication. The peer leaders also reported enhanced skills in problem solving and understanding basic concepts in biology and chemistry. They developed confidence and facility in working with groups and became respected colleagues of the faculty. Another major bonus that has been noted in the three years that peer learning has been in place at the University of Portland, has been the change in our academic culture among majors favoring teaching as a career.

Table 4
Peer Leaders—Source of Future Teachers

<table>
<thead>
<tr>
<th>Year</th>
<th>Mentors Planning on Teaching Career</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chemistry</td>
</tr>
<tr>
<td>1999-2000</td>
<td>3 out of 9</td>
</tr>
<tr>
<td>2000-2001</td>
<td>5 out of 11</td>
</tr>
<tr>
<td>2001-2002</td>
<td>5 out of 9</td>
</tr>
</tbody>
</table>

This is from a science major pool which, in its first year at the University of Portland, had a student population in which only 2% indicated teaching as a career choice. Among the biology mentors in 1999-2000, all the graduating seniors pursued teaching fields or volunteered in a classroom setting immediately after graduation, even though none of these students had considered teaching as a career option before serving as peer mentors. This suggests that the workshop approach using peer leaders may be an effective remedy in addressing the critical shortage of future science teachers.

Institutionalizing Peer-Led Team Learning at the University Of Portland

Peer-Led Team Learning began in first-semester Introductory Biology and Introductory Chemistry in Fall 1999 at the University of Portland. By Fall 2002, it had been extended to the
full year sequence in General and Organic Chemistry, General Physics, as well as continuing in General Biology. The success of this approach at the University of Portland is due to: administrative support from the dean of the College of Arts and Sciences and the department heads of Biology and Chemistry; a critical mass of four faculty implementing the selection and training of peer leaders; our pioneering cohort of peer leaders (eleven in chemistry and nine in biology); and, in no small measure to the group of students who were the first to learn with this approach.

Acknowledgments

This work was supported in part by the Workshop Project Dissemination Grant of the National Science Foundation, Award 9972457; the Oregon Collaborative for Excellence in the Preparation of Teachers of the National Science Foundation, Award 9996453; and, WRITE ON! a writing retreat facilitated by the Oregon Collaborative for Excellence in the Preparation of Teachers, and funded by a National Science Foundation grant DUE-9653250 and 0222552.

Bios

Agnes Tenney is Associate Professor of Chemistry, and Becky Houck is Professor of Biology at the University of Portland.

References


THE DEVELOPMENT OF INSTRUMENTS FOR ASSESSMENT OF INSTRUCTIONAL PRACTICES IN STANDARDS-BASED TEACHING

C. L. WAINWRIGHT
College of Education, Pacific University
Forest Grove, OR 97116
wainwric@pacificu.edu

L. FLICK
Mathematics and Science Education, Oregon State University
Corvallis, OR 97331
flickl@ucs.orst.edu

P. MORRELL
School of Education, University of Portland
Portland, OR 97203
morrell@up.edu

Abstract

We provide a description and rationale for the development of two instruments: 1) a classroom observation protocol; and, 2) a teacher interview protocol—designed to document the impact of reform-based professional development with undergraduate mathematics and science faculty, and its impact on the resultant preparation of teachers. Constructed upon review of the research on teaching and standards documents in mathematics and science, these instruments form the basis for data collection in a three-year longitudinal study of teaching practice among early career teachers as well as undergraduate college faculty. In addition, we suggest further applications of the observation protocol beyond the original purpose of our research study.

Introduction

In 1997, the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT) was established with funding from the National Science Foundation. It was designed to improve the preparation of science and mathematics teachers in elementary, middle, and high schools, and to attract a more diverse group of students to the teaching profession.
College level mathematics and science courses tend to promote the success of those who major in the subject and find the subject matter intrinsically interesting, thus limiting the number of students who enroll in these courses. Elementary and middle level teachers are expected to teach mathematics/science to all students at crucial points in our educational system. Thus, preservice teachers form an important population who ought to enroll in numerous content courses and should, ideally, enjoy these valuable mathematics and science experiences.

Making content courses both more effective and more inviting for a broader range of students is an important goal in the development of a mathematics/science literate society; this is especially critical in the preparation of future teachers. More effective teaching and assessment methods that will motivate and challenge students who are not majoring in mathematics/science and may not find these content areas intrinsically interesting have a research base in the literature of mathematics and science education [1-3]. However, the educational research literature in higher education is at an early stage of development, and includes studies which are qualitative in design and diverse in perspective. Methods for more effective teaching and assessment have also been highlighted in recent reform documents in mathematics and science education which are primarily focused on K-12 education [4-10].

OCEPT was designed to foster innovations in the teaching and assessment of college level mathematics and science courses. Prospective elementary, middle level, and secondary teachers taking these courses will have firsthand experience in learning mathematics and science through the modeling of strategies and technologies that should not only benefit them as learners, but should also support more effective pedagogy when they begin their own teaching. They should view these courses as a valuable component in their preparation for classroom teaching.

As OCEPT approached its fifth and final year, a variety of evaluation strategies were developed in order to determine its effectiveness. Numerous methods were implemented, including: a) the development of case studies at core institutions; b) tracking Faculty Fellows’ professional development; and, c) collecting data on supply and demand trends within the state, as well as quantitative data on the number of teachers entering the profession from underrepresented groups. In addition, the Outcomes Research Study was designed to determine the impact OCEPT Fellows and their courses have had on the quality of newly-licensed Oregon teachers.
The Outcomes Research Study

The specific research study questions sought to be answered by the Outcomes Research Study are:

1. What is the relationship between student teachers’ instructional practices and their undergraduate preparation?
2. How did Faculty Fellows’ participation in OCEPT contribute to their instructional design and practice?
3. How do student teachers’/Faculty Fellows’ teaching practices reflect those recommended by current research in mathematics/science education?
4. What is the relationship between student teachers’/Faculty Fellows’ perceptions of their own instruction and the observed classroom practice?

Our goal was to document and describe standards-based practices in college courses taught by OCEPT Faculty Fellows. In addition, we wanted to study the classrooms of student teachers who had been enrolled in those courses. In both settings, we wanted to compare teacher instructional intentions (as described during the interviews) with observations of actual classroom teaching.

Purpose

The purpose of this study is to develop the instruments considered necessary for conducting the Outcomes Research Study. In preparing to engage in this study, we faced a classic problem of research in relatively undeveloped fields of study. There are few accepted methods and a dearth of good data from which to build. New approaches and new instruments are necessary to address the meaningful questions posed by scholars in the field. Jenks and Riesman expressed the problem in the preface to their analysis of higher education over three decades ago: “...responsible scholarship must invent methods and data appropriate to the important problems of the day. To reverse this process, choosing one’s problems to fit the methods and data that happen to be most satisfactory, strikes us as an invitation to triviality...”[11] Consequently, this is the first of a series of reports designed to describe our efforts to study reformed teaching at the college level and its impact on new teachers. In so doing, we hope to avoid another longstanding and contrasting criticism of scholars and innovators in educational reform—that past work is ignored as though there is nothing on which to build
Between these two critical positions, we hope to develop innovative methods while maintaining a clear connection to past scholarship.

Existing Protocols

Choosing an observation protocol for this study involved thinking about the context of teaching both in college courses as well as in K-12 classrooms. From the perspective of college instructors, educational reforms are intended to improve understanding and use of subject matter. From the perspective of K-12 teachers, the purpose is similar, but reform goals give a greater emphasis to improving student-teacher interactions. Further reflection on these two contexts suggests that they are more similar than they are different; this is especially true for college science and mathematics courses designed for non-majors such as elementary and middle level teachers. In these courses, reform advocates have stressed the need for significant improvement not only in translation of content into instruction, but also about the necessity of positive and encouraging student-teacher interactions [4]. For these reasons, protocol design proceeded under the assumption that the same observation tool would be used in classrooms from the elementary level through undergraduate college level.

The broad use of such an observation tool came with obvious caveats. We knew from the outset, for example, that we would not see the same constellation of behaviors in an undergraduate mathematics class as we would see in a mathematics lesson in an elementary school classroom. There was no a priori expectation that all K-12 teachers and college instructors would be meeting the same criteria. Further, we knew that when observing college lecture classes, the kinds of student-teacher interactions afforded by that setting would be significantly different from what is possible and desirable in a recitation section. There are numerous other differences that became a matter of reflection as we put the instruments to use. This will be discussed in more detail in the Implementation section of this paper.

Several scholars have attempted to design classroom observation protocols that assessed standards-based teaching practice. Methods of validation have tended to be ad hoc in nature. For example, Sawada and Piburn worked from personal expertise to design an observation protocol (RTOP) of 25 items in three categories supplemented by observational field notes [13]. Reliability data was derived primarily from observer training and inter-rater reliability. They have achieved some correlation with RTOP ratings and student achievement. These interesting results provide no methods for isolating intervening variables. The problem is that there is no
agreed-upon set of practices that represent the mathematics and science standards. Even the expected standards-based outcomes are open to wide interpretation. What does it mean, for instance, for a student to engage in problem solving in mathematics or inquiry in science? Other observational protocols have proceeded with significantly different assumptions about the nature of reformed teaching. For example, an unpublished paper by L. Dana, “The Situated Laboratory Activity Instrument (SLAI): A User’s Handbook” focuses on a protocol based on instructional activity in laboratory settings. Another unpublished paper by N.G. Lederman and R. Schwartz, “Nature of Science and Scientific Inquiry: Operational Definitions and Teaching Approach as Promoted in Project ICAN” describes a procedure based on teaching about the nature of science.

The literature base also lacks clarity when it comes to determining what is going on in classrooms when standards-based instruction is taking place. There is often confusion in research reports between learning theory and instructional theory. For example, a researcher conducts a study and describes what students are doing and assesses what they are learning. From this, the researchers may inappropriately infer what teachers should do, when in fact no data were collected on the actions of the teacher [14, 15]. Data on how students learn and conditions for learning do not translate directly into teaching practices. Instructional design theory is concerned with what a teacher does and must include specific instructional method variables. Learning theory is concerned with mental representation, memory, reasoning, and other inferred mental processes. The distinction is important because instructional design theory directs teachers to emphasize particular variables that have been operationalized in research. Operationalizing learning theory research for the classroom, however, is much more subtle and challenging for the teacher [16].

After examining the published instruments and protocols, we decided that none of the existing tools and methods met our needs. We determined that we needed to develop our own tools to carry out the Outcomes Research Study.

**Development of New Protocols**

We examined two decades of research on explicit teaching for initial guidance on the development of an observation protocol [17]. This work has produced the following reliable set of observable instructional principles [18] relative to a defined perspective of teaching:
• Review previous and prerequisite learning.
• Clearly state learning goals.
• Present new material in small steps.
• Give clear and detailed instructions and explanations.
• Provide high levels of active practice for all students.
• Ask large numbers of questions and obtain responses from all students.
• Guide students during initial practice.
• Provide systematic feedback.
• Provide explicit instruction for independent practice and continually check for understanding.

Research on explicit teaching has provided a productive background for researchers and teachers interested in developing constructivist teaching approaches. More recent research has learned that high school and college age students have trouble using logical competence in scientific reasoning despite their presumed attainment of the Piagetian level of formal thought. Examining ninth graders through adults, Kuhn’s results show broad problems in argumentation skills [19]. These problems include confusing co-occurrence of events with cause and effect, preference for confirming rather than disconfirming evidence, and failure to consider potentially important factors by judging them irrelevant. A critique of this work by Koslowski and Maqueda suggested that Kuhn’s evaluation may be overly restrictive [20]. However, Koslowski and Maqueda emphasized that these capabilities require purposeful practice involving reflection on the relationships between theory and evidence and how they mutually constrain possible conclusions. In their review of these issues, Driver, Newton, and Osborne emphasize the significance of explicit teacher support in modeling, and providing practice in thinking through various interpretations of evidence [21]. The message is that relevant cognitive skills are not developed ready for use in classrooms or daily experience, but must be prompted, exercised, coached, and reinforced.

We also relied on the existing observation protocols in helping in our design. We appreciated the observational categories of Sawada and Piburn [13]. Dana’s (2000) laboratory observation protocol presented two useful dimensions: the student’s role and the teacher’s role.
We reviewed studies of the Social Science Education Consortium which utilized the 5E model and provided descriptions of teacher and student actions consistent with the model [22,23]. The Lederman and Schwartz study (2001) described relevant characteristics of the nature of science and scientific inquiry appropriate for classroom teaching, identifying reform practices by specific statements delivered by the teachers in class. The Horizon Research Corporation observation protocol provided valuable descriptive categories [24]. Finally, we examined the protocol designed by Lawrenz, Huffman, Appledoorn, and Sun for use in National Science Foundation Collaborative projects such as ours [25].

Building primarily on the work of Sawada and Piburn, the Social Science Education Consortium, and Lawrenz, et al., the authors designed the OCEPT Classroom Observation Protocol (O-TOP) (see Appendix A) [13, 22, 25]. As we each reviewed and revised the instrument, it was circulated repeatedly among the three of us for feedback. Further review of the initial instrument suggested that observations of teaching should consider what is happening to include not just teacher actions, but also student behaviors. As noted by Good and Brophy “…observers often try to reduce the complexity of classroom coding by focusing their attention exclusively on the teacher…but it is misplaced emphasis. The key to thorough classroom observation is student response. If students are actively engaged in worthwhile learning activities, it makes little difference whether the teacher is lecturing, using discovery techniques, or using small-group activities for independent study.” [26]

During the revision phase, the authors reviewed the instrument with respect to personal background and expertise in science education reform-based practices. In addition, the team reviewed the instrument for:

- limiting the observation categories to a number that an observer can remember and reflect upon during a class period;
- developing examples so that trained observers experienced in classroom teaching could reach agreement on meaning; and,
- setting a scale for each category that could be reliably applied.

The resultant instrument was examined by the entire research team, consisting of four science and/or mathematics education faculty and three graduate students. As a group, we discussed the meaning of each item and the wording used as prompts. The team proposed
revisions and additions to the instrument wording. When we felt there was sufficient agreement, we viewed a videotape of classroom teaching and individually rated the observed instruction on each of the ten items. Table 1 shows the percent agreement among the seven observers for rating each item with the same score, as well as for rating each item within one point difference. For eight of the ten items, more than half of the research team agreed on the same score. For the same eight items, all seven observers were within a one-point differential.

Two of the items initially caused a problem in interpretation. For Item #2 (Metacognition) and Item #5 (Student Preconceptions), there was a 57% and 71% agreement within one on the five-point scale. The graduate students on the team had less experience with the topic of metacognition than the college faculty, and less experience in applying the research on misconceptions/preconceptions as well. Through discussion, the group reflected on personal classroom experience and related this to the meaning of reform standards. In the end, we were able to identify specific changes warranted in the instrument as a whole and, for Items #2 and #5 in particular, to ensure reliability in the use of the instrument. Further validation and reliability checks were carried out by pairs of researchers observing actual classrooms at the elementary, middle, high school, and college levels.

Table 1

<table>
<thead>
<tr>
<th>Item</th>
<th>Same Score</th>
<th>Within One</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>2</td>
<td>29%</td>
<td>57%</td>
</tr>
<tr>
<td>3</td>
<td>57%</td>
<td>100%</td>
</tr>
<tr>
<td>4</td>
<td>57%</td>
<td>100%</td>
</tr>
<tr>
<td>5</td>
<td>43%</td>
<td>71%</td>
</tr>
<tr>
<td>6</td>
<td>57%</td>
<td>100%</td>
</tr>
<tr>
<td>7</td>
<td>71%</td>
<td>100%</td>
</tr>
<tr>
<td>8</td>
<td>86%</td>
<td>100%</td>
</tr>
<tr>
<td>9</td>
<td>71%</td>
<td>100%</td>
</tr>
</tbody>
</table>
We felt the resultant instrument captured what needed to be observed and did so in a way that was manageable with a reasonable amount of training. In addition, the authors also designed an interview protocol, OCEPT Teacher Interview Protocol (O-TIP), based directly on the O-TOP (see Appendix B). The four open-ended questions prompt broad discussion within the ten categories of the classroom observation protocol. The process of reviewing and refining the O-TIP was considerably shorter given that the major categories had already been validated. Using the O-TIP along with the O-TOP acts to further validate the observational data and adds an in-depth description of the instructor’s perspective.

The interview and observation protocols were further examined and evaluated by various expert groups. For example, the team presented the instruments at the OCEPT summer institutes and Oregon Academy of Science conference. Feedback from all groups was readily accepted and applied in strengthening the instruments.

**Pilot Study**

A pilot study to field test the instruments was implemented at three institutions (Oregon State University, University of Portland, and Pacific University). For this process, students were identified who were currently accepted into a teacher education program, working toward initial licensure, and had taken at least two courses from OCEPT Fellows. Twelve student teachers and six Faculty Fellows were involved in the pilot study. Most student teachers were observed teaching on three occasions; the Faculty Fellows were observed twice. Global scan field notes were taken during each observation, and the O-TOP instrument was completed following each class. As noted above, the initial observations were done by two members of the research team to check for inter-rater reliability in the use of the instrument. After the series of observations, the student teachers/Faculty Fellows were individually interviewed using the interview protocol. The interviews (typically thirty minutes in length) were audiotaped and later transcribed.
Data Analysis

The amount of data collected during the pilot study was daunting. We had 48 sets of observational field notes, 48 completed O-TOP instruments, and eighteen interview transcripts. We realized that when we applied these tools to our actual study, where we hoped to have a sample of twenty student teachers and fifteen Faculty Fellows, the amount of data would be even larger.

To assist in analyzing this volume of data, the observers wrote a composite for each participant summarizing data from the field observations, the O-TOP instruments, and the O-TIP transcribed interview. The composites specifically included these items:

1. A table listing the student teacher’s O-TOP rating for each item for each observation
2. A graph showing the sets of O-TOP ratings for comparisons
3. A description of the context
   - class type/methodology (e.g., lecture, lab, demonstration)
   - subject content/topic
   - place in sequence of unit (e.g., introduction, on-going, review) and/or relationship of observations (three consecutive days, etc.)
   - description of students and makeup of the class (e.g., sophomores and juniors in an elective class)
   - size of class
   - institution (public v. private, etc.)
   - important constraints (e.g., room setup, equipment limitations)
4. A description of the observed behaviors that led to the O-TOP scores for each observation
5. Patterns and interpretations of the total data set, relying on observations, O-TOP ratings and interview data
6. Additional pertinent comments/concerns not captured above

The authors then analyzed all the composite case studies—referring to primary documents when necessary—to see if any generalizable patterns emerged. We are hopeful this method of analysis will be manageable as we continue with an expanded three-year longitudinal study.
Results

We were pleased with the actual application of the protocols. We were able to reliably gain the data we needed to answer the questions posed for the Outcomes Research Study. It should be noted, however, that the broad use of the observational tool came with obvious caveats. We knew from the outset, for example, that we would not see the same constellations of behaviors in an undergraduate mathematics class as we would see in an elementary mathematics class. There was no a priori expectation that all K-12 teachers and college instructors would be meeting the same criteria. Further, we knew that when observing college lecture classes, the kinds of student-teacher interactions afforded by that setting would be significantly different from what is possible and desirable in a recitation section.

Additionally, unlike several other observation protocols (for example, MacIsaac and Falconer) that rate the teaching experience and then total the numerical ratings, the O-TOP is meant to be a descriptive tool [27]. We designed the O-TOP to generate a profile of what was happening across instructional settings rather than to assign a score to a particular lesson. In other words, we treat the ratings on the O-TOP items as categorical rather than interval data. This differs from the way the R-TOP has been used in recent reports [13]. We see the O-TOP results in combination with interviews and field notes from classroom visits as a prelude to theory building. Our understanding of how the items of the O-TOP performed in classroom observations had to be informed by the class context as well as the teacher’s perspective.

Implications for Future Research

A great deal of interest in the observation instrument has developed from various sources suggesting applications of the O-TOP tool beyond its original intent in the Outcomes Research Study. Several school of education university supervisors have reported using the instrument to provide feedback to their student teachers while observing in the field. Higher education faculty members have adopted the O-TOP as the protocol for implementing peer reviews within their departments. New teachers have indicated that the O-TOP provides a user-friendly checklist of good practices to consider during lesson planning, while experienced teachers have utilized the observation protocol as a component of their ongoing professional development. Some teachers have asked their principals to use the O-TOP during the annual evaluation process, especially principals who are unfamiliar with standards-based teaching in mathematics and science. Even
college faculty and teachers outside of mathematics and science education have commented on the O-TOP’s ability to describe effective teaching in their own content areas. For each of these applications, a preference has been expressed for the non-numerical version of the O-TOP, in which the “scoring” is recorded on a continuum rather than on a “0 to 4” scale (see Appendix C).

The program of research stimulated by OCEPT that generated the instruments described here asks the broad question, “How does the whole of the college experience develop teacher knowledge and skill?” Specifically, we are interested in the higher education experiences that influence K-12 teaching in mathematics and science. It was a new concept for many faculty in mathematics and science departments to think of themselves as part of the teacher education process. Another broad implication from our work is the need to address the question, “How can we design tools that help higher education faculty evaluate their curriculum and instruction to better meet the needs of future teachers (as well as their non-education students)?” When considering the needs of elementary teachers, as compared to high school teachers, this implication has an even greater impact. Elementary teachers are an important subset of a much larger population of students taking content coursework who are non-majors. Therefore, investigations that lead to an improvement in the academic experience of prospective elementary teachers will also improve the experience of the majority of all other students taking those mathematics and science content courses.

Discussions among science, mathematics, engineering, and technology (SMET) faculty often focus on the expectation that teachers need additional subject matter courses, despite the fact that the courses available to non-majors are often taught in lecture-dominated formats where content is unconnected to familiar situations. Meetings with SMET faculty often confront the fact that about half of prospective elementary teachers take fewer than six semesters of science and almost half of those will not take any physics or chemistry at all. The mathematics faculty are only mildly appeased by the fact that virtually all students (96%) take a “mathematics for elementary teachers” sequence, but most will take no additional college mathematics courses. Education faculty are aware that only about half of future elementary teachers will meet NSTA’s course background standards [28].

The O-TOP instrument is the kind of tool that can provide a common language for higher education faculties to use when discussing the structure and delivery of courses for teachers. Increasing faculty interest in new approaches to upgrading the content knowledge of future and
practicing teachers holds the promise of promoting collaborative research efforts between SMET and education faculties. The O-TOP tool is a starting point for research in designing data-based feedback to professors and graduate teaching assistants for the improvement of teaching. It provides a positive response to glaring shortcomings that have been identified in mathematics and science curriculum and instruction [4].

One outcome from the OCEPT project has been the development of a set of indicators to assist faculty in designing and evaluating their course revisions with respect to their value for prospective teachers. The Indicators for Selection of Mathematics and Science Content Courses Appropriate for Future Teachers (see Appendix D) were evaluated by SMET and education faculties of various institutions and organizations before they were employed as a self-evaluation tool for course modifications supported by OCEPT. These broad recommendations are consistent with recommendations for changes in science education at the collegiate level [29].

The demands of teaching for higher order outcomes, such as promoting understanding of problem solving or scientific inquiry, is resulting in an increased awareness of teachers’ interactions with students. The O-TOP instrument provides a starting point for K-12 teacher reflection on instructional practices. As higher education faculties become more aware of the impact of student-teacher interactions on student outcomes, they too have cause for reflection on their instructional practices. In a recent analysis of her own teaching, for example, Parsons outlined the implicit emphasis on reflection in teaching [30]. She cites a large body of research dealing with: a) defining reflection; b) developing curriculum to facilitate reflection; and, c) examining the developmental process associated with reflection. She notes that the literature is rich in K-12 in-service and pre-service teaching, but sparse concerning reflection in college and university teaching. Not only can O-TOP provide a valuable tool for feedback that will support reflection for college and K-12 teachers, it can also be a starting point for a common dialogue on teaching that spans K-16 instruction.

Summary

Our research team has developed instruments for classroom observations and interviews which have a variety of applications at multiple levels of instruction. Through the use of these protocols, we hope to report on the relationship between beginning teachers’ instructional strategies and the courses/instruction they experienced as an undergraduate. These instruments
are appropriate for encouraging reflection and self-evaluation among K-12 teachers and college-level instructors alike.

References


THE DEVELOPMENT OF INSTRUMENTS FOR ASSESSMENT ...


This instrument is to be completed following observation of classroom instruction. Prior to instruction, the observer will review planning for the lesson with the instructor. During the lesson, the observer will write an anecdotal narrative describing the lesson and then complete this instrument. Each of the ten items should be rated "globally"; the descriptors are possible indicators, not a required "check-off" list.

### 1. This lesson encouraged students to seek and value various modes of investigation or problem solving.

(Focus: Habits of Mind)

<table>
<thead>
<tr>
<th>Not Characterizes</th>
<th>Observed</th>
<th>Lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4</td>
<td></td>
</tr>
</tbody>
</table>

**Teacher/Instructor:**
- Presented open-ended questions
- Encouraged discussion of alternative explanations
- Presented inquiry opportunities for students
- Provided alternative learning strategies

**Students:**
- Discussed problem-solving strategies
- Posed questions and relevant means for investigating
- Shared ideas about investigations

### 2. Teacher encouraged students to be reflective about their learning.

(Focus: Metacognition – students’ thinking about their own thinking)

<table>
<thead>
<tr>
<th>Not Characterizes</th>
<th>Observed</th>
<th>Lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4</td>
<td></td>
</tr>
</tbody>
</table>

**Teacher/Instructor:**
- Encouraged students to explain their understanding of concepts
- Encouraged students to explain in own words both what and how they learned
- Routinely asked for student input and questions

**Students:**
- Discussed what they understood from the class and how they learned it
- Identified anything unclear to them
- Reflected on and evaluated their own progress toward understanding

### 3. Interactions reflected collaborative working relationships and productive discourse among students and between teacher/instructor and students.

(Focus: Student discourse and collaboration)

<table>
<thead>
<tr>
<th>Not Characterizes</th>
<th>Observed</th>
<th>Lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4</td>
<td></td>
</tr>
</tbody>
</table>

**Teacher/Instructor:**
- Organized students for group work
- Interacted with small groups
- Provided clear outcomes for group

**Students:**
- Worked collaboratively or cooperatively to accomplish work relevant to task
- Exchanged ideas related to lesson with peers and teacher
4. Intellectual rigor, constructive criticism, and the challenging of ideas were valued.  
(Focus: Rigorously challenged ideas)

<table>
<thead>
<tr>
<th>Teacher/Instructor:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encouraged input and challenged students’ ideas</td>
</tr>
<tr>
<td>Was non-judgmental of student opinions</td>
</tr>
<tr>
<td>Solicited alternative explanations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Students:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provided evidence-based arguments</td>
</tr>
<tr>
<td>Listened critically to others’ explanations</td>
</tr>
<tr>
<td>Discussed/Challenged others’ explanations</td>
</tr>
</tbody>
</table>

5. The instructional strategies and activities probed students’ existing knowledge and preconceptions.  
(Focus: Student preconceptions and misconceptions)

<table>
<thead>
<tr>
<th>Teacher/Instructor:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-assessed students for their thinking and knowledge</td>
</tr>
<tr>
<td>Helped students confront and/or build on their ideas</td>
</tr>
<tr>
<td>Refocused lesson based on student ideas to meet needs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Students:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expessed ideas even when incorrect or different from the ideas of other students</td>
</tr>
<tr>
<td>Responded to the ideas of other students</td>
</tr>
</tbody>
</table>

6. The lesson promoted strongly coherent conceptual understanding in the context of clear learning goals.  
(Focus: Conceptual thinking)

<table>
<thead>
<tr>
<th>Teacher/Instructor:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asked higher level questions</td>
</tr>
<tr>
<td>Encouraged students to extend concepts and skills</td>
</tr>
<tr>
<td>Related integral ideas to broader concepts</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Students:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asked and answered higher level questions</td>
</tr>
<tr>
<td>Related subordinate ideas to broader concept</td>
</tr>
</tbody>
</table>

7. Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.  
(Focus: Divergent thinking)

<table>
<thead>
<tr>
<th>Teacher/Instructor:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accepted multiple responses to problem-solving situations</td>
</tr>
<tr>
<td>Provided example evidence for student interpretation</td>
</tr>
<tr>
<td>Encouraged students to challenge the text as well as each other</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Students:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generated conjectures and alternate interpretations</td>
</tr>
<tr>
<td>Critiqued alternate solution strategies of teacher and peers</td>
</tr>
</tbody>
</table>
8. **Appropriate connections were made between content and other curricular areas.**  
(Focus: Interdisciplinary connections)  

<table>
<thead>
<tr>
<th>Teacher/Instructor:</th>
<th>Students:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated content with other curricular areas</td>
<td>Made connections with other content areas</td>
</tr>
<tr>
<td>Applied content to real-world situations</td>
<td>Made connections between content and personal life</td>
</tr>
</tbody>
</table>

9. **The teacher/instructor had a solid grasp of the subject matter content and how to teach it.**  
(Focus: Pedagogical content knowledge)  

<table>
<thead>
<tr>
<th>Teacher/Instructor:</th>
<th>Students:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presented information that was accurate and appropriate to student cognitive level</td>
<td>Responded to instruction with ideas relevant to target content</td>
</tr>
<tr>
<td>Selected strategies that made content understandable to students</td>
<td>Appeared to be engaged with lesson content</td>
</tr>
<tr>
<td>Was able to field student questions in a way that encouraged more questions</td>
<td></td>
</tr>
<tr>
<td>Recognized students' ideas even when vaguely articulated</td>
<td></td>
</tr>
</tbody>
</table>

10. **The teacher/instructor used a variety of means to represent concepts.**  
(Focus: Multiple representations of concepts)  

<table>
<thead>
<tr>
<th>Teacher/Instructor:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used multiple methods, strategies and teaching styles to explain a concept</td>
</tr>
<tr>
<td>Used various materials to foster student understanding (models, drawings, graphs, concrete materials, manipulatives, etc.)</td>
</tr>
</tbody>
</table>
Appendix B

Outcomes Research Study
OCEPT Teacher Interview Protocol (O-TIP)

Student thinking:
How does your instruction support development of thinking skills?

1. [Habits of Mind] This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.

2. [Metacognition] Teacher encouraged students to be reflective about their learning.

5. [Students preconceptions and misconceptions] The instructional strategies and activities probed students’ existing knowledge and preconceptions.

7. [Divergent Thinking] Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.

Social skills & collaboration:
How does your instruction support development of social and collaborative skills?

3. [Students discourse and collaboration] Interactions reflected collaborative working relationships among students (e.g., students worked together, talked with each other about the lesson) and between teacher/instructor and students.

Content:
How does your instruction support development of content understanding?

4. [Rigorously challenged ideas] Intellectual rigor, constructive criticism, and the challenging of ideas were valued.

6. [Conceptual thinking] The lesson promoted strongly coherent conceptual understanding in the context of clear learning goals.

8. [Interdisciplinary connections] Appropriate connections were made to other areas of mathematics/science, to other disciplines, and/or to real-world contexts, social issues, and global concerns.

9. [Pedagogical Content Knowledge] The teacher/instructor had a solid grasp of the subject matter content and how to teach it.
Instruction:
Besides student thinking skills, content understanding, and social/collaborative skills, what else guides your selection of instructional approaches?

10. [Multiple representations of concepts] The teacher/instructor used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.

Additional Questions:
Student teachers/Early Career Teachers: In your undergraduate classes, what strategies were modeled that you now use? How did your undergraduate preparation contribute to your instructional design and practice? (If students don’t name OCEPT Faculty Fellows, prod for them specifically.)

Faculty Fellows: Describe your level of participation in OCEPT activities. Has your affiliation with OCEPT contributed to your instructional design and practice? If so, how?
# OCEPT-Teacher Observation Protocol (O-TOP) Outcomes Research Study – 2002

This instrument is to be completed following observation of classroom instruction. Prior to instruction, the observer will review planning for the lesson with the instructor. During the lesson, the observer will write an anecdotal narrative describing the lesson and then complete this instrument. Each of the ten items should be rated ‘globally’; the descriptors are possible indicators, not a required ‘check-off’ list.

## 1. This lesson encouraged students to seek and value various modes of investigation or problem solving.
*(Focus: Habits of Mind)*

<table>
<thead>
<tr>
<th>Teacher/Instructor:</th>
<th>Students:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presented open-ended questions</td>
<td>Discussed problem-solving strategies</td>
</tr>
<tr>
<td>Encouraged discussion of alternative explanations</td>
<td>Posed questions and relevant means for investigating</td>
</tr>
<tr>
<td>Presented inquiry opportunities for students</td>
<td>Shared ideas about investigations</td>
</tr>
<tr>
<td>Provided alternative learning strategies</td>
<td></td>
</tr>
</tbody>
</table>

## 2. Teacher encouraged students to be reflective about their learning.
*(Focus: Metacognition – students’ thinking about their own thinking)*

<table>
<thead>
<tr>
<th>Teacher/Instructor:</th>
<th>Students:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encouraged students to explain their understanding of concepts</td>
<td>Discussed what they understood from the class and how they learned</td>
</tr>
<tr>
<td>Encouraged students to explain in own words both what and how they learned</td>
<td>Identified anything unclear to them</td>
</tr>
<tr>
<td>Routinely asked for student input and questions</td>
<td>Reflected on and evaluated their own progress toward understanding</td>
</tr>
</tbody>
</table>

## 3. Interactions reflected collaborative working relationships and productive discourse among students and between teacher/instructor and students.
*(Focus: Student discourse and collaboration)*

<table>
<thead>
<tr>
<th>Teacher/Instructor:</th>
<th>Students:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organized students for group work</td>
<td>Worked collaboratively or cooperatively to accomplish work relevant to task</td>
</tr>
<tr>
<td>Interacted with small groups</td>
<td>Exchanged ideas related to lesson with peers and teacher</td>
</tr>
<tr>
<td>Provided clear outcomes for group</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Not Observed</th>
<th>Characterizes Lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. Intellectual rigor, constructive criticism, and the challenging of ideas were valued.
(Focus: Rigorously challenged ideas)

Teacher/Instructor:
- Encouraged input and challenged students’ ideas
- Was non-judgmental of student opinions
- Solicited alternative explanations

Students:
- Provided evidence-based arguments
- Listened critically to others’ explanations
- Discussed/Challenged others’ explanations

5. The instructional strategies and activities probed students’ existing knowledge and preconceptions.
(Focus: Student preconceptions and misconceptions)

Teacher/Instructor:
- Preassessed students for their thinking
- Helped students confront and/or build on their ideas
- Refocused lesson based on student ideas to meet needs

Students:
- Expressed ideas even when incorrect or different from the ideas of other students
- Responded to the ideas of other students

6. The lesson promoted strongly coherent conceptual understanding in the context of clear learning goals.
(Focus: Conceptual thinking)

Teacher/Instructor:
- Asked higher level questions
- Encouraged students to extend concepts and skills
- Related integral ideas to broader concepts

Students:
- Asked higher level questions
- Related subordinate ideas to broader concept
7. Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence. (Focus: Divergent thinking)

<table>
<thead>
<tr>
<th>Teacher/Instructor</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accepted multiple responses to problem-solving situation</td>
<td>Generated conjectures and alternate interpretations</td>
</tr>
<tr>
<td>Provided example evidence for student interpretation</td>
<td>Critiqued alternate solution strategies of teacher and peers</td>
</tr>
<tr>
<td>Encouraged students to challenge the text as well as each other</td>
<td></td>
</tr>
</tbody>
</table>

8. Appropriate connections were made between content and other curricular areas. (Focus: Interdisciplinary connections)

<table>
<thead>
<tr>
<th>Teacher/Instructor</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated content with other curricular areas</td>
<td>Made connections with other content areas</td>
</tr>
<tr>
<td>Applied content to real-world situations</td>
<td>Made connections between content and personal life</td>
</tr>
</tbody>
</table>

9. The teacher/instructor had a solid grasp of the subject matter content and how to teach it. (Focus: Pedagogical content knowledge)

<table>
<thead>
<tr>
<th>Teacher/Instructor</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information presented was accurate and appropriate to student cognitive level</td>
<td>Responded to instruction with ideas relevant to target content</td>
</tr>
<tr>
<td>Selected strategies that made content understandable to students</td>
<td>Appeared to be engaged with lesson content</td>
</tr>
<tr>
<td>Was able to field student questions in a way that encouraged more questions</td>
<td></td>
</tr>
<tr>
<td>Recognized students’ ideas even when vaguely articulated</td>
<td></td>
</tr>
</tbody>
</table>
10. The teacher/instructor used a variety of means to represent concepts.
(Focus: Multiple representations of concepts)

<table>
<thead>
<tr>
<th>Not Observed</th>
<th>Characterizes Lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher/Instructor:</td>
<td></td>
</tr>
<tr>
<td>Used multiple methods, strategies and teaching styles to explain a concept</td>
<td></td>
</tr>
<tr>
<td>Used various materials to foster student understanding (models, drawings, graphs, concrete materials, manipulatives, etc.)</td>
<td></td>
</tr>
</tbody>
</table>

Teacher/Instructor:
Characteristics of the Course:

- National and/or state Standards are incorporated in course design. (National Council of Teachers of Mathematics Standards, National Science Education Standards, AAAS Benchmarks, and/or Oregon Content Standards)

- An integral part of the course is student engagement in activities (laboratory experiences use of manipulatives).²

- Opportunities are provided for students to learn about and engage in inquiry.²

- Instruction is designed to encourage conceptual development through the use of a variety of methods, activities, resources and educational technologies.²

- Course content integrates relevant issues of science, mathematics and society.

- Lecture portion of course is closely coordinated with laboratory, discussion and/or recitation sections.

- Course grades are based on a variety of evaluation methods including authentic assessment (such as the Oregon CIM scoring guides – Mathematics Problem-Solving or Scientific Inquiry Scoring Guides).

- Opportunities exist for connections to the K-12 classroom environment.

Characteristics of the Instructor:

- Engages students interactively in instruction.
- Takes student prior knowledge into account when planning for instruction.
- Promotes a sense that all students can succeed in the course.
- Models thinking and study skills important for succeeding in the course.
- Emphasizes the value of science, mathematics and technology for all people of all ages.
- Models an enthusiasm for an inquiry orientation to learning.
- Is familiar with K-12 classrooms and teachers.

---

¹ Developed by participants in the Oregon Collaborative for Excellence in the Preparation of Teachers National Science Foundation grant project, 1999

² OCEPT recommends that all educators study and utilize current research-based instructional methods such as those described by Rutherford and Ahlgren in Ch. 13 of Science for All Americans and in How People Learn (NRC).
A DESCRIPTIVE COMPARISON OF ONE UNIVERSITY INSTRUCTOR’S INSTRUCTION DURING PRE-SERVICE MATHEMATICS COURSES AND THE SUBSEQUENT MATHEMATICS AND SCIENCE INSTRUCTION OF THREE OF HIS STUDENTS DURING THEIR STUDENT TEACHING EXPERIENCE

S. BLAIR
Portland State University
Portland, OR 97207
sblair65@yahoo.com

Introduction

Current recommendations for mathematics education cite the need for instruction which is more student-centered and inquiry-based [1]. One aspect of teacher preparation that should help prepare potential teachers to meet these recommendations is their experience in pre-service mathematics courses [2]. As explained by two respected mathematics educators,

Pre-service teachers need to have ideas about how to structure classrooms so that they can help their students develop understanding. Since experience is a powerful teacher, it makes sense that these preservice teachers need to learn by experiencing mathematical ways of thinking, reasoning, analyzing, abstracting, generalizing, proving, and applying in environments that model good instruction [3].

The above statement presents a theoretical argument. Such considerations, however, do not provide information concerning how such experiences will compare with the pre-service teachers’ subsequent instruction as they begin teaching themselves. One way to do this is to compare descriptions of the instruction students received in their pre-service mathematics courses to that of their own mathematics instruction as they become teachers. This paper involves a qualitative study of one university instructor who teaches mathematics courses for pre-service elementary teachers and three of his students during their student teaching. The study involved describing each participant’s instruction according to ten characteristics of inquiry-based teaching. Common aspects of the instruction of the university instructor and the student teachers were then identified. The most prominent characteristics identified in this study involved the use of multiple representations, including concrete manipulatives, and the use of student collaboration, especially within small groups.
Methodology

The current study took place as part of the Outcomes Research Study of the Oregon Collaborative for the Excellence in the Preparation of Teachers (OCEPT) project funded by a grant from the National Science Foundation. This grant supported a variety of initiatives involving science and mathematics faculty at universities throughout the state over a five-year period. Among these initiatives was an elementary/middle school mathematics strand which focused on helping faculty members improve their instruction in the courses taken by pre-service and in-service teachers. In particular, the project provided a network of instructors who regularly shared methods and materials for making their instruction more student-centered and inquiry-based. At Portland State University (PSU), this included Math 211: Foundations of Elementary Mathematics I and Math 212: Foundations of Elementary Mathematics II. These two mathematics courses are offered by the mathematics department, and are prerequisites for PSU’s Graduate Teacher Education Program in elementary education.

One goal of the Outcomes Research Study was to provide descriptions of the instruction of faculty members involved in the project, and also of some of their students as they became elementary teachers. Case studies of each participant were conducted to provide a qualitative description of their instruction during the 2001-2002 school year. Each participant was observed by the researcher three times during the 2001-2002 school year. During the observations, the researcher took copious field notes. Immediately after each observation, the researcher reviewed his notes and completed an OCEPT-Teacher Observation Protocol (O-TOP) for the observation [4]. After all three observations, the researcher interviewed each participant using the OCEPT-Teacher Interview Protocol (O-TIP)[5]. These interviews were audio taped and later transcribed. From the observation field notes, O-TOP descriptions, and O-TIP transcript a case study composite of each participant was written.

The O-TOP instrument was developed in 2001 by three researchers involved in the study, L. Flick, P. Morrell, and C. Wainwright, drawing on instruments from similar projects and on the body of research involving effective science and mathematics instruction [6-8]. The instrument focused on ten characteristics of O-TOP inquiry-based instruction:
1) habits of mind  
2) metacognition  
3) student collaboration  
4) rigorously challenged ideas  
5) student preconceptions and misconceptions  
6) conceptual thinking  
7) divergent thinking  
8) interdisciplinary connections  
9) pedagogical content knowledge  
10) use of multiple representations

Several possible indicators corresponding to observable actions by both the teacher and the students were described for each of these categories [4]. For example, with regard to student collaboration, the indicators are:

Teacher/Instructor:
- Organized students for group work
- Interacted with small groups
- Provided clear outcomes for the group

Students:
- Worked collaboratively or cooperatively to accomplish work relevant to task
- Exchanged ideas related to lesson with peers and teacher

The degree to which each characteristic was observed during the participant’s instruction was gauged globally for each lesson as either N/O (not observed) or from 1 to 4 where “4” means it was highly characteristic of the lesson. The intent of this instrument is not to evaluate the lesson, but rather to provide one part of an overall description that focused on a number of specific characteristics identified with effective inquiry-based instruction. However, since the instrument does include a quantitative aspect, attempts were made to establish inter-rater reliability on the instrument. All of the observers for the OCEPT Outcomes Research Study (four university professors and three graduate students) were trained in the use of the instrument, and a number of initial observations were conducted by multiple observers and then reviewed to evaluate the consistency of the O-TOP ratings. In particular, the researcher at PSU participated in five different joint observations with all but two of the other observers. The few inconsistencies in the different observers’ ratings from the joint observations were discussed until consensus was reached. This process established a shared sense of how to use the instrument which minimized the differences of the observers. Since the intent of the instrument was as an aid in the description
of the participant and not as a source of data for further quantitative analyses, more formal measures of reliability were deemed unnecessary by the project coordinators.

The interviews were conducted to provide the participants’ perspective on their instructional methods. The interview protocol included a number of open-ended questions to elicit the participants’ instructional strategies involving the development of thinking skills, social and collaborative skills, as well as content understanding [5]. Their responses provided details concerning not only their preferred instructional strategies, but also of (perceived or real) impediments within the context of student teaching. The student teachers were also asked to comment on their experiences in their undergraduate mathematics and science courses. This provided them with an opportunity to describe their experiences as students in faculty member’s classes and how it has or has not affected their instruction as they become teachers themselves.

The researchers realized that a number of intervening factors and limitations inherent in the study make causal comparisons between faculty members and student teachers untenable. For example, the student teachers’ experiences in their methods courses, as well as the constraints placed upon them by their supervising classroom teachers, contribute to their instruction. Also, due to limitations in the study, it was not possible to observe the university instructor at the time when the participating student teachers were in his/her classes. Therefore, the case studies were intended to provide descriptions from which possible comparisons could be identified rather than causally established. As such, this research follows the tradition of qualitative methods in educational research in that it is meant to be suggestive rather than definitive [9].

One PSU mathematics faculty member, “Scott,” together with three of his former students, “Toni,” “Carol,” and “Wendy,” agreed to participate in the study (note that the names used here are pseudonyms). All three student teachers had taken Math 211, Math 212, or both from Scott during the time he was actively involved in the OCEPT project. Julie and Wendy were student teaching in a first grade classroom and Toni was in a fourth grade classroom. Each of the participants were observed by the researcher three times during the 2001-2002 school year, and then interviewed according to the methodology described above. The following composites of each participant were then written from these data sources.
Description of Scores for Each Observation—Scott

Table 1

Composite for Scott, PSU Mathematics Faculty

<table>
<thead>
<tr>
<th>1st Ob</th>
<th>2nd Ob</th>
<th>3rd Ob</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTOP</td>
<td>ITEM</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Observation 1 — Scott had students work on four word problems which involved different uses for fractions, i.e. part/whole, quotient, and ratio. Students first worked individually, then in their small groups. Each group then made a poster illustrating their solutions to share with the whole class (higher on items 1, 3, 7, and 10). While they worked in groups, Scott moved among the groups listening and asking probing questions (high on items 2, 4, 5, and 9). After a break, Scott led a discussion in which each group explained their solutions using their poster. Scott asked follow-up questions, mostly to draw out ideas and to get the students to focus on the unit (items 1, 2, 4, 6, 7, and 9). Also, as misconceptions arose, such as confusing division by \( \frac{1}{2} \) with multiplying by \( \frac{1}{2} \), Scott used probing questions to get students to discuss it without “telling” them the “correct” way to think about it (items 1, 5, 6, and 9).

Observation 2 — Scott started with a whole group discussion of a word problem. He drew a picture and discussed several different solutions by writing them on the board and then by soliciting student ideas (high on items 1, 2, 4, 5, 7, and 9). He then asked students to explain why dividing by a fraction is the same as multiplying by its reciprocal. One student volunteered, and explained with help from both Scott and the other students (items 2, 3, 4, and 5). Scott then presented a visual (area) model for multiplying fractions (items 9 and 10).

Scott then started a new topic, decimals, by having them represent different amounts using base ten pieces in their small groups (items 1, 3, and 10). During this activity, Scott moved from group to group, listening and asking questions. He then led a whole group discussion building on the visual model, and used a second visual model (decimal grids) to explain the connection between fractions and decimals. Also, by having them represent \( \frac{1}{3} \) on decimal grids, he discussed repeating decimals. He then asked if \( \frac{1}{7} \) is a repeating decimal (most were unsure).
So he had them divide 3 by 7 using long division and discussed the connection (items 1, 5, 6, and 7).

**Observation 3** — Scott’s first activity involved having students work on a number of word problems involving percents (item 8). They started working individually, and then began sharing ideas within their small groups. In particular, many students were sharing alternate solutions with each other (items 1, 3, 4, and 7). He then had the students discuss the problems with the whole group, stressing multiple solutions (items 2, 4, and 7).

Scott then discussed a more complicated problem involving a discount with the whole group, soliciting and comparing different strategies. He then showed them a particular visual model (percent grids) to represent the problem, and had several students explain their strategy using the model (strong on items 2, 9, and 10). He then asked them to revisit the earlier problems and model each using percent grids, which they did in their small groups (items 3, 9, and 10). After this, he gave them some more complicated problems, such as “A shirt is marked down at a 20% discount, and then by an additional 30% off the already discounted price. What is the total percent discount?” After the students worked on them in small groups, Scott had several students present their solutions to the whole class while he facilitated with probing questions (high on all items).

**Patterns and Interpretations**

Several things are common to all three observations. The activities were centered on having students work on problems in context, first individually and then in small groups (items 1 and 3). During this time, Scott listened to the students and helped by asking probing questions and by asking them to explain their thinking.

Most students seemed comfortable working on the problems in their groups and sharing their ideas (items 2, 4, 5, and 7). Also, Scott always had several students explain their solutions to the whole group, either using posters or at the overhead. During this time Scott was nonjudgmental, but pointed out important aspects and asked questions. Scott noted in the interview that the “procedure of talking with other people about how they thought about the problem” is the main way he gets students to develop thinking skills. He also noted that collaboration occurs not only within the small groups, but also when students share at the overhead with the whole group.
Another common aspect was the presentation of visual models and manipulatives as one means to represent problems. Interestingly, these models were not presented as “the way,” but as one of several useful ways. In the interview, Scott noted that he focuses on developing a solid conceptual understanding by helping students “get a concrete picture in their head of a model” (items 9 and 10).

**Influence of OCEPT**

Scott noted that his involvement in OCEPT has given him a better awareness of the need for good math teachers and his role in mentoring his students, especially students from underrepresented groups. He also noted the usefulness of getting to know other university faculty around the state who are working on the same kinds of issues.

**Additional Comments**

After some probing during the interview, Scott also discussed the importance of having students reflect in his classes. Furthermore, he noted that he doesn’t make as many connections to other areas (item 8) as he would like, though his use of problems in context helps to some extent.

**Description of Scores for Each Observation—Toni**

<table>
<thead>
<tr>
<th>OTOP ITEM</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Ob</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2nd Ob</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3rd Ob</td>
<td>3</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Observation 1 — Items 3 and 10 were higher as she had them work in small groups at “stations” with a variety of manipulatives. The tasks were somewhat open-ended (item 1) and during the lesson she interacted with each group, asking probing questions and helping them when they expressed confusion (items 5 and 9). The remaining items (2, 4, 6, 7, and 8) were low as the tasks (modeling addition equations with manipulatives and then recording them on paper) were mainly repetitive and placed a low cognitive demand on most of the students.
Observation 2 — Item 10 was high as the activity had students create a visual (stair-step) diagram showing the different ways to sum to ten (1+9, 2+8, etc.). Also, even though each student made his or her own diagram, there was lots of interaction between students (item 3). The task, however, was essentially the same as previous ones with smaller sums like six, and therefore was routine for most of the students. Indeed, for many students, the task was essentially one of coloring and minimally connected to mathematics (low on items 1,4,5,6,7,8).

Observation 3 — The first half of the lesson included a number of different activities using manipulatives with a partner (higher on items 1, 3, and 10). During this time, Toni interacted with most of the groups, probing them with directed questions and helping them write equations correctly (items 5 and 9). The second part of the lesson was a whole class game during which they had to answer simple sums (e.g., 6+4) (items 1 and 5). The lesson was reinforcement of previously learned concepts and low on items 2,4,6,7, and 8.

Patterns and Interpretations

A theme of Toni’s instruction involves math “stations” where students work on activities in small groups using a variety of manipulatives placed at different spots throughout the room. This type of instruction helps to keep the students actively engaged (item 9).

Toni consistently uses a variety of concrete manipulatives (item 10), staying away from worksheets. In the interview she stated, “I think that they definitely go beyond what would be on a worksheet. They figure out how to solve problems on their own. They are able to say, if they need to group 4 + 3, that they can take 4 dinosaurs and then count 3 more and then add.”

Another strong point of her instruction is her use of small groups and pairs (item 3). She notes in the interview that with four or five students at a math station, “sometimes they can work by themselves in that group or other times they will have to develop a pattern with all the members of the group.” She generally rotates between groups during the small group activities, asking probing questions and helping students (item 5), which also allows students to discuss their thinking (item 1).

On the other hand, the three lessons observed were all focused on reinforcing concepts the students had previously encountered without much reflection, conjecturing, or connections to other concepts or broader situations. Hence, she scored consistently low on several items, namely
2, 4, 6, 7, and 8. During the interview, she stated that she valued using contextualized story problems in order to support content understanding, but this was not seen during the observations.

**Influence of OCEPT**

Toni stated that the most influential math class she took was the one taught at PSU by Scott. She noted that her previous experiences with math had been mostly memorization and routine worksheets. “I think that when I took Scott’s class it was like the first time that the whole idea of like base 10 made sense to me. He presented it by showing, we were using manipulatives, and all of a sudden it just clicked.” She then contrasted this approach to her earlier experience, “I think it is a good way to present it to kids, because like I said, I was good at math, but never really had it presented to me that way. It was like I never thought about it until I took this class.” She emphasized the link to manipulatives when teaching place value by stating, “I think it is important that they understand what they are actually adding.”

**Additional Comments**

Toni’s use of small groups and manipulatives, while keeping the students engaged, also contributed to a number of classroom management incidents throughout the observations. At times, the students would argue with their partners, and some played with the manipulatives rather than using them in the intended way. During the lessons, she spent extra time with a few of the most unruly students, and was able to keep most of the students on task most of the time. She noted in the interview that a goal of her instruction is to build social skills. She states “our class in particular seems to have a problem working together. So we try to do it often.”

**Description of Scores for Each Observation—Carol**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>OTOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Ob</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>2nd Ob</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>3rd Ob</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3

Composite of Carol, PSU Student Teacher
Observation 1 — For a science lesson on electricity (insulators and conductors), Carol gave groups of students a “tester” circuit (battery and wires hooked to a motor in a kit) and a bag of different materials (wood, nail, foil, cardboard, etc.). In these groups, they predicted which materials would complete the circuit, and then tested their predictions (high on items 1, 3, 5, and 10, somewhat on items 4, 6, and 7). Some groups made other discoveries, such as that using two sheets of foil made the motor run faster than using one (strong item 1). After their investigation, Carol asked the whole group what was similar about the conductors (they responded that they were metal). She then had them compare this to a previous activity with magnets (item 8). Then each group went on a “conductor hunt” where they tested a variety of objects in the room (strong on items 3, 9, and 10). During this time, Carol circulated among the room, asking them about their results and suggesting other objects to predict and check (such as the window). After the search, she discussed their results in the whole group, and then noted the similarity/difference between being a conductor and being attracted to a magnet. She had each student name a conductor (item 7) and then read to them about insulated power lines (item 8).

Observation 2 — With math, Carol started with a “problem of the day,” to form an “H” on their geoboard with a perimeter of 24 units and then find its area (item 10). Carol roamed around as they worked individually and as the students finished, they wrote their names on an “I got it list” at the board. After ten minutes, Carol had several different students explain their solutions, even one girl who had measured the wrong figure (items 5, 7, and 9). She then returned a test they had taken the previous day and reviewed each question. She did this by using questions and by drawing sketches. She also had them review \( \frac{1}{4} + \frac{1}{4} \) using their rulers (high on items 2, 8, and 10). She also reviewed the difference between degrees F and C by asking questions related to temperature; e.g., “Would it be cold enough to snow if it were 10 degrees C outside?” Also, on some questions she had several students explain their different solutions to the whole class (items 2, 5, and 7).

Observation 3 — For the math lesson, Carol started with a problem of the day: “Three kids’ ages add to 47. What will be their combined ages in ten years?” As students finished, they wrote their names on the board and then became helpers for the remaining students. Carol noticed that the students had solved the problem in many ways, so she had several of them explain their reasoning (items 1, 5, and 7). She also showed them a different way (the way presented in the answer guide), and discussed a common mistake (item 9). She then had a race to review long division of
whole numbers and decimals. She had the winner explain the solution, and then let them chose a “crazy hat” to wear (items 9 and 10).

For the next activity, she passed out different amounts of unifix cubes to each student, and asked the students to find the average amount in their small groups (items 3 and 10). Carol roamed from group to group checking them and helping them use the algorithm while emphasizing that the sum is not the average. One group split up their cubes evenly, something Carol hadn’t expected, and she didn’t draw out the link between this and the algorithm. She did, however, have the students discuss some of the shortcuts they used to determine the sum by multiplying when an amount was repeated (items 1, 4, and 7).

Patterns and Interpretations

Carol’s use of a “problem of the day” in her math instruction gave students the opportunity to approach a significant problem from a variety of ways. This, combined with the subsequent discussion of different solutions, is reflected in higher scores on items 1, 5, 9, and especially 7 (divergent thinking). She noted in the interview that she liked this method of math instruction because it helps them “work on all kinds of different problem solving processes.” This approach of discussing multiple solutions was even used during the review of a test, and it really strengthened student engagement. She also consistently used concrete materials, such as geoboards and unifix cubes, to present problems and to help explain solutions (item 10).

Her science instruction, though only observed once, scored well on most items, though it didn’t involve the level of student sharing as in math. Her science lesson, however, presented inquiry-based activities (item 1), were more cooperative (item 3), and more connected to other areas than her math lessons. In both her math and science lessons, she responded well to student ideas and questions and kept the students actively engaged; as she stated in the interview, “It seems like when we just do stuff directly out of the text, it is boring to them” (high on item 9).

Influence of OCEPT

Carol made several references to the positive influence of taking Scott’s Math 211 class. She noted how he focused on the concepts, which helped her because “after you get old enough that that is what it is or you have memorized it, you forget how the concept is.” She liked actually using manipulatives for fractions and other concepts that are in the elementary curriculum. She
noted, “Scott’s class really helped as far as understanding the concept, working in groups.” She also noted that she did a lot of reflection in that class, which she likes to do in her own classes, such as having kids reflect on what they learned in math at the end of each week.

Additional Comments

Some of Carol’s activities, such as the review of the test in observation 2, were part of the regular teacher’s routine.

Description of Scores for Each Observation—Wendy

Table 4

<table>
<thead>
<tr>
<th>Composite of Wendy, PSU Student Teacher</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTOP</td>
</tr>
<tr>
<td>1st Ob</td>
</tr>
<tr>
<td>2nd Ob</td>
</tr>
<tr>
<td>3rd Ob</td>
</tr>
</tbody>
</table>

Observation 1 — For the math lesson, Wendy started with a whole group discussion about place value (item 5). She then distributed objects (shells, etc.) to each child along with paper cups, and the children counted the objects by making groups of ten (item 10). As they worked, Wendy checked each child, asking them questions to check their progress and to help them stay on task (item 9). Switching to science, Wendy reviewed the previous day’s activity on webbed feet (using forks and spoons to stir ketchup). Some of the students explained what happened to the whole group (items 2, 4, and 5). Wendy then discussed “adaptation” and had them think about why a frog needs to swim fast (items 4, and 8). They then saw a video on frogs (item 10). For the last activity, the children worked in groups to make a poster answering questions about one type of animal, such as mammals, fish, birds, or frogs (items 3, 5, and 10).

Observation 2 — In the whole group, the class used the calendar to find sums and differences for the current date (the fifteenth). The students offered several solutions, e.g. 95-80, 7+8, etc. (items 1, 5, and 6). They then reviewed how to write the time using a large clock set to different times (item 8). Then they worked individually on place value problems from a workbook as Wendy moved among them checking their work. As they finished, she had them work in informal groups
making stacks of unifix cubes of various multiples of ten, which kept the faster kids engaged (items 3, 9, 10).

Wendy then brought out a large piece of paper and materials to make a “wetlands mural.” She first organized the children into groups according to what they wanted to make (fish, trees, owls, etc.). They then worked together as Wendy helped (items 3, 8, and 10). As they worked, Wendy asked them probing questions, such as “What should be in the water and what should be along the shore?” discussing the theme of the mural (frog habitat), and artistic considerations (items 1, 5, 6, and 8). The questions weren’t very challenging, however, hence lower scores on items 4 and 7.

Observation 3 — Math began with them writing numbers for the groups Wendy said, such as 74: “I’m thinking of a number with four ones and seven groups of ten.” She then had them write the time for different placements of the hands on a clock (all of this was an easy review for the students). Then, she passed out a workbook assignment involving estimation and place value, and moved among the children as they worked individually. Hence, the math portion scored low on most items, particularly items 1 – 7. For science, Wendy discussed “amphibians” with them, and then showed a video of the life cycle of frogs (higher on item 10). After the video, she led a whole group discussion on the stages of a frog’s life using a poster and a puppet (items 9 and 10). She also asked them questions about their experiences with frogs; e.g., where would they go to get frog eggs? She also used new vocabulary, “metamorphosis,” to practice their reading skills (higher on item 8).

Patterns and Interpretations

In math, Wendy tends to use a variety of activities, including discussions and standard workbook problems along with counting and grouping activities using manipulatives. She also switches between different topics (e.g., between place value and time) in order to keep students engaged. When not using the workbook, she engages the children in more discussion, and allows them to discuss their ideas with each other in the whole group, as with her calendar-based activity.

For the science classes, Wendy uses a wide variety of activities: discussions, posters, videos, the mural-making project, etc. to engage kids in a common theme (all three lessons focused on amphibians). She emphasizes connections to the children’s personal life, and also uses
science terminology to connect to reading skills (generally high on items 8, and 10). Some of these activities are more open-ended and active and involve a lot of group work (e.g., poster and mural activities). Also, while watching the videos are passive, Wendy used discussions before and after them to engage students more actively. In both math and science, her strongest items are 8 and 10, while the weakest is 7.

**Influence of OCEPT**

Wendy notes in the interview that she gained “100%” of her ideas and confidence teaching math from her two classes with Scott. She states, “I would be frozen in teaching math without his preparation … they helped me tremendously … the way that I encourage them to play … and construct their own understanding.” Her PSU background in science, however, focused on physical science since she already had a background in life science. So, since she’s been teaching life science, she notes that the physical science hasn’t influenced her teaching much.

**Additional Comments**

By comparing her math and science instruction, it is clear that Wendy is more comfortable and uses more creativity in her science instruction. Her mixed use of routine workbook activities and more open-ended problems/discussions in math seem to reflect a desire to be more creative (as noted in the interview) that she has not been able to fully realize. However, the workbook she used is part of the regular teacher’s curriculum, and it appears that the regular teacher has allowed Wendy more freedom in science than in math.

**Comparisons**

The above descriptions do not give a comprehensive characterization of the four participants’ instruction. They do, however, give some details regarding instances of their instruction with regard to the ten characteristics of inquiry-based instruction. For example, all ten characteristics were generally present in Scott’s instruction. Also, while this was not the case for any of the three student teachers, several characteristics were present in their instruction as well. Furthermore, several characteristics that were emphasized in Scott’s instruction were also present in the instruction of the students.

Perhaps the strongest similarity in Scott’s instruction and that of all three student teachers is item 10, the use of multiple representations. Visual models and/or concrete manipulatives were
used in each of Scott’s lessons, and were explicitly referred to by him in the interview. All three of the student teachers also consistently used a variety of representations during their instruction. Additionally, both Carol and Toni explicitly referred in the interview to the benefit they gained by using manipulatives in Scott’s class.

Another characteristic that was consistently present in Scott’s instruction and also evident in all three student teachers was item 3, student collaboration. Nearly every activity in Scott’s lessons included some amount of small group discussion, often in combination with individual reflection and whole group discussion. Indeed, Scott noted in the interview that the “procedure of talking with other people about how they thought about the problem” is the main way he gets students to develop thinking skills. All three of the student teachers also included student collaboration in their instruction, generally by having students work in pairs or small groups. It is also interesting to note that Toni valued the use of student collaboration even though it sometimes led to classroom management problems. The possible connection between the student teachers’ use of student collaboration and their experience in Scott’s class was also highlighted when Carol noted that “Scott’s class really helped as far as understanding the concept, working in groups” during her interview.

Other characteristics of Scott’s instruction were not as consistently present in the instruction of all three student teachers. Carol’s mathematics instruction, however, contained two other important characteristics in common with Scott’s instruction, namely items 1 and 7: habits of mind and divergent thinking. Like Scott, Carol gave students non-routine problems to work on, and then had multiple students share their solutions to problems with the whole group. They also both used probing questions to help facilitate these discussions so that a variety of different solutions would be presented and compared. Carol noted in the interview that she liked this method of mathematics instruction because it helps the students to “work on all kinds of different problem solving processes.”

One reason why all three student teachers included the use of multiple representations and student collaboration may lie in the relative ease by which these aspects can be addressed. All of the classrooms contained a variety of manipulatives, and the students were generally seated in clusters of four or five desks. The other characteristics, on the other hand, may take more experience before they can be comfortably included by a beginning teacher. Another factor may be the level of students being taught by the student teachers. Both Toni and Wendy were in first
grade classrooms, which may have influenced their choice of instruction. Since Carol was in a fourth grade classroom, she may have been more comfortable using more non-routine problems and allowing multiple students to share their thinking with the whole class.

In addition to the characteristics of inquiry-based instruction, another aspect of the student teachers’ experience in Scott’s class was mentioned in their interviews. All three students mentioned that their experience in Scott’s class increased their confidence in both doing and teaching elementary mathematics. Carol made several references to the positive influence of taking Scott’s Math 211 class. In particular, she noted how he focused on the concepts, which helped her because “After you get old enough that that is what it is or you have memorized it, you forget how the concept is.” Toni contrasted his approach to her earlier experience and stated, “I think it is a good way to present it to kids, because like I said, I was good at math, but never really had it presented to me that way. It was like I never thought about it until I took this class.” His influence was particularly evident in Wendy’s interview when she said that she gained “100%” of her ideas and confidence teaching math from her two classes with Scott.

**Possible Implications**

The descriptions of the participants’ instruction in this study suggest that connections do exist between the instruction students received in their pre-service mathematics courses and the subsequent instruction they used during their student teaching experience. Hence, the need for pre-service teachers to learn by experiencing inquiry-based approaches, as exposed by Even and Lappan and reflected in the Professional Standards for Teaching Mathematics, is supported [3, 7].

All aspects of effective inquiry-based instruction, however, were not seen to be connected in this study. While all ten aspects of effective inquiry-based instruction were highly characteristic of Scott’s instruction, only the use of multiple representations and collaborative groups were consistently characteristic of Toni, Carol, and Wendy’s instruction. Other aspects, such as those involving facilitating discussions where students explain their mathematical thinking, were not highly characteristic of Toni, Carol, and Wendy’s instruction. This suggests that experiencing inquiry-based instruction in their pre-service classes may not be sufficient for enabling beginning teachers to implement all aspects in their own instruction.

One implication of this may be that pre-service teachers’ experiences during their pre-service mathematics courses only “sow the seeds” of the more difficult aspects of inquiry-based
instruction. Beginning teachers may need a longer period of classroom teaching experience and other professional development experiences before they are able to incorporate some aspects in inquiry-based instruction. Hopefully, however, by experiencing such instruction themselves during their pre-service classes, they have personally recognized the usefulness of such instruction. A three-year extension of the OCEPT project has begun and will follow a number of teachers, including Wendy, as they begin their teaching careers. This should provide more evidence regarding how connections between Scott and Wendy’s instruction do or do not develop over time.

Another implication may be that university faculty, such as Scott, need to explore ways in which students can connect their experiences in his classes to the instruction that they will use in their subsequent teaching. One possibility may be by making the students more aware of the instructional methods he is using in his classes. Perhaps explicit discussions of his inquiry-based “methods” may help the students envision how they could enact these methods themselves as they begin teaching. Research involving this possible implication would be a significant extension to the current study.

References


Abstract

Uri Treisman's Emerging Scholars Workshop model has been implemented on many college campuses over the last twenty years. The Treisman model is based on groups of students meeting regularly in a social atmosphere to work collaboratively in solving challenging mathematics problems related to their introductory coursework. Emerging Scholars Programs (or Math Excel as it is called in many settings, including ours) have been particularly successful in increasing the academic success and participation of underrepresented groups in mathematics. The primary responsibilities of a workshop leader include the design of a session’s worksheet, as well as the facilitation of students’ problem solving efforts during the workshop session itself. In this paper, we discuss a mathematical tasks framework proposed by researchers in the Quantitative Understanding: Amplifying Student Achievement and Reasoning (QUASAR) project that may be especially helpful to workshop leaders in making a successful implementation of Math Excel. This framework emphasizes the notion of the cognitive demand of a mathematical task. The level of cognitive demand is not a static attribute and may well change as students undertake a task in a classroom setting. QUASAR researchers noted how the initially high demands of a task may not be maintained in the classroom, and how teachers’ actions may lower the demands and consequently limit learning opportunities for students. Although the QUASAR project involved middle school mathematics instruction, we believe that this mathematical tasks framework can provide valuable lessons for Math Excel workshop leaders, and it suggests how critically important both the choice of problem tasks and the workshop leaders’ facilitation of student work can be. In this paper, we review the mathematical tasks framework and illustrate its application to scenarios actually encountered in our Math Excel workshops.

What Exactly Is Math Excel?

In solving a murder mystery, detectives look for motive and opportunity. Those are also two crucial ingredients in a successful Math Excel program. Students must provide the motive, whether it is directed toward an extrinsic goal of improved grades or a more intrinsic goal, such as a deeper understanding of the course material. Math Excel workshops provide the opportunity in terms of a structured schedule (one to three meetings per week in addition to the regular class meetings) where students can work in small collaborative groups solving challenging problems related to the work they are doing in their regular classes. Neither ingredient should be taken for
granted. Students’ motivation must be sufficient for them to make a commitment to the extra time demanded by the workshop schedule. In turn, the workshops must provide problems that are clearly relevant to the current coursework and demanding enough to stimulate student discourse in a setting where students receive the encouragement and support to persevere.

The particular administrative logistics of implementing a Math Excel program can differ widely from setting to setting. The workshops themselves may be led by course instructors, graduate students, or by undergraduate peer leaders (often alumni of previous Excel classes). The workshops may be formally “attached” to a special section of a course (for example, Math Excel workshops may take the place of a recitation meeting for students electing that section) or may be offered as an “add-on” separate course carrying additional credit. Common to most implementations is a strict requirement of faithful attendance and participation by the students. The primary activity in a workshop session is that of students working together in small collaborative groups on a worksheet, i.e., a collection of problems.

The key elements of a successful Math Excel program are the people (students and leaders), the process (collaborative learning in a supportive social atmosphere), and the problems (worksheets providing rich and substantive problem-solving opportunities). In this paper, we take a closer look at the interactions between students and leaders in a Math Excel workshop session. In particular, we want to emphasize the critical role that the workshop leader plays in facilitating fruitful student discourse, and how easy it can be for a leader to inadvertently limit opportunities students have for learning.

**Background: Treisman’s Emerging Scholars Workshop Program**

In 1975-76, Uri Treisman conducted a study at the University of California, Berkeley, in which he documented the study habits of a group of twenty African-American and a group of twenty Chinese American students enrolled in *Introductory Calculus* [1]. Treisman found that the most striking difference between these two groups were in how they viewed what “studying math” meant. The African-American students tended to work in isolation, rarely consulting with other students or teaching assistants. In effect, these students had compartmentalized their daily life into academic and social components. In contrast, the Chinese American students often met in peer study groups and had integrated this activity into their social lives.

Out of this experience, Treisman developed the Mathematics Workshop Program to provide supplementary peer collaborative problem solving experiences in a social atmosphere for
students enrolled in *Introductory Calculus*. Now called the Emerging Scholars Program, it has enjoyed success in increasing the representation of African-American and Latino mathematics majors (Treisman replicated the program at University of Texas at Austin starting in 1988). The model has been adapted at many other campuses with a similar goal—to increase both the success and the participation of underrepresented students in mathematics. What constitutes an underrepresented target group varies—it could be female students, students of color, students with disabilities, students from rural backgrounds, etc. Bonsangue found that the minority students in the Emerging Scholars workshops at University of California, Pomona, when compared to minority students not enrolled in the workshop, achieved significantly higher grades in the calculus course [2,3]. At the University of Kentucky, Michael Freeman founded the Math Excel program based on Treisman’s model, with the target population consisting of students from predominantly rural communities. Freeman found that the students enrolled in these Treisman style collaborative workshops consistently achieved higher grades than students not in the workshops [4].

The Math Excel program at Oregon State University began in 1998 with initial funding from Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT) and was patterned closely on the University of Kentucky implementation. Math Excel workshop sessions at Oregon State University are currently offered twice a week for *College Algebra, Precalculus, Differential Calculus,* and *Integral Calculus*. Duncan and Dick documented the success of the program over nineteen different sections of Math Excel across all four courses during the first two years of the program [5]. According to their study, student achievement averaged approximately half a grade point higher than predicted (by mathematics SAT scores).

**Leading a Math Excel Workshop: Using QUASAR’s Mathematical Tasks Framework**

Despite the initial success of Math Excel at Oregon State University, the care and nurturing of the program requires continuing attention and ongoing efforts. It is clear to us that the role of the workshop leader is critical to the success or failure of the model. However, adequately communicating the distinguishing characteristics of an effective Math Excel leader can be difficult. To assist workshop leaders, one must move beyond vague general directives, such as “show that you care about your students.” The nuts and bolts of a good workshop lie in the details of worksheet preparation and workshop facilitation; prospective leaders need specific advice on both problem selection, as well as techniques for encouraging fruitful student discourse.
A framework that we believe is helpful for elaborating on this discussion is the Mathematical Tasks Framework described by researchers involved in the QUASAR project during the early 1990s [6]. Quantitative Understanding: Amplifying Student Achievement and Reasoning (QUASAR) was a national project aimed at improving mathematics instruction to middle school students in economically disadvantaged communities. The project was funded by the Ford Foundation and directed by Ed Silver at the Learning Research and Development Center at University of Pittsburgh. Although QUASAR concerned middle school mathematics instruction, its emphases on critical thinking, reasoning, problem solving, and the communication of mathematical ideas are entirely consistent with the goals of a Math Excel workshop session. The researchers in the QUASAR project developed the Mathematical Tasks Framework to guide their analysis of observed classroom lessons. They found the Framework useful not only as a research tool, but also as a tool for teachers who “began to use it as a lens for reflecting on their own instruction and as a shared language for discussing instruction with their colleagues.” [6] We would propose that the Mathematical Tasks Framework is also well suited for Math Excel leaders to reflect on their worksheet preparation and workshop facilitation. The Framework provides a useful vocabulary for leaders to discuss with each other the dynamics of a workshop session—what went “right” and what went “wrong”—in terms of accomplishing their goals.

Description of the Mathematical Tasks Framework

A central idea of the Mathematical Tasks Framework is that of the cognitive demand of a task. Different mathematical problems require different kinds of thinking from students in order to solve them. Moreover, the cognitive demand of a particular task should not be considered a static attribute of the task—the level of cognitive demand of a task can shift as students work on it, and teachers (leaders) can have a great influence on this shift of level. Stein and Smith [7] identify three phases that tasks pass through:

- **Phase one** — as they appear in curricular/instructional materials
- **Phase two** — as they are set up by the teacher (leader)
- **Phase three** — as they are implemented by students

The level of cognitive demand can shift from its originally intended level (Phase one) at either Phase two or Phase three. The teacher can influence this shift not only at Phase two, but also through the type of assistance or direction provided to students during Phase three. These shifts, in turn, have consequences ultimately in student learning outcomes.
What are the different levels of cognitive demand that a mathematical task can have? The Mathematical Tasks Framework identifies two lower levels, *memorization* and *procedures without connections*, and two higher levels, *procedures with connections* and *doing mathematics*. These categories were used to analyze hundreds of middle school mathematics lessons during the QUASAR lesson and are illustrated in detailed case studies [6]. However, we find that the framework works very well for other levels of mathematics. Below, we identify some of the key features of each level using example tasks from *Introductory College Calculus*.

**Memorization** — Memorization tasks involve simply reproducing previously learned facts, rules, formulae, or definitions (or committing these to memory). These tasks can be performed without making any connections to underlying concepts or meanings.

**Example:** What is the derivative \( \frac{dy}{dx} \) of each of the following functions?

\[ a)\ y = \sin x \quad b)\ y = \cos x \quad c)\ y = \tan x \quad d)\ y = \sec x \]

**Procedures Without Connections** — These are algorithmic tasks that are focused on producing correct answers. There is no ambiguity in what steps need to be performed and they can be successfully completed without making any connections to underlying concepts or meanings.

**Example:** Find an equation for the tangent line to the curve \( y = x^3 - 4x^2 + 10x - 7 \) at the point \((2,5)\).

**Procedures With Connections** — These tasks involve procedures, but students need to engage with the underlying concepts and meanings in order to successfully complete the task. They often involve multiple representations and require making connections. These tasks are intended to develop deeper understanding of the underlying concepts and meanings.

**Example:** Below is a graph of the function \( y = f'(x) \). If \( g(x) = f(x^2) \), for what values \( x \) does \( g \) have a relative minimum?
Doing Mathematics — These tasks require complex, nonalgorithmic thinking and there is not a predictable, well-rehearsed path suggested by the task, instructions, or by previously worked example. Such tasks require students to explore and understand the nature of mathematical concepts, processes, or relationships and to analyze and actively examine task constraints. They may involve some level of anxiety or frustration for the student due to the unpredictability of the solution process.

**Example:** Graph \( y = \cos(x^{2/3}) \) on a graphing calculator. Is \( y = \cos(x^{2/3}) \) differentiable at \( x = 0 \)? How can you reconcile the results of the chain rule with your graph?

**Applying the Mathematical Tasks Framework to Math Excel**

Researchers in the QUASAR project noted in their middle classroom studies that the cognitive level of a task originally appearing or set up at higher cognitive levels could be lowered by the teacher. We have found that this phenomenon aptly describes what can go awry in a Math Excel workshop session. For example, consider the example calculus task given as an illustration of procedures with connections. Assuming that the students have the requisite knowledge of the chain rule and the first derivative test for extrema, there is a procedure they can follow to solve the task. However, carrying out this procedure will require students to connect the graphical representation conceptually to both the chain rule and the first derivative test. If one or more groups of students is struggling with the task, a Math Excel leader might be tempted to illustrate the procedure with a different example. However, such a move may well lower the cognitive demand of a task to that of a procedure without connections—students may be “successful” (in the sense of getting the correct answer) by mimicking the leader’s example, but perhaps miss out on the opportunity to grapple with the representational connections.
A preferable alternative is to employ what the QUASAR researchers call *scaffolding*—questioning that supports student reasoning without simplifying the task at hand. For example, a leader could suggest that the students think about how they would approach the task if they had an explicit formula for $g$ or $f$, and encourage them to look for ways that the given graph of $f''$ could be exploited to yield similar information.

As students make promising steps toward a solution, it is also important for the leader not to lapse into the role of a “certifying authority.” It is important to hold students accountable for their reasoning, and continually ask for justifications and explanations. The leader who answers questions with questions initially may be a source of frustration to students, but is more likely to be successful in maintaining high cognitive demands.

**Discussion and Concluding Remarks**

We believe that the Mathematical Tasks Framework provides not only a helpful vocabulary for highlighting key characteristics of a successful Math Excel workshop, but also a means by which workshop leaders can reflect on and analyze their practice. Indeed, the Framework directly touches on two of the most important responsibilities of a workshop leader: the preparation of an appropriate worksheet of problems (Phase two) and the facilitation of student work on those problems during the workshop session (Phase three).

To be sure, the Framework does not address all aspects of implementing a successful Math Excel workshop. Another important responsibility of the workshop leader is in setting and maintaining expectations of the students for collaborative learning. Students bring varying degrees of experience with collaborative learning to a Math Excel workshop. Thus, it is important to spell out early the expectations the students should have of each other: showing respect for other members of the group, coming prepared to work and participate, being an active contributor and listener, and providing encouragement for one another’s efforts are the most essential. Specific rules for group work should also be laid out explicitly. For example, it may be permissible for a group to choose to work on the day’s worksheet problems in some other order than presented, but this should be a group decision and all members of the group should be working on the same problem at the same time. While a social atmosphere is welcomed in Math Excel workshops, students may stray into too much off-task conversation. The leader’s presence can help students stay on task. A leader also plays the role of cheerleader. This becomes
especially important as fatigue sets in toward the later part of the term or semester and students may need extra encouragement to persevere.

The fuel that makes a Math Excel workshop run is the problem worksheet. Putting together a good worksheet is one of the most important duties of a Math Excel workshop leader. The Mathematical Tasks Framework highlights the importance of setting up and maintaining high cognitive demands. Most worksheet problems should be challenging enough to stimulate students to work together and discuss them. Some fairly routine problems aimed at building basic skills are fine, especially as early “warmups.” However, student discussion of such problems tends to be limited to comparing individual answers. At the other extreme, including one or two very difficult problems is appropriate, especially to challenge the better students, but too many of these on a worksheet can be discouraging.

Two other important attributes of good worksheet problems are: relevance—students should be able to tell at a glance that most of the problems on the worksheet pertain to material they are studying currently in the corresponding class; and, variety—a mix of problems helps keep students engaged (problems that illustrate applications, require interpretations of graphical or tabular displays of data or quantitative relationships, or questions that expose commonly held misconceptions are great types of problems for Excel worksheets). Finally, an especially difficult problem or two at the end can ensure that even the best students do not finish early. There is no quota of problems to be finished on an Excel worksheet. The aim is to keep all students actively and productively engaged in problem solving throughout the workshop.

Adapting to the role of a facilitator is perhaps hardest for leaders who are experienced lecturers. It can be difficult to fight the urge to demonstrate solutions, especially to a group of students who are frustrated and struggling with a problem. Asking the right question at the right time (the art of scaffolding) is the most valuable help that a Math Excel leader can provide. When a group of students is “spinning their wheels,” the challenge is to find just the right helpful push rather than to serve as a tow truck.

Acknowledgments

The National Science Foundation awarded funding from 1997-2002 to the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT). The project involves virtually all of the public universities and community colleges, as well as many private colleges in
Lessons Learned in Math Excel Workshop ... 73

Oregon involved in the preparation of mathematics and science teachers. An explicit goal of OCEPT from its beginning has been the promotion of programs in mathematics and science based on Treisman's Emerging Scholars model. The Math Excel program at Oregon State University began in 1998 with initial funding from OCEPT. We would like to express special appreciation for the helpful advice and encouragement from Professor Emeritus Michael Freeman, the founder of the originally named Math Excel program at the University of Kentucky. Thanks, too, to the Dana Center of the University of Texas at Austin for providing their Emerging Scholars instructors' workshop.

Bio

Thomas Dick is Professor of Mathematics and Director of Oregon State University's Math Learning Center and Math Excel program, and a co-leader (with Thomas Stone) of the Excel strand for OCEPT. His research interests in mathematics education are in the uses of technology to improve mathematics learning and instruction.

References


Abstract

This article addresses the disconnect that in-service and pre-service secondary school teachers feel between the material presented in upper division mathematics courses and high school classroom practice. Two examples are given from an abstract algebra course in which this problem is addressed.

The Vertical Disconnect

“How has your classroom practice been affected by the abstract algebra course you took in college?” I’ve asked this question to several groups of high school teachers in Oregon over the past few years, getting responses that range from laughter to groans. I’m not surprised at these responses. Teachers often say that abstract algebra has nothing to do with their teaching because they never talk about groups, rings, fields, and the like. Although many upper division mathematics courses have a large number of prospective teachers, seldom do university mathematics faculty connect the material in advanced mathematics courses to high school level material. In an article addressed to research mathematicians, Al Cuoco of the Center for Mathematics Education at the Education Development Center calls this phenomenon the “vertical disconnect.” He writes:

Most teachers see very little connection between the mathematics they study as undergraduates and the mathematics they teach. This is especially true in algebra, where abstract algebra is seen as a completely different subject from school algebra. As a result, high school algebra has evolved into a subject that is almost indistinguishable from the precalculus study of functions. Another consequence is that, because individual topics are not recognized as things that fit into a larger landscape, the emphasis on a topic may end up being on some low-level application instead of on the mathematically important connections it makes. [1]
It is widely recognized that prospective teachers can benefit from taking advanced mathematics courses such as abstract algebra. In *The Mathematical Education of Teachers*, the Conference Board of the Mathematical Sciences recommends that prospective teachers take courses in abstract algebra and number theory in order to more fully understand the mathematical structures that underlie algebra and number systems [2]. In the NCATE Mathematics Program Standards, we find the recommendation that pre-service teachers “understand and apply the major concepts of abstract algebra.” [3] Zazkis recommends that prospective teachers study unfamiliar number systems and algebraic structures to encourage them to “reconsider their basic mathematical assumptions and analyze their automated responses. [These types of activities] constitute an essential tool for the development of critical thinking in mathematics teacher education.” [4] She claims that, “Working with non-conventional structures helps students in constructing richer and more abstract schemas, in which new knowledge will be assimilated.” Dubinsky claims that “constructing an understanding of even the very beginning of abstract algebra is a major event in the cognitive development of a mathematics student” and that this course is critical in developing prospective teachers' attitudes toward abstraction [5].

Although abstract algebra can be of great benefit to prospective teachers, it does not always fulfill that promise. According to Usiskin, undergraduates do not automatically recognize that the material they study in an abstract algebra course provides underpinnings for high school algebra [6]. These connections are rarely made by university faculty, and students are left to rely on their high school algebra experiences, experiences which are “likely to have been focused on an algorithmic approach to mathematics and unlikely to have contributed to conceptual understanding.” [7] But the problem goes beyond a failure to make these connections as researchers find that “many who are to be ambassadors and salespersons for mathematics at the secondary level develop a negative attitude towards mathematics in general and a fear of abstraction.” [8]

This article presents two case studies of methods I have used, and continue to use, to address the “vertical disconnect” in an abstract algebra course at the University of Portland. This work was supported by the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT).
Work Sample Collaboration

In their senior year, our prospective secondary school teachers are required to prepare and implement a “work sample”—a series of lesson plans addressing a coherent unit of study. Usually these work samples are supervised by a faculty member in the School of Education who gives valuable input on lesson design and classroom management issues, but does not have the expertise to give guidance on the mathematical content. This is an excellent opportunity for mathematics faculty to play a role in bridging the “vertical disconnect.”

Angie Mai was a student in my upper division, Abstract Algebra course at the University of Portland in 2002. Her student teaching responsibilities prevented her from taking the second semester of the course, so we arranged a “directed study” class. The purpose of this class was for Mai to incorporate the knowledge, methods, and point of view she had been learning in Abstract Algebra to her student teaching, specifically to her work sample. Along the way, we looked at many connections abstract algebra has to high school algebra. After considering many topics, we settled on the complex numbers. The complex numbers had come up in the Abstract Algebra class in a variety of ways, providing examples of groups, rings, and fields. In chapter nine of The Mathematical Education of Teachers, we find the following observation: “It is important for prospective teachers to understand how most extensions of the number system, from natural numbers through complex numbers, are accompanied by new algebraic properties, and why the field axioms are so critical for arithmetic.” [2] In parallel to Mai's development of her work sample, I guided her through an investigation of Hamilton's quaternions. Throughout the project, we found many interesting parallels between her learning about this extension of the complex numbers and her high school students’ discovery of the complex numbers as an extension of the real numbers.

Mai's placement was in three sections of “Advanced Algebra” (Algebra II) and an introduction to complex numbers was a normal part of the curriculum for that course. The textbook presented a brief and largely unmotivated presentation of addition and multiplication of complex numbers. We felt that with the deeper understanding of the complex numbers we had gained in class and with the perspective on mathematics afforded by the abstract algebra class, we could do a better job.

A reservation I often hear when I talk to teachers or mathematicians about connecting abstract algebra and high school algebra is that such a project could only benefit the top students.
This has most definitely not been my experience in the past and it has not been Mai's experience in this project. By the time she started to teach the complex numbers material, Mai was quite familiar with the skill levels and abilities of her students. Across all three classes, her observation was that even, and sometimes especially, our approach to the complex numbers benefited the "weaker" students.

An Overview of the Lesson

The discussion below gives a brief outline of two weeks of lessons. The questions were presented in class discussions and investigated in small groups working on carefully designed worksheets and through homework assignments we designed. The students also worked their way though the material in their textbook, making the appropriate connection to our approach. One of the main points of this article is that often the point of view of abstract algebra (or any advanced mathematics course), more than the actual theorems and definitions, can make real contributions to teaching high school topics. As you read through this example, think about how generalization is used, how axioms play an important role, and how the students are put in the role of researchers with the question: "How can we build a number system that is even bigger than the real numbers?"

Our approach to the complex number is geometrical and relies on a generalization from the real numbers. The students review the creation of the real numbers in stages, each new number system being motivated by the solution of a new kind of equation (e.g., the rational numbers are needed to solve $3x = 5$). Even with the real numbers in hand there are equations we cannot solve (e.g., $x^2 = -3$), but from a geometric point of view we are at a dead end—the number line is filled up completely! Students were able to suggest a possible solution: move off the line and look at the plane. This gives rise to our basic problem: "How do we turn the points in the plane into a number system?"

To make progress, we are guided by our geometric point of view and the generalization from the real numbers. Using this geometric point of view, a real number (a point on the number line) is specified by its (signed) distance to the origin. When we make our generalization to points in the plane, we need to take into account the distance to the origin, but distance to the origin is not enough information to specify a point. What other information is needed? By responding to a question like, "I live five miles from here—what else do you need to know to get to my house?"
students discover that direction is the missing ingredient. In this way, we develop the polar
description of points in the plane, denoting the point at distance $r$ and angle $\theta$ by the symbol $r@\theta$.

We decided to focus on discovering the definition of complex multiplication. Students
generalize from their knowledge of multiplication of real numbers, both positive and negative.
From our new point of view, we know how to multiply points in the plane if their angles are 0° or
180°. Through worksheets and homework assignments, students conclude that we need to
multiply the lengths of our new kind of numbers, but what to do with the angles is a bit of a
mystery at this point. Students translate previous knowledge that “negative times negative is
positive” to a new situation, finding that when they multiply two numbers with angle 180° we get
a number with angle 0°. For example, the real multiplication fact $(-2)(-3) = 6$ becomes the
complex number fact that $(2 @180°)(3 @180°) = (6 @ 0°)$. Students find themselves left with a
choice: “Should we add the angles or subtract them?”

We decided to answer this question with a classroom debate. Students chose sides (“Add
the angles” vs. “Subtract the angles”) and were given homework assignments to help them
prepare for the debate. The class was divided into two teams facing each other: angle addition vs.
angle subtraction. Each team took turns presenting an argument and teams were allowed to
huddle and offer each other help before presenting an argument. When a team called a huddle on
its turn, both teams were allowed to huddle for up to thirty seconds. Once the thirty seconds were
up, the team who called the huddle presented an argument or used advice from Mai as a wild card
(but only twice). To ensure equal participation, each student had to speak before another student
was able to speak again. At the end of the debate, students were asked to choose which operation
they believe is the correct operation in a silent secret ballot. Angle addition won the day.

**The Role of Abstract Algebra**

More than the actual theorems and methods of abstract algebra, we found ourselves using
more general ideas and points of view from that course. In this section, we will highlight those
contributions.

**Investigation: Playing the Researcher** — Inquiry- or discovery-based learning is popular now in
many fields of study, but many of the examples of this pedagogy tend to lead students along a
carefully prepared path with carefully prepared steps. Often lacking is a real sense of
investigation of the sort experienced by researchers. This kind of experience is typically
introduced in upper division mathematics courses where students “get a taste of research.” But that kind of investigative activity is available at all levels. In our treatment of the complex numbers, the students definitely don't know what the answer is and instead of laying out the steps needed to get to the “right” answer, we emphasize the same kind of tools and strategies that researchers (in mathematics and many other fields) actually use. The first of these is generalization.

Generalization as Guide to Discovery — We treat the complex numbers as a generalization of the real numbers. Starting from the perspective that we want to multiply points in the plane, we discuss what form would be most appropriate. In this decision, we are guided by generalization. How do we multiply points on the real line? We just find out how far they are from the origin and then multiply those numbers. So when we represent points in the plane, distance is important. If you know the distance from a point to the origin, what else do you need to know to locate that point? If someone tells you they live five miles from here, what else to you ask them to find out where they live? Direction! In this way, we arrive at our $r@\theta$ notation for points in the plane. This part of the lesson is more strongly guided by questioning than the next phase in which we decide how to multiply complex numbers.

Where should we look for guidance when we ask, “How should we multiply two points in the plane?” The principle of generalization says that whatever definition we come up with had better agree with our method of multiplication of real numbers, so we can use that information to guide us in our exploration. As we saw above, this gives us some information, but doesn't quite decide the matter. We need another perspective from abstract algebra.

Axioms Decide the Debate — In abstract algebra, we study many structures defined by axioms: groups, rings, fields and the like. The perspective is that these axioms are a guide to useful mathematics and should not be easily sacrificed. Many of the arguments in the “great debate” were based on preservation of the axioms we have depended on in our study of integers, rational numbers, and real numbers. In deciding for adding angles over subtracting angles, the crucial arguments were, “Do you really want to give up a property like $ab = ba$ or $(ab)c = a(bc)$?”

Payoff — After we come up with our definition of complex multiplication and check that our definition corresponds to the algebraic definition, it's time to reap some benefits. As I say many times in our abstract algebra course, whenever there is more than one way to look at a given
question good things can happen. The first benefit of the geometric definition is that the complex number $i$ appears naturally—in fact, the students discover it on their own. What else can we do with our new perspective on complex multiplication? In their textbook, the students learn the $a + bi$ definition of complex numbers and their operations. Are there questions that are easier to answer with our different (yet equivalent) definition? The students explore these questions mainly in homework, where they discover more general roots as well as the various “roots of unity” that our abstract algebra class studied as well. Could we have done this using the algebraic definition? Possibly, but if you try you will find yourself quickly in difficulty. The connection between these two perspectives is the addition formulas for sine and cosine, but that connection will have to wait for a later class.

**In-Service Workshops**

A wonderful opportunity to connect upper division mathematics material to high school teaching practice comes in the form of in-service workshops for high school teachers. I design workshops that build connections to abstract algebra for in-service teachers and I use students in my upper division classes as teaching assistants. The workshop is very much activity-based with the high school teachers working in small groups. My abstract algebra students are expert in the topic and use the questioning strategies of the Peer-Led Team Learning model as they assist the teachers [9].

**An Outline of the Workshop**

The workshop I will outline takes material my students were learning about symmetry groups, specifically dihedral groups, and connects this material to standard topics in the high school curriculum: properties of functions, matrix multiplication, and trigonometric identities.

The workshop begins with each teacher learning to use a “dihedral calculator” (Figure 1). This is simply a regular hexagon made of posterboard with labeled vertices on the front and back. We investigate and list all the possible symmetries of this object, finding that there are twelve-six counterclockwise rotations of $0°, 60°, 120°, 180°, 240°, 300°$ which we call $R_0, R_1, ... , R_5$, respectively (the subscript representing the number of “clicks” we rotate counterclockwise) and six “flips” over the six lines of symmetry, which we call $L_1, ..., L_6$ as shown below.
The workshop begins with the high school teachers working their way through some exploratory exercises with composition of symmetries. For example, in Figure 2 below, the hexagon begins in “standard position,” then the symmetry $L4$ is performed interchanging left and right. This is followed by the symmetry $L5$ and the teachers observe the composition, $L5 \circ L4$ is equivalent to a $300^\circ$ counterclockwise rotation. After some discussion about which order to write this in, we agree on

$$L4 \circ L5 = R_5$$
From this point, we begin to investigate different ways to represent our "dihedral calculator" symbolically. For example, using permutations, we can represent the symmetry $R_5$ as the permutation

\[
\begin{pmatrix}
A & B & C & D & E & F \\
B & C & D & E & F & A 
\end{pmatrix}
\]

Through a guided set of activities, investigating this way of looking at symmetry pushes on the teachers’ understanding of basic concepts such as function, onto, one-to-one, inverse function, and associative and commutative laws. Usually, one of the teachers will recall the definition of an abstract group, and there will be some discussion about how this concept was taught in their abstract algebra course.

Finally, we look at matrix representations of these functions. Many, but by no means all, of the teachers are able to represent the transformation $R_1$ as a matrix. After first introducing a coordinate system, the teachers use trigonometry, to find that the rotation $R_1$ can be represented as:

\[
R_1 = \begin{pmatrix}
\cos 60^\circ & -\sin 60^\circ \\
\sin 60^\circ & \cos 60^\circ 
\end{pmatrix}
\]
and more generally, a counterclockwise rotation through an angle $\alpha$ is given by

$$\begin{pmatrix}
\cos \alpha & -\sin \alpha \\
\sin \alpha & \cos \alpha
\end{pmatrix}$$

This way of representing a rotation is familiar to some, but new to many of the teachers and we do several examples of applying these transformations to vectors until everyone is comfortable with the concepts. What is new to most of the teachers is the connection to sum of angle formulae for trigonometric functions. We begin by investigating the composition $R_1 \circ R_1 = R_2$ and comparing it to the matrix calculation

$$\begin{pmatrix}
\cos 60^\circ & -\sin 60^\circ \\
\sin 60^\circ & \cos 60^\circ
\end{pmatrix} \begin{pmatrix}
\cos 60^\circ & -\sin 60^\circ \\
\sin 60^\circ & \cos 60^\circ
\end{pmatrix} = \begin{pmatrix}
\cos 120^\circ & -\sin 120^\circ \\
\sin 120^\circ & \cos 120^\circ
\end{pmatrix}$$

The equality of this matrix multiplication is equivalent to the double angle formulas for sin and cos. Further experiments with other $R_i$ and rotations through general angles reveal the connection to the general sum formulas for sin and cos.

**Benefits for In-Service and Pre-Service Teachers**

Although the workshop is ostensibly for the in-service high school teachers, I see the greater benefits accruing to the pre-service abstract algebra teachers. The in-service teachers are usually very happy to see these connections between material they currently teach and a class from college they had supposed was irrelevant to their teaching. However, in a one-day workshop, there is little chance this experience will actually make a long-lasting difference in their classroom teaching practice. For my abstract algebra students, there are more substantial benefits. They begin to build the expectation that the material they are exposed to in upper division courses should connect to high school mathematics topics. They begin to ask questions of me and of themselves about these connections. As they help the high school teachers through the material, many useful conversations occur in which the teachers relate actual classroom situations in which the concepts addressed in the workshop arise.
It is interesting to note the connection between the material on complex numbers that Mai presented to her Algebra II classes and the material presented above that could be part of any high school trigonometry class. If we had thought of the hexagon as being part of the complex plane, we could have represented the rotations as multiplications by a complex number. For example, the rotation $R_1$ could be represented as multiplication by the complex number $1 \@ 60^\circ$. The connection to the trigonometric addition formulas comes about by writing the multiplication of complex numbers in polar form and in rectangular form, and comparing the answers. Although none of the high school teachers thought to do this, they might well have if their abstract algebra or complex analysis professors at college had bridged the "vertical divide."

References


Abstract

Success in mathematics by underrepresented and nontraditional college students is measured not only by academic performance (grades), but also by the continued participation and persistence of these students in mathematics coursework. The Math Excel program at Oregon State University attempts to build "learning communities" with a sharp academic focus in support of students concurrently taking introductory level mathematics courses. The Math Excel program is based heavily on Uri Treisman's Emerging Scholars Workshop model of collaborative problem solving. In this article, we examine the experience of minority students in the Educational Opportunities Program participating in the Math Excel program. While the program had appeared successful in terms of improving academic performance in the concurrent mathematics course, the continued participation and persistence of these students in mathematics was disappointing. On a trial basis, structural changes were made to build a much stronger identification of the Math Excel learning community with a section of College Algebra. In the next term, there was a much higher incidence of participation in the subsequent Precalculus using the same Math Excel structure. While the collaborative problem solving activity provided in Math Excel was crucial to students' successful academic performance, these results suggest that subtle issues related to students' recognition of and identification with a learning community may be critically important to underrepresented and nontraditional students' continued persistence in mathematics.

Introduction

Success in mathematics by underrepresented and nontraditional college students is measured not only by academic performance (grades) but also by the continued participation and persistence of these students in mathematics coursework.
The Educational Opportunities Program (EOP) at Oregon State University provides academic and special admission support for nontraditional students, including students of color and students with disabilities, to assist them in successfully entering and navigating the educational system. The EOP unit functions as a smaller community within the larger university community, whose student body is predominately European American in ethnic background and middle class in socioeconomic status. Academic and personal advising is provided by counselors who come from diverse backgrounds themselves.

The primary entry-level mathematics course for students at Oregon State University is *College Algebra*. For many students, this course is the first and last college mathematics course they will ever take. For some students, *College Algebra* provides a foundation for additional courses such as business mathematics. For other students, it is the first step toward a technical major in engineering or science, requiring significant additional mathematics coursework, including *Precalculus*, *Differential* and *Integral Calculus*, and several more advanced mathematics courses.

For EOP students entering college with an inadequate mathematics background to enroll in *College Algebra*, the program provides a range of developmental courses and tutoring sessions to provide the necessary mathematical prerequisites. Historically, *College Algebra* has been a terminal mathematics course for many underrepresented minority EOP students at Oregon State University.

Starting in the year 2000, the Math Excel program became an integral part of EOP's mathematics instructional support strategy. The Math Excel program is based on Uri Treisman's Emerging Scholars Workshop model and employs collaborative learning groups engaged in problem solving in support of concurrent mathematics course enrollment. While Math Excel is open to all students, a target audience for recruitment is that of underrepresented students; EOP's involvement accounts for almost all of the minority student enrollment in Math Excel.

In this article, we will consider the experiences of Oregon State University’s EOP minority students in Math Excel in terms of academic performance, participation, and persistence in mathematics. In particular, we will discuss how some structural changes made in the Math Excel program for *College Algebra* may have significant implications for the continued persistence of underrepresented students in mathematics. Institutions considering starting similar
programs may find these results useful in making implementation decisions. To provide some background to that discussion, we will review some of the factors related to persistence in mathematics, how collaborative learning models address these factors, and describe the key characteristics of Treisman's Emerging Scholars Workshop model on which the Math Excel program is based.

Factors Related to Persistence in Mathematics

The issue of choosing and persisting in a mathematics-based major, especially when this decision concerns underrepresented students, is one that has received much attention in recent years. Some of the factors thought to be related to students' choices of major are their view of the usefulness of mathematics, their perception of the difficulty of mathematics, their view that mathematics is an asocial discipline, and their enjoyment (or lack thereof) of studying mathematics courses [1]. In Leitze's study, the most prominent reason found for choosing a major was the enjoyment of the field of study, including likes and dislikes regarding experiences with specific courses and professors. While a quality like "enjoyment" is difficult to examine, the asocial aspect of traditional mathematics pedagogy is thought to contribute to a lack of enjoyment of mathematics studies. As a result, "introductory level courses [i.e., lower-division courses] are vitally influential in determining undergraduates' choice of major." [1]

A study by Linn and Kessel concerning which students will switch out of mathematics-based majors and the reasons for their switching found that over half of students who plan to study mathematics in college eventually switch to other fields [2]. They found that the GPA difference between those students who switch and those who persist was not statistically significant, but that the switchers, who are often among the most talented males and females, most often complained that the learning environment was what had driven them away from taking further mathematics courses. Students were found to feel frustrated that the courses were designed to filter students out of the program rather than to encourage talented students to persist. The authors raise the issue that "quality of instruction more than success in mathematics motivates students to switch out of mathematics." [2]

Research supports the hypothesis that improved methods of teaching mathematics at the college and university level can have a positive effect on both the success and the persistence of students in mathematics. This may be especially true for minority students, as Bonsangue cites
evidence that their perceptions of "their own academic worth and social fitness are forged by institutional structure, departmental practices, and faculty attitudes." [3]

Collaborative Learning as a Means to Encouraging Persistence

The use of collaborative learning situations is one of the most popular suggestions for improving the rates of participation and retention of students in mathematics classes. The intent of collaborative learning, involving group discussions, is to make the classroom a student-centered learning environment. Hoyles found that group discussions and problem solving possessed three main characteristics that help in the development of mathematical understanding [4]. First, talking and listening involve both the cognitive articulation of thoughts and the communicative sharing of ideas. Second, because the situation demands verbalization, students often think more deeply about the concepts. Third, listening and reflecting allow the students time to think over new ideas and develop reasoning. Hoyles believed this type of classwork could help end the days of students feeling alienated and bored with mathematics.

Linn and Kessel suggest that “all learning takes place in a social context, so the goal [in collaborative learning] is to structure social interactions to support all learners.” [2] Leitze contends, “By incorporating collaborative learning into the classroom, diverse learning styles are accommodated and more positive attitudes about mathematics are promoted.” [1] According to Astin, “students learn by becoming involved,” which refers to, among other things, a continuous “investment of physical and psychological energy.” [5] Tinto adds that group involvement is necessary, but for it to be sufficient the group must be perceived as a central part of the institutional structure [3,6]. Pascarella also found that social integration was a particularly important factor in black students’ persistence and degree completion [7]. Thus, integrating collaborative learning into the mathematics classroom would seem to address the issues thought most likely to influence persistence in mathematics, particularly for minority students.

Treisman's Emerging Scholars Model

In 1975, Uri Treisman conducted an informal study of undergraduate students at the University of California, Berkeley (UCB) to attempt to determine “what distinguishes strong mathematics students from weak students.” [8] He noticed that the African-American students were disproportionately listed among the weaker students and the Chinese American students were more often listed among the stronger students. This observation led Treisman to change the
Treisman found that, while African-American students usually studied alone and kept their social life separate from the academic, Chinese American students usually studied in groups which also served as social groups [8]. Treisman found a connection between the two groups' study habits and their academic success. Based upon these findings, he developed the Mathematics Workshop Program (MWP) at UCB. The MWP was primarily designed as an honors program for African-American and Hispanic freshmen. The program was thought to be successful because the workshops provided students with "academically oriented peer groups" where success was prized, more study time was spent on "learning tasks," and students acquired both study and social skills they could use throughout college [8].

Treisman's model has been adapted and implemented at more than 100 colleges and universities since his initial program was developed at UCB. Treisman himself later implemented the program at the University of Texas at Austin under the name of the Emerging Scholars Program (ESP). According to Bonsangue, some of these Emerging Scholars Programs have "dramatically lowered drop rates and increased the number of minority students majoring in MSE [Mathematics, Science, and Engineering] fields." [3]

Bonsangue also conducted a study at California Polytechnic State University, Pomona, that included a group of African-American and Hispanic ESP students, a group of African-American and Hispanic non-ESP students, a group of Caucasian non-ESP students, and a group of Asian and Pacific Island non-ESP students, all of whom were enrolled in the same lecture sections of first-quarter calculus [3]. He analyzed the students' academic performance over three to five years, had the students complete a Student Involvement Questionnaire, and interviewed upperclassmen who had participated in ESP as freshmen. When he compared results concerning achievement and persistence between the corresponding minority groups, he found that ESP minority students earned higher mean grades in first- and second-year calculus than their non-ESP peers. He also found that, due to course failure, it took the non-ESP minority students an average of one quarter more than the ESP students to complete their first-year calculus sequence. Additionally, the study showed that "within three years after entering the institution, more than half (52%) of the minority non-workshop students had either withdrawn from the institution or changed to a non mathematics-based major, compared to fifteen percent of the workshop [ESP]
students.” [3] When comparing the ESP minority students with the non-ESP white and Asian students, Bonsangue found that the ESP students' achievements and course-repeating patterns were not significantly different from the others. The Caucasian and Asian students had a higher withdrawal or switching rate at 50% and 41%, respectively. While stating that all of the factors that contribute to this outcome cannot be determined, the author concludes that “achievement among underrepresented minority students in mathematics, science, and engineering disciplines may be less associated with precollege ability than with in-college academic experiences and expectations.” [3]

Treisman's ESP model of collaborative learning workshops appears to be a particularly promising means of positively influencing both performance and persistence of underrepresented students in mathematics. On one hand, the opportunity to engage in discourse with other students on problems directly related to the academic coursework has direct cognitive benefits. On the other hand, the affective benefits to be gained from belonging to a social learning community that is considered an integrated part of students' academic lives appear to have a real impact on persistence in mathematics coursework.

The Math Excel Program

In 1990, Professor Michael Freeman of the University of Kentucky founded the Math Excel Program as an adaptation of Treisman's Emerging Scholars Program workshop model. It is this adaptation on which Oregon State University’s Math Excel Program is largely based [9]. Math Excel was first implemented at Oregon State University in Fall 1998, with workshops for College Algebra, Precalculus, and Differential Calculus. Workshops for Integral Calculus were added in Winter 1999. The regular introductory mathematics courses involve three lectures (80–200 students) and one recitation (30–40 students) per week. In general, there are limited opportunities for discourse between students and instructor during the lecture sessions. Activities during the recitation session include discussion of homework problems and some structured problem solving “labs” where students may work either individually or in small groups.

A student may enroll in Math Excel for one or two additional credits as a separate course and participate in two workshop sessions each week (eighty minutes each for College Algebra and Precalculus; 110 minutes each for Differential and Integral Calculus). Any student taking the corresponding course is also eligible to enroll in the Math Excel section supporting that course, though enrollment is strictly limited to 25–30 students per workshop. Thus, the students
in a single Math Excel workshop may come from several lecture sections with different instructors. Grading for the Excel workshops is Pass/No Pass, and based on a minimum of 90% attendance. The Math Excel program is not considered to be either an honors program or a remedial program, but to provide an opportunity for any student willing to make the commitment to participate faithfully in the workshop sessions.

During the workshop sessions, students are arranged and rearranged into groups of three to five students that work together on a set of problems designed to reinforce and extend their understanding of that week's course work. The workshop is led by a graduate teaching assistant along with additional TA’s and student helpers (a ratio of one assistant to eight students is considered optimal). The goal of the leaders is not to tutor nor to provide direct instruction, but rather to facilitate group discussion of the problems and thereby assist the students to develop and carry out solution strategies on their own. Creating and maintaining expectations for effective group dynamics are major responsibilities of the leaders and assistants.

The workshop leader communicates with the lecture instructors throughout the term and creates worksheets that are tied to the course content being covered in the lecture section each week. Before midterm exams, Excel workshop leaders often create worksheets based on problems obtained from exams of previous terms. This communication between the Excel leader and the instructors in designing the worksheets is important in establishing some level of integration with the concurrent mathematics course.

It is important to note that other adaptations of the ESP model provide a much higher degree of integration with the mathematics course they support. For example, the Math Excel model at the University of Kentucky establishes a direct linkage between the workshops and a specially designated lecture section of calculus in lieu of recitations. That is, all students enrolling in a particular lecture section attend three Math Excel workshops instead of two recitations. This model has the advantage of tighter integration at the expense of some scheduling flexibility.

**Math Excel and Performance Results for EOP Minority Students**

Duncan and Dick conducted a study to assess Oregon State University’s Math Excel program's effectiveness in helping students earn higher mathematics grades [9]. For each of five academic quarters (Fall 1998–Winter 2000), they tracked students who were grouped by
enrollment in *College Algebra, Precalculus, Differential Calculus*, or *Integral Calculus* and by enrollment or non-enrollment in the Excel workshops. During the last term of the study, minority students made up 34% of the Excel enrollment and 64% of the *College Algebra* Excel enrollment. The data collected in the study included scores from the mathematics portion of the Scholastic Achievement Test (SAT-M) and the mathematics course grades on a four-point scale.

For each term, a linear regression prediction equation was derived for each course with grades predicted by the SAT-M scores. A predicted mean was computed based on each Excel workshop's mean SAT-M score and compared with the actual workshop grade average. The study found that "the overall mean difference between the actual grade averages and predicted grade averages for the Math Excel sections was 0.615, significant at the .001 level." [9] Also, the Excel students, on average, earned higher grades than the non-Excel students, and overall the difference was more than half of a grade point.

Of special interest here was the Winter 2000 *College Algebra* Excel workshop, for this marked the first major involvement of EOP students within the Math Excel program. For this group, the actual class grade average in *College Algebra* was 2.31 as compared to the predicted average of 1.87, a positive difference of 0.44 grade points. Thus, the Math Excel workshops also appeared to be successful in improving the academic performance of the EOP minority students.

**Math Excel and the Persistence of Minority Students in Mathematics**

Student involvement in programs using collaborative learning groups appears to have a positive and significant effect on academic performance. These types of programs seem to address many of the issues that, especially for minority students, play a large role in choice of major, persistence in that major, and overall self- and group-perception of academic worth and ability. However, the factors related to persistence in mathematics are more difficult to quantify and their influence may be subtle. As mentioned above, this study found encouraging academic performance results for the program in general, and for EOP student involvement with *College Algebra* in particular [9].

How did involvement in the Math Excel program affect EOP minority student participation and persistence in mathematics beyond *College Algebra*? For a baseline comparison, course enrollment data was gathered for all EOP minority students enrolled in *College Algebra* during the six previous academic terms, 1997–99. The numbers of these
students who successfully completed *College Algebra* with a grade of C- or higher were tracked for subsequent enrollment in additional mathematics courses. Numbers of attempts and successful completions (again, defined as a grade of C- or higher) in subsequent courses in either the business math sequence or the technical precalculus/calculus sequence for science and engineering majors were recorded through Fall 2001. Table 1 summarizes these results.

### Table 1

**Numbers and Percentages of Underrepresented Minority Students in Oregon State University’s EOP 1997–98 and 1998–99 Mathematics Enrollment History (through Fall 2001)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1997–98: n=31</td>
<td>26 (83.9%)</td>
<td>14 (45.2%)</td>
<td>10 (32.3%)</td>
<td>10 (32.3%)</td>
<td>7 (22.6%)</td>
<td>5 (16.1%)</td>
<td></td>
</tr>
<tr>
<td>1998–99: n=41</td>
<td>26 (63.4%)</td>
<td>14 (34.1%)</td>
<td>12 (29.3%)</td>
<td>10 (24.4%)</td>
<td>15 (36.6%)</td>
<td>13 (31.7%)</td>
<td></td>
</tr>
</tbody>
</table>

Starting in Winter 2000, EOP students began participating in Math Excel. Table 2 summarizes similar course enrollment data for EOP minority students who participated in Math Excel in 2000 and 2001. Tables 1 and 2 together provide an opportunity to compare the participation and persistence of EOP minority students before Math Excel with that of EOP minority students involved in Math Excel.

### Table 2

**Numbers and Percentages of Underrepresented Minority Students in Oregon State University’s EOP Math Excel Winter 2000–Winter 2001 Mathematics Enrollment History (through Fall 2001)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n=31</td>
<td>26 (83.9%)</td>
<td>10 (32.3%)</td>
<td>9 (29.0%)</td>
<td>5 (16.1%)</td>
<td>12 (38.7%)</td>
<td>8 (25.8%)</td>
<td></td>
</tr>
</tbody>
</table>

Starting in Winter 2000, EOP students began participating in Math Excel. Table 2 summarizes similar course enrollment data for EOP minority students who participated in Math Excel in 2000 and 2001. Tables 1 and 2 together provide an opportunity to compare the participation and persistence of EOP minority students before Math Excel with that of EOP minority students involved in Math Excel.
It is important to note that the subsequent course enrollment data is only through Fall 2001; hence, the data for the Math Excel EOP students are not “final” (in the sense that many of these students are still currently enrolled as undergraduates and may well attempt additional mathematics courses in the future). Nevertheless, it is not unreasonable to assume that students intending to pursue additional mathematics coursework beyond *College Algebra* would likely attempt such a course shortly after successfully completing *College Algebra*. So, while the performance data in College Algebra as reported by this study is promising, the participation and persistence data are less striking [9].

**A Pilot Program—A Change in Structure for Math Excel**

Student evaluation of the Math Excel experience has tended to be overwhelmingly positive (every term since its inception, over 90% of the students involved report on end-of-term evaluations that they perceived Math Excel had a positive impact on their learning and on their course performance). However, if students view the Math Excel experience primarily as a helpful peripheral aid and not as a centrally integrated part of their learning, then its benefits may tend to be more short-term in the sense of performance in the concurrent course and not long-term in the sense of encouraging further participation and persistence [6]. In an effort to build stronger recognition for and identification with the "learning community" that a Math Excel workshop section seeks to establish, Oregon State University’s Department of Mathematics and the Educational Opportunities Program piloted structural changes in the program for *College Algebra* for Winter 2002 followed by similar changes for *Precalculus* in Spring 2002. The goal of these changes was to encourage the view of participation in a learning community as an integral part of success in the course in the hopes that more minority students would persist on to the next mathematics course. These changes were:

1) designation of a special section of *College Algebra* that required concurrent enrollment in Math Excel in lieu of a recitation session; and,

2) direct involvement of the instructor for the lectures for *College Algebra* with the Math Excel workshop sessions.

Table 3 shows the EOP minority student participation in the special *College Algebra* and their subsequent course enrollment results for the term immediately following (Spring 2002).
Table 3  
Numbers and Percentages of Underrepresented Minority Students in Oregon State University’s EOP Math Excel Winter 2002 and Mathematics Enrollment Spring 2002

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 38</td>
<td>34 (89.5%)</td>
<td>34 (89.5%)</td>
<td>20 (52.6%)</td>
<td>9 (23.7%)</td>
<td>8 (21.1%)</td>
<td>9 (23.7%)</td>
<td>9 (23.7%)</td>
</tr>
</tbody>
</table>

Discussion

The recent structural changes to Math Excel at the College Algebra and Precalculus levels do indeed seem to be making a positive difference in participation and persistence. Since the lead instructor for the pilot sections of Math Excel also had experience with the original structure, he was in a position to share observations on how the changes made in the Math Excel program might impact the factors affecting student participation and persistence mentioned earlier in the paper. While his reflections are admittedly anecdotal, the persistence data suggest that the changes made some significant positive differences.

Student Perceptions of Collaborative Learning as Central to Institutional Structure — Registration for College Algebra was limited to sixty students and also required that each student register for a section of Math Excel in lieu of recitation. The course requirements and grading structure as outlined in the course syllabus addressed the Excel workshops and the lecture as two components of a single course. Based upon a study of assessment practices in a cooperative learning setting, individual incentives for group success were established (if everyone in the course earned a passing grade on a given exam, a 2% bonus was awarded to all students) to emphasize cooperative goals [10]. Since all students in the same lecture section were involved in Math Excel workshops, it was possible for the instructor to make explicit references to worksheet problems in lecture as well as to comment on lecture material during group work in the Excel sessions. Over time, the instructor noticed the culture and mores of collaborative group work in the Excel workshops carrying over to the lecture section and even outside of class. In lecture, when the instructor had difficulty presenting a concept in a way that was understandable to a particular student, other students would offer their own understanding of the concept, which would lead to greater understanding on the part of the other students. The instructor noticed...
several of the Excel groups studying together outside of class. A number of students were witnessed checking up on each other whenever one of them missed a day or two of lecture. Because of the Excel workshop, students felt more comfortable asking questions in lecture as evidenced by one student comment:

I liked the way that we were allowed, and even encouraged, to socialize with others in the class, which made the atmosphere comfortable. Because I felt comfortable in class, it was easier for me to ask questions when I didn't understand the material.

Lowering Risk and Building Confidence — Providing an environment in the Math Excel workshops where students felt safe to ask questions of each other carried over to the lecture environment. Seeing the same students in this setting lowered the risk of making comments and engaging in discourse with the instructor. Since the majority of the tougher problems were approached collaboratively within the Excel workshop, the students developed less apprehension toward attempting challenging word problems. Some even came to enjoy the more challenging problems and requested that similar problems be put on the exams. While students were reluctant at first to discuss their understanding of a concept, by the end of the term most of the students surveyed reported that sharing their views helped to refine and improve their understanding of the concept, and it also made learning enjoyable. One student sums this up well with the comment:

One thing that this class taught me was that I could figure many things out on my own without the help of anyone. That was especially due to the fact that the teacher assistants refused to walk me through problems and instead just gave me a few clues to help me, and then trusted my ability to solve the problems. Even though I wasn't very grateful at the time it did help me a great deal.

Students appeared to build their personal math confidence level over time. A number of students commented on a pre-assessment form that one reason they did not enjoy math was because they did not feel confident doing math. Once they made it through a few problems with only minimal help from the assistants, they would comment on how their math confidence was back or how good it felt to feel confident for the first time. They felt that the instructors trusted their ability and so they came to trust themselves. One student summed it up best when she stated,
"As soon as I started Math Excel immediately I started seeing my math confidence increase, and saw drastic improvements in my math skills."

**Conclusions and Recommendations**

Math Excel was initially implemented at Oregon State University with the goal of enhancing student performance in concurrent introductory mathematics courses and persistence in continued mathematics coursework. While the academic performance results have been encouraging, the goal of increasing the persistence of students, especially underrepresented minority students in the Educational Opportunities Program, has proved more elusive. The initial results of structural changes made to increase the integration of Math Excel with *College Algebra* appears promising enough to merit consideration of expanding the pilot project to include differential and eventually integral calculus courses and beyond.

The Emerging Scholars Workshop model has shown itself to be flexible to different types of implementation in adapting to the particular needs of institutions. For institutions considering implementing an Emerging Scholars program, the implications of our experience depend on the goals of the program. If the primary goal is strictly improved academic performance in the associated course, then a less integrated, stand-alone implementation affords scheduling flexibility and less complexity in instructional organization. However, if another goal is improved participation and persistence in subsequent mathematics courses, then a strong consideration should be given to tighter integration between the workshop and lecture, especially if the target audience is that of underrepresented students.

**Acknowledgments**

The National Science Foundation awarded funding from 1997-2002 to the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT). An explicit goal of OCEPT from its beginning has been the promotion of programs in mathematics and science based on Treisman's Emerging Scholars model. The Math Excel program at Oregon State University began in 1998 with initial funding from OCEPT. We would like to express special appreciation for the helpful advice and encouragement from Professor Emeritus Michael Freeman, the founder of the originally named Math Excel program at the University of Kentucky. Thanks, too, to the Dana Center of the University of Texas at Austin for providing their Emerging Scholars instructors’ workshop.
Bios

Charisse M. Hake is an instructor of mathematics at Oregon State University. Her master’s paper on the Math Excel program provided the framework for this article.

Michael Little Crow is an instructor of mathematics for the Educational Opportunities Program at Oregon State University. He has been heavily involved with the Math Excel program since its inception.

Thomas Dick is Professor of Mathematics and Director of Oregon State University’s Math Learning Center and Math Excel program, and a co-leader (with Thomas Stone) of the Excel strand for OCEPT.

References


LESSONS LEARNED FROM EFFORTS AT INSTITUTIONAL CHANGE: CASE STUDIES OF SIX OCEPT INSTITUTIONS

T.G. CHENOWETH and M.K. KINNICK
Graduate School of Education, Portland State University
Portland, OR 97207-0751
Chenoweth@pdx.edu; Kinnickm@pdx.edu

R.D. WALLERI
Research and Planning, Mt. Hood Community College
Gresham, OR 97030
Wallerid@mhcc.edu

Abstract

As one part of a multifaceted evaluation of the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT), a case study approach was used to enable a deeper understanding of how a diverse group of six institutions attempted to achieve OCEPT goals and to learn more about factors that facilitated or hindered their efforts. Multiple sources of data were used, with heavy reliance on a series of on-site interviews. The analytical framework included a “depth” and “pervasiveness” typology of institutional change and a view of change as encompassing “meaning,” “organization,” and “effects.” While goals and accomplishment levels, as well as the depth and pervasiveness of change, varied across the six institutions, OCEPT-influenced changes most likely to be sustained included: new kinds and levels of faculty collaboration; peer-led teaching and learning approaches, and attention to evidence that these approaches positively affect student course performance; increased faculty awareness of their role in teacher recruitment, with related changes in classroom practices; and, continued strengthening of access to information and academic advising for those preparing to become teachers. These institutions, however, did not make significant progress on one major goal of the project—to increase the numbers of underrepresented groups interested in teaching careers. Change was affected by the compatibility of OCEPT goals with institutional and faculty culture, as well as by local collaborative leadership, the size and complexity of the institution, the presence of “boundary spanners,” and how OCEPT resources were used.

Introduction

The Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT) is a statewide collaboration of institutions of higher education dedicated to strengthening the math and science preparation of future teachers and encouraging greater involvement of underrepresented groups in the teaching profession. Many other collaboratives funded by the National Science Foundation (NSF) have focused primarily on changes to specific courses
required for initial teacher licensure and involved a relatively small number of institutions. OCEPT’s strategy for change relied heavily on faculty development, including the introduction of teaching and learning strategies designed to further the goals of OCEPT, and involved 36 different institutions (public, private, two-year, and four-year). Figure 1 depicts OCEPT’s “theory of change,” derived by the authors from a review of OCEPT’s planning documents and reports. Expected outcomes, labeled as “3rd stage change,” are a greater number and a more diverse group of K-12 teachers better prepared to teach mathematics and science. These outcomes flow from a series of interventions. In “1st stage change,” the focus is on faculty development and formation of a series of inter-institutional disciplinary teams as well as several statewide interdisciplinary teams. In “2nd stage change,” the focus shifts to efforts to affect broader change in a smaller number of institutions, to bring about specific kinds of curricular and pedagogical reforms across institutions, and to increase faculty capabilities for teaching diverse learners.

![Figure 1. OCEPT Theory of Change.](image-url)

---

**T. CHENOWETH, M. KINNICK and R. WALLERI**
During the third year of the project, a focus on institutional-level change was added to that of the initial focus on individual faculty development. This strategy was designed to bring about institutional change that could be sustained in furtherance of OCEPT goals. Six “core” institutions from among the 36 initially involved with OCEPT were selected for special attention and resource allocation over the final three years of the project.

A case study methodology, one part of the multifaceted formal evaluation of OCEPT, was designed to address two major questions: 1) did these core institutions achieve OCEPT goals, and if so, to what extent? And, 2) what helped or hindered their efforts? The case study approach was designed to enable a deeper understanding of how a diverse group of OCEPT institutions attempted to achieve OCEPT goals and to learn more about the process of institutional and faculty change and the major challenges to such change. Findings on “lessons learned” are aimed at leaders in institutions considering a similar change effort, prospective funding agencies of such efforts, and those involved in the reform of mathematics and science education.

The case studies are built on institutional documents, OCEPT participant project reports, and a series of on-site interviews with both OCEPT participants and others at the institution with an interest in or involved in activities related to the goals and objectives of OCEPT.

The Case Study Design
Selection of Institutions — Using the criteria shown in Table 1 (not all of which applied to each of the institutions selected), the six institutions selected were: Oregon State University (OSU), Portland State University (PSU), Pacific University (Pacific), Portland Community College (Cascade and Sylvania campuses) (PCC), the University of Portland (UofP), and Western Oregon University (WOU). In the selection process, consideration was also given to the institution’s potential for moving beyond selected faculty and departments to a broader institutional effort in achieving the OCEPT goals. For example, Portland Community College was included since it has the highest enrollment level of minority students among OCEPT institutions. The result was a mix of types of institutions, including two private universities, one large urban community college, and three state universities. Among the three state universities, one began as a teacher’s college (WOU), another is the state land grant university (OSU), and the last is the state’s public urban university (PSU). Table 2 provides a brief overview of these institutions.
Table 1
Criteria Used to Select the Six Case Study Institutions

- Critical mass of faculty fellows from OCEPT Years 1, 2 & 3
- Perceived presence of strong local leadership
- Diversity of institutional type (private-public, 2yr.-4yr., research-teaching mission)
- Relatively large teacher education program
- Diversity by level of teacher preparation program offered—a mix of undergraduate and graduate programs
- Likelihood that faculty fellows’ courses/projects are serving, and/or will serve future teachers
- Potential for a significant number of students who enter their teacher education programs to have completed their lower division or undergraduate mathematics and science course work at the same institution or at a local community college
Table 2
Overview of the Six Case Study Institutions

<table>
<thead>
<tr>
<th>Institution</th>
<th>Type</th>
<th>Annual Headcount Enrollment</th>
<th>UG/Grad Teacher Educ. Programs</th>
<th>Faculty Fellows &amp; Staff Funded</th>
<th>Total OCEPT $s Received over 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oregon State Univ.</td>
<td>public, land-grant univ.</td>
<td>~18,000+</td>
<td>Grad. level only</td>
<td>20</td>
<td>~$290,000</td>
</tr>
<tr>
<td>Portland State Univ.</td>
<td>public, urban univ.</td>
<td>~20,000</td>
<td>Grad. level only</td>
<td>16</td>
<td>~$260,000</td>
</tr>
<tr>
<td>Pacific Univ.</td>
<td>private, indep. univ.</td>
<td>~2,020</td>
<td>UG &amp; Grad.</td>
<td>8</td>
<td>~$166,000</td>
</tr>
<tr>
<td>Portland Community College(Cascade &amp; Sylvania Campuses)</td>
<td>public, two yr.</td>
<td>Cascade-~17,200 Sylvania—~24,900</td>
<td>Not applicable</td>
<td>13</td>
<td>~$160,000</td>
</tr>
<tr>
<td>University of Portland</td>
<td>private, indep., Catholic univ.</td>
<td>~2,600</td>
<td>UG &amp; Grad.</td>
<td>18</td>
<td>~$200,000</td>
</tr>
<tr>
<td>Western Oregon Univ.</td>
<td>public univ.</td>
<td>~4,800</td>
<td>UG &amp; Grad.</td>
<td>25</td>
<td>~$260,000</td>
</tr>
</tbody>
</table>

Data Collection — The case studies offer observations on the status of each institution’s involvement in the OCEPT project through June 2002. The focus is on activities conducted from Fall 1999 through Spring 2002. Each case study is based on a review of OCEPT documents (annual OCEPT project reports, as well as proposals and reports from OCEPT faculty fellows) and a series of yearly individual and group interviews on-site. The first wave of interviews was designed to acquaint the researchers with the institution, its specific plan of OCEPT-related activities, key participants and institutional leaders, and progress toward goals. A second set of interviews included additional participants as well as other administrators and faculty who were not directly involved in OCEPT, but had been identified by OCEPT participants as working on related issues or could be viewed as critical to the overall success of the institutional change effort. A final round of interviews included individuals previously interviewed to ascertain progress, as well as new participants or others seen as critical to the success of the project. This last round of interviews involved many small groups in addition to individual interviews.
The interviews with OCEPT faculty fellows followed an interview protocol designed by the authors, and was structured to identify key components of the institution’s OCEPT-related plan, current success in implementation, and challenges in achieving OCEPT goals and objectives. Interviews with non-OCEPT personnel were more open-ended. A modified protocol was used in Year five interviews, and sought to identify what had changed and the degree of institutionalization of OCEPT initiatives. All sessions were tape recorded if approved by interviewees. The tapes were subsequently transcribed. Quotes or other information associated with a particular individual were not used without the individual’s consent.

Beginning in 2000, various drafts of the case studies were prepared and distributed to those interviewed and the OCEPT institutional leaders for feedback. Recipients were asked for feedback on the accuracy and completeness of the case write-up, and permission was sought for inclusion of quoted remarks. The drafts included a final section where the case study team member identified some “issues to be considered,” issues that had to do with progress toward OCEPT and institution plan goals. The draft was intended to help local leaders review progress and strengthen their project. Sharing of the drafts was intended as an intervention; that is, to have an effect on local developments. While feedback was received, there is little evidence to suggest that sharing the drafts had any appreciable effect on the direction or progress of the OCEPT-related activities at four of the institutions. Exceptions were Pacific and the University of Portland where the feedback appeared to cause participants to become much clearer about what they were trying to accomplish. Further, at Pacific, feedback and subsequent discussions related to the feedback may have contributed to the creation of the Natural Sciences Advisory Group, a development occurring at the end of the project.

Analytical Framework — The analytical framework used for the study was shaped primarily by three sources. Chenoweth and Everhart [1] suggest three conceptual organizers as a useful way to learn about change:

- **Meaning**—what the change effort means to those involved, how they feel about what is occurring, the language they use to talk about OCEPT, and their beliefs, values and symbols associated with OCEPT and the change effort; when there is ambiguity and lack of clarity, there is often a lack of deep commitment to or motivation for the change effort.
LESSONS LEARNED FROM EFFORTS AT INSTITUTIONAL CHANGE ...

- **Organization**—how the planned change is implemented and may be sustained, through what old and/or new structures, mechanisms and people, curriculum and instruction, sources of support, and timeframe.

- **Effects or Outcomes**—change in behavior, activities, perceptions, attitudes of faculty and students, and culture.

Interview protocol was developed to learn more about each of these dimensions of change.

Eckel, Green, Hill, and Mallon offer a useful two-dimensional “typology of change” in a higher education institution, one that considers both the depth (D) and the pervasiveness (P) of change (Figure 2) [2]. The result is four ways that change might be characterized: Type I—LowD/LowP=Adjustments made (tinkering, revising, revitalizing); Type II—HighD/LowP=Isolated Change (limited to one unit or particular area); Type III—LowD/HighP=Far-Reaching Change (pervasive, but doesn’t affect the organization very deeply); and, Type IV—HighD/HighP=Transformational Change (change touches the entire institution in deep and meaningful ways).

![Typology of Change](image)

Paulsen and Feldman offer a basis for evaluating the OCEPT change effort, one that focused heavily on faculty instructional practices [3]. In their framework, two factors play a
critical role in the instructional improvement process—the strength of the teaching culture of the institution and the nature of feedback to faculty about their instructional practices. Their model forces a consideration of both the organizational culture, and the motivation and learning processes of the individual faculty members in that organization [4]. Paulsen and Feldman suggest that the nature of that culture can serve to support or to impede efforts to improve instruction [3].

In addition to these three frameworks, Colbeck provides an analysis of a project similar to OCEPT with a focus on institutionalization of change [5]. In an attempt to assess an educational reform project in higher education institutions funded by the NSF, Colbeck developed an “institutionalization process model” that consists of three factors influencing the diffusion of reforms in curriculum and pedagogy. Diffusion is judged as occurring when “increasing numbers of individuals adopt the behaviors and attitudes associated with the innovation.” Her “regulative process indicators” correspond to the Chenoweth and Everhart “organization” dimension of change [1]. Her other two factors, “normative” and “cognitive” process indicators, generally correspond to the “meaning of change” dimension in the Chenoweth and Everhart schema. Reform diffusion in Colbeck’s model corresponds to “effects” in the Chenoweth and Everhart model. Colbeck found that normative and cognitive processes had greater effect than the regulative dimension on the diffusion of reform.

Limitations — Three limitations to the research design should be noted. The study relied primarily on interviews with OCEPT participants: faculty, staff and administrators. As indicated, an effort was made to identify and interview non-participants, but this was not conducted through any systematic sampling schema. Due to time and resource constraints, students were not interviewed except in one instance. Finally, the researchers relied on research and evaluation data generated by institutional faculty and staff about specific aspects of their projects, including effects on students. Some institutions received specific funding for such local research activity.

Findings: What Changed?

Viewing the six case studies as a whole, major findings were identified in four areas: peer-led team learning (PLTL), professional networks/collaboration, advising and dissemination of information related to teaching careers, and diversity. Sustainability of change in these areas is considered in a final section.
Peer-Led Team Learning — A primary effect of OCEPT at the six institutions featured in our case studies has been the successful development of Peer-Led Team Learning (PLTL) and Excel programs that spread to a number of the gateway or introductory courses in mathematics and the sciences. These courses include biology, chemistry, physics, and mathematics.

PLTL is designed for all students in large lecture classes and began as workshop chemistry at the City College of New York. In PLTL, students who have successfully completed the course serve as mentors to small groups of students in weekly discussion and problem solving sessions. Each student works with the same small group for the duration of the course. This approach personalizes instruction by opening up discussion to those reluctant to ask questions in the larger lecture format, and also has become a powerful means of enticing mentors into considering teaching as a career option. As one faculty member said, until this program, our students “didn’t understand the inherent satisfaction in helping someone learn.” Sample faculty comments corroborate the efficacy of the PLTL model:

The main benefit, everyone agreed, is what happened to those wonderful team leaders. And they just learned so much more chemistry and developed, you might call them teaching skills, but just being able to impart their knowledge. I set it up so there was a 2–hour optional workshop...It turned out to be more than just the chemistry questions. I think it helped with retention and just a feeling of community within the class. A number of them have talked about teaching and that they had never considered it before...They were held in such high esteem by both the students and the faculty that it became an honor to be chosen.

I have been here for 25 years and I don’t know of anything that I have had the opportunity to participate in that I feel has been so significant in changing for the better the academic culture for faculty, students, and peer mentors themselves. It is kind of a simple idea.

Excel, a similar program that originated with the work of Uri Triesman and his development of Math Excel for minority students in Texas and California college calculus
classes, provides a supplemental curriculum usually offered as a separate and optional workshop attached to a course. In the workshop, one or more student mentors monitors several small groups of students at the same time while the students work at problem solving. Faculty comments indicate very positive experiences with Excel:

I think that it was very successful. We had only nine students the first term. But everybody who ended up taking the class did really well in their regular lecture, as expected. But everybody was interested...we had people at the beginning who were really against it, a couple of students didn’t like the group work, thought it was a waste of their time. And at the end, they were the strongest advocates. It was really kind of funny so I had them write some evaluations. They have all been really positive. We’ll see. I think that it is really valuable. They have been encouraging other students to sign up for it the next term. So I think it was a really positive thing. I think it was really valuable for our peer leader, too. She really got a lot out of it.

It’s so easy to see students who are naturally good teachers when they are working with Excel groups. They’re all teaching one another. The natural ability to teach and explain things and to not just tell how to do it, but to actually teach and draw out and coach and draw out things from their peers. It’s so obvious in working in those Excel groups. It’s a place where we can encourage students to think about teaching as a career.

Two faculty members from one of the institutions, one in chemistry and the other in biology, described the effects of PLTL on mentors based upon mentor journals, student evaluations, and general observations [6]. They suggest that PLTL has five benefits for mentors: 1) better content mastery; 2) improved teaching skills; 3) fun (a surprise to many); 4) an opportunity for service and to feel valued; and, 5) the consideration of teaching as a career. Other data suggested that it was of great benefit for students as well. One biology student, for example, wrote in her course evaluation:

I really enjoyed the workshops and feel they are a big part of my improvement in this class. On the first exam, I did horrible...I jumped up 30 pts on the 2nd test...
Workshop leaders are so wonderful and nice. Always willing to help and answer questions. I give them an A+

Other assessment data also indicate strong effects on faculty and students (both mentors and regularly enrolled students). For example, faculty members, in describing their relationship with mentors, reported, “they really blossomed as colleagues.” Faculty members found their interactions and exchanges with mentors to be more time consuming, but extremely rewarding and very worthwhile in terms of their own professional growth and development as teachers. Mentors found their discussion and dialogue with professors about the challenges they were facing as teachers to be extremely motivating.

Serving as mentors clearly became the most powerful vehicle for attracting students into the teaching profession. Virtually all of the mentors found their experience to be profound, and many have begun to give consideration to teaching as a career. Even those, for example, who have decided to maintain their pre-med focus walk away with higher regard for the teaching profession and greater admiration and support for those who teach. It should be noted that the student culture typically frowns upon career choices that lead to teaching. There is a perceived status and economic differential that discourages students from following their hearts.

Evidence is convincing that the PLTL program has led to improved instructional techniques, powerful and increased rates of learning (especially for freshmen mid range—C and D students), higher grades, a personalized learning community, improved and collegial relations with peers and faculty, and the consideration of teaching as a possible career choice for a great number of the mentors. One faculty member, for example, reported that five out of six of her first graduating mentors went into some kind of teaching position or program. It should be noted that one of the authors of this study had lunch with a group of nine mentors and personally felt their enthusiasm for teaching as well as how they were wrestling with career decisions that would lead to teaching opportunities. Their interest in teaching as a career was not necessarily limited to high school, but also included the possibility of college and career-related training and professional development.

One OCEPT leader shared that while this impact on the mentors was envisioned by program planners, faculty came to perceive and value this outcome as the program developed.
Most faculty interviewed came to regard this program outcome as the most significant. Faculty are currently involved in further assessment activities to determine “what’s working, what needs to be changed, and how mentoring has impacted career choices.” Faculty will learn more from mentor journals and follow up observations to determine if students who have participated in peer learning have retained more in science. One research study completed at OSU found that Excel math students outperformed and attained higher grades than non–Math Excel students [7]. Two other research studies at OSU provide similar evidence of student performance, one involving students from the Educational Opportunity Program (a program that serves first generation and significant numbers of African-American, Hispanic, and Native American students) in mathematics and another of students in an introductory chemistry sequence.

Professional Networks/Collaboration — OCEPT has led to numerous professional development and learning opportunities for faculty across the institutions featured in the case studies. Most of the institutions have seen increased levels of collaboration between arts and sciences and education faculty, as well as increased levels of collaboration with colleagues at a statewide level leading to the emergence of a powerful statewide professional network. There are in fact many success stories. Virtually everyone interviewed reported numerous opportunities for collaboration with colleagues both on campus and at other institutions around the state. These collaborations have brought together community college and four-year institution faculty from the same discipline, K-12 teachers (as teachers-in-residence, supported by OCEPT) working alongside and collegially with university faculty, and math/science and education faculty together reviewing national and statewide standards that affect teacher licensure and developing new lower division courses.

People are very excited about team teaching and about interdisciplinary studies in the sciences... I think that OCEPT was a facilitator.

I think that the involvement that I’ve had with colleagues around the state would not have happened anywhere near the extent it has as a result of OCEPT.

I think one of the things that has been most valuable for me... is making contacts with other people that I wouldn’t normally have done. Often through the various meetings like the Showcase meetings and the Oregon Academy of Sciences...So
really developing some connections with other people at other institutions. That has been very useful for me.

Prior to OCEPT, there was little connection in most of these institutions between the school of education and the college of arts and sciences. One arts and sciences dean reported that, "In some ways, faculty are like farmers: this is my field; that's your field; his field is over there; you don't tell me to plant beets and I won't tell you what to do with your corn." Using the image of the field, OCEPT has had a significant impact on developing a "shared field."

It [OCEPT] gave us permission to talk to each other...and gave us permission through funding support to think that change is not a bad thing...I think one of the biggest successes with OCEPT was the conversation, the dialogue that was started between liberal arts and sciences and education...I think those chains of communication between math and science and education are excellent. We have young faculty, maybe not chronologically, but newer faculty who are talking to each other.

Thus, there have been increased instances of team teaching, cross-disciplinary curriculum planning, faculty sharing and learning from one another, and the inclusion of K-12 teachers as colleagues working alongside faculty. There has been increased networking and sharing of innovative ideas at: statewide OCEPT-sponsored summer institutes, showcases, disciplinary team meetings, writing retreats and assessment retreats; annual meetings of professional associations; and, statewide meetings of mathematics, science and technology councils, two of which were founded with OCEPT leadership. All of this type of work was encouraged and greatly enhanced by OCEPT’s financial support for professional development in ways not normally covered (i.e., release time, travel, lodging, etc.).

Advising and Dissemination of Information Related to Teaching Careers — OCEPT has also had a significant effect on beginning efforts to improve advising and the dissemination of information related to teaching as a career possibility. Several new education clubs have been founded and are growing. And, although the numbers are low, minority students are beginning to be actively recruited by faculty at several of the institutions to serve as peer mentors for PLTL and Excel programs. This approach may well become a very powerful advising and recruitment tool.
Other advising changes across the institutions include: changes in student handbooks and bulletin descriptions of careers in teaching; linkages with community foundations, student enhancement programs, and community colleges for supporting and mentoring K-12 and community college students toward university admission; improved articulation with community colleges through web-based information dissemination; the development of introductory classes in education for those considering careers in teaching; and, growing awareness by faculty of state and national K-12 standards in math and the sciences, as well as specific state requirements for teaching licensure.

Notably, one of the smaller private universities developed a natural sciences educational advisory group made up of representative faculty members from physics, chemistry, math and biology. A faculty member, with joint appointments in education and physics, facilitates the group. A mathematics professor reported:

The most significant outcome of OCEPT is the Natural Sciences Educational Advisory Group...It has had an impact on the material that we have available to students in terms of which classes they should be taking, what resources are available on this campus, and how students should go about preparing to become a teacher.

At one of the larger state universities, new student orientation procedures now include the identification of new students interested in teaching as a possible career path and subsequent regular communication with them through a listserv maintained by the college of science. Over 400 students are now on the list. A new education club communicates with prospective new members using a listerv. In general, greater attention is now being devoted to the advising of prospective teachers, much like what traditionally has been done in pre-medicine and other health-related fields.

Diversity — A primary goal of OCEPT across the institutions featured in the case studies was to increase the numbers of underrepresented minorities in math and science teaching. This was a challenging goal given Oregon’s relatively small minority population—16.8%. Perhaps reflecting this challenge, in the two private institutions studied and one of the public institutions, there appeared to be a sense of faculty resignation that recruiting a more diverse pool of math and
science teachers was currently beyond their capabilities. Although a number of promising initiatives have been developed, for the most part this goal has not been met. Faculty awareness of and a desire to attract underrepresented students, however, appear to have increased as a result of OCEPT participation.

Promising diversity initiatives identified include: partnerships with foundations and school districts; targeted scholarships; the mentoring and coaching of local middle and high school students; new advising structures, publications, and websites; the creation of a multicultural resource center; the creation of an education and science club; new linkages with community colleges; service learning opportunities in local schools; and, institutes aimed at helping high school students meet state standards.

These efforts are all promising but their payoffs appear to be years away. At least three of the institutions are located in centers of Hispanic populations, but very few inroads have been made into these communities. Beyond faculty awareness and some promising initiatives, systemic efforts to recruit and support students from underrepresented groups into math and science teaching appear to be absent. To date, only a relatively small number of prospective math and science teachers has been identified through direct efforts related to OCEPT; and, even fewer students from underrepresented populations have been recruited or identified. Although diversity has become an institutional initiative and priority at many of the institutions, how it relates to mathematics and science, and the recruitment and preparation of future teachers remains unclear.

Sustainability — PLTL and Excel workshops appear to be sustainable. They have been very successful, as documented through formal research, in terms of changing the academic culture about how teaching and learning can occur successfully, and in the “hearts and minds” of faculty. While the PLTL or Excel models have been adapted to fit the situation at each institution, faculty across the institutions have become more reflective about their teaching and clearly realize the advantages of using peer mentors in a workshop format for the development of smaller learning communities. Learning for students has become more personalized and thus more meaningful. PLTL- and Excel-organized courses have become institutionalized through a variety of means (i.e., PLTL-like workshops replacing traditional recitation sections, Excel workshops financed through regular departmental budgets, etc.), and it appears highly unlikely that instruction will revert back to the traditional lecture and recitation section format. The likelihood of
sustainability is great because the new course structures have become embedded in the culture of the institutions. Moreover, it’s more cost effective for institutions to work retaining and supporting students than it is to recruit them. One of the deans interviewed reported:

I think that we are all very convinced that this [PLTL] is helpful for the students and it is helpful for the peer instructors and it is helpful for us. That combination means that we really have a commitment to try to maintain it.

The development of professional networks and increased collaboration was another significant outcome of OCEPT. Most faculty interviewed reported that they would maintain their new relationships with colleagues both on and off campus. This may be a challenge, however, without OCEPT funds that enable their coming together (through release time, travel, lodging, and conference registrations). Moreover, in the future, new faculty may not have a specific structure or mechanism like OCEPT to encourage their collaboration and the development of professional networks.

Finally, all of the institutions studied have made promising efforts to improve their advising function and to disseminate more and clearer information about the possibility of teaching as a career. These efforts have deepened the knowledge base and awareness of advising issues. New structures have been created ranging from advising centers to coordinating groups to education clubs to new websites. At one university, a series of new formally approved education options associated with chemistry, botany, and environmental science have been developed for undergraduate students. Better and more accessible information on teaching as a career option has spread across all of the institutions.

Dealing with student diversity issues and the recruitment of underrepresented minorities remains a considerable challenge. There appears to be institutional commitment to dealing more effectively with the recruitment and support of increasingly diverse student populations. Furthermore, faculty awareness and a desire to be responsive is strong. However, there is a general sense of resignation or powerlessness about what can actually be done. What’s lacking is systemic institutionalized support and a laser-like focus on the recruitment of underrepresented
minorities into math and science teaching. Many interesting and promising initiatives are in the works, though, that could pay dividends in the coming years.

Findings: What Helped and Hindered the Change Efforts?

In this section, the Eckel, et al. framework is used to characterize the depth and pervasiveness of the change [2]. Then, using the several other analytical frameworks identified for use in this study, findings are identified and discussed regarding factors that appear to have helped or hindered the change efforts.

Depth and Pervasiveness of the Change — Using the Eckel, et al. framework, we found it difficult to place each case study institution—in one typology—high or low on pervasiveness of the change, and high or low on the depth of the change. Change at Western Oregon University and the University of Portland, and at Pacific University to a somewhat lesser extent, seems best characterized as Type IV or “transformational change,” high on both depth and pervasiveness. Change was evident in teaching and assessment practices, curricular structure, relationships between arts and sciences and education faculty, and recruitment and advising structures. Considerable evidence of change was found in faculty culture having to do with how things are done and with whom they are done.

OSU’s efforts were more difficult to categorize. One aspect of change, the recruitment and advising of prospective teachers, might also best be characterized as “transformational,” affecting many undergraduate science programs through the addition of education options and information made available to prospective teachers, including those at community colleges. However, another aspect of change, in teaching and learning practices in mathematics and the sciences, might best be characterized as “isolated change,” high on depth and low on pervasiveness, since the most significant change took place in parts of the mathematics, the chemistry, and the biology curriculum. Still, there appears to be some promise for the spread of these teaching and learning practices to additional parts of the curriculum in these departments and in physics.

At PSU, which also served as administrative agent for the grant, change in teaching and learning practices might also best be characterized as “isolated change,” high on depth (in mathematics and chemistry) and low on pervasiveness. Change may broaden, however, with the
recent receipt of a multi-year, NSF grant to support the Center for Teaching and Learning West (CTLW). CTLW will continue PSU's efforts at changing teaching and learning practices in the sciences and in education, and through the initiation of a special mathematics and science preservice education cohort in education. Changes related to the recruitment and advising of undergraduate students might be described as either “mixed” or tenuous.

Finally, at PCC, change in curricular and teaching practices were either confined to one faculty member (at Cascade campus) or are too formative at this point to characterize (at Sylvania campus).

Factors Enabling Deeper and More Pervasive Change — The Everhart and Chenoweth conceptual schema for accounting for organizational change (the dimensions of “meaning,” “organization,” and “effects”) and the Colbeck framework for accounting for the diffusion of reform in curriculum and pedagogy (“normative” and “cognitive” process indicators and “regulative” process indicators), provide a basis for identifying the conditions facilitating the change effort [1,5]. The “transformational” change observed at WOU, the University of Portland, and Pacific appears due to a combination of both “meaning” (similar to “normative” and “cognitive” process indicators) and “organizational” (similar to the “regulative” process indicators) factors. The nature of the OCEPT-promoted change, having to do largely with teaching and learning, was compatible with the existing faculty cultures in these three institutions, cultures reflecting the primacy of the teaching mission. While a similar faculty culture was present at PCC, many organizational factors were not and significant change has yet to occur. Table 3 offers a summary of the six conditions identified as enabling the deeper and more pervasive change at the three institutions.
Table 3
Six Conditions for Transformational Change at OCEPT Institutions

1. *Relatively small size*—less organizational complexity, more focus, greater cross-disciplinary interaction
2. *Strong collaborative leadership*—not only administrative support, but active encouragement and involvement on the part of administrators
3. *Undergraduate teacher education program*—facilitates strong connection between math, science and education faculty
4. *Boundary-spanners*—credible and active cross-disciplinary facilitators
5. *Strong teaching mission*—faculty culture where teaching is valued and rewarded
6. *Resource use*—providing opportunities for faculty to become engaged in the project and work with other faculty within their discipline as well as with faculty from other disciplines and from other institutions; a necessary, but not sufficient condition for change

*First,* the size of these three institutions, in terms of enrollment, is considerably smaller than the other three case study institutions. Change simply may be easier in smaller institutions where there is greater cross-disciplinary interaction, both formally and informally.

*Second,* strong local and collaborative leadership was enacted at all three institutions. As someone once said, “If you want change, you have to be the change.” Each of these institutions had individuals who were consistent advocates of and champions for the change and who were also involved directly in the change process. One institutional leader was a dean of arts and sciences and, notably, a biologist, who provided leadership at her own institution, as well as to the statewide OCEPT biology team, meeting regularly with her institutional OCEPT team. Another was a dean of education committed to change in teacher education, including standards-based teaching and assessment. Before OCEPT began, she had initiated conversations with faculty in liberal arts and sciences that led to increased subject matter requirements for prospective teacher educators. The efforts of this individual were coupled with that of two education faculty members with deep roots in the sciences and a new dean of arts and sciences who became a co-leader of the project. The third served as the coordinator of the teacher education program who at one time held a position in the physics department. This individual was also committed to standards-based teaching and assessment changes in math and science, and regularly convened her local OCEPT team to review activities and progress. Interestingly, the three key leaders are women.
Third, all three institutions have an undergraduate teacher education program. PSU and OSU have only fifth-year teacher education programs. While these programs serve some students from their own institutions, most come from other institutions. This structural condition appears to make more difficult connections between undergraduate math and science faculty and faculty in education. At the three institutions with undergraduate teacher education programs, many more students begin as freshmen, completing their math and science course requirements there. Faculty may be more apt to share responsibility for undergraduate education and to come together more easily around shared issues of teacher preparation. Notably, OSU and PSU, with fifth-year programs only, initiated significant efforts to help students identify an undergraduate career pathway to prepare to become teachers of mathematics and science. These efforts took the form of new student “clubs” and creation of new databases listing students expressing an interest in becoming teachers. These lists could be used to invite students to various events, club memberships and other activities. OSU’s expansion of “education options” for undergraduates majoring in a variety of science fields is a notable change and another way to help these students find a pathway into graduate level teacher education programs.

A fourth condition was the presence of individuals who might be called “boundary spanners,” those who enjoyed the respect of colleagues in mathematics, science, and education. Each of these boundary spanners played several critical roles, helping to convene planning groups and providing leadership for curricular change efforts involving cross-disciplinary teams. Three of these individuals were education faculty members. All three exerted enormous informal influence to help bring about change and were held in very high esteem by their mathematics and science colleagues. While such a “boundary spanner” existed at PSU, the “meaning” and other “organizational” factors were insufficiently present to enable the same level of change. No such “boundary spanner” was identified at OSU. Several of the Teachers-in-Residence (former or current K-12 teachers) at these three institutions, funded in part by OCEPT, also served as “boundary spanners” and in addition helped the university faculty come to understand more about the challenges facing K-12 teachers.

Fifth, each of these three institutions has a strong teaching mission and a faculty culture where teaching is highly valued. Indeed, at both Pacific and UofP, their very existence depends in large part on their ability to attract and retain their students. In the tenure and promotion process, high regard is given to teaching excellence, teaching and curriculum innovation, and related-
research and scholarly writing. Compared with WOU, UofP, and Pacific, few new tenure-track faculty at OSU and PSU became involved and/or sustained their involvement in OCEPT. Promotion criteria at OSU depends largely on research and publications; and at PSU, norms may be changing, with greater emphasis placed on research and publications for faculty advancement.

Paulsen and Feldman suggest that the instructional improvement process is strengthened where a strong teaching culture exists in the institution and faculty receive feedback about their instructional practices [3]. The second condition appears to have been present through increased opportunities for faculty to work collaboratively with other faculty in order to bring about course and instructional practices changes, as well as the initiation of formal inquiry into the learning of students associated with these changes. Faculty at all three institutions qualitatively and quantitatively received more feedback related to their efforts to change curriculum and instruction.

Finally, the sixth condition was the opportunity for faculty to meet and work with other faculty, both within their own discipline, but equally importantly, across disciplinary and institutional boundaries. Here is where OCEPT played a critical role, enabling these opportunities through making release time available, providing funds for travel and professional meeting attendance (including the OCEPT Summer Institutes held during the first three years), and money for student assistants and mentors, as well as for supplies and materials. The six case studies suggest, however, that financial support, in the absence of the other five conditions, could not have brought about the depth and pervasiveness of change observed at these three institutions and the considerable promise of the sustainability of this change.

Implications

This section identifies implications of the study for three different audiences: institutions interested in implementing a similar change effort, public and private funders, and mathematics and science reformers.

Institutions — Results from this study suggest that curricular and instructional change that can be categorized as “transformational,” and, by definition, sustainable, will be more likely in institutions that have a strong faculty teaching culture and a promotion and tenure system that values faculty involvement in these kinds of change efforts. The presence of individuals with
special collaborative leadership skills is also critical, and in particular, those who can “boundary span” mathematics, science, and education and bring these diverse academic sub-cultures to work together. Support from key deans appears important as does at least a lack of interference, if not full-scale support, from higher administrators. In this study, the buy-in, support, and active involvement of key institutional leaders, particular key deans, was critical to enabling deeper and broader change.

In institutions with a teaching mission, faculty teaching loads can be heavy. Time is scarce for faculty to work together to plan for curricular and instructional change. Funding is needed to provide release time during the academic year, summer stipends, and travel to professional meetings. The development of new professional networks, both inside and outside the institution, can help to sustain change efforts. Support for Teachers-in-Residence from the K-12 community also appears to help the change effort, in particular to help mathematics and science faculty come to see the critical role they play in teacher preparation.

Finally, the experiences at these six institutions suggest that efforts to increase the involvement of underrepresented groups in the teaching profession requires a more focused and sustained commitment by more individuals in an institution than a handful of faculty in mathematics and science. Such efforts most likely need to be multifaceted, including initiation of outreach and recruitment efforts, and targeting funds to minority students.

**Funding Entities** — The study suggests that preference in funding similar initiatives should be given to institutions that evidence an institutional culture supportive of the values underlying the planned change. This suggests that funding be targeted at institutions with strong teaching missions and a faculty culture that rewards efforts to improve teaching and learning. This is not to say that significant change, particularly in certain courses or in certain departments, cannot occur at institutions with a strong research mission; broader institutional change, however, appears to be much more difficult in these institutions.

Where a goal of the funding is to increase the representation of African-American, Hispanic, Native American, and Asian American students as future mathematics and science teachers, preference in funding should be given to institutions that have already developed a track record for outreach to these groups.
Mathematics and Science Education Reformers — Efforts by faculty at each of the case study institutions provide evidence, both research-based and anecdotal, that peer-led teaching and learning and Excel models that involve undergraduate and graduate peer mentors have considerable promise for increasing student learning in mathematics and science. Such curricular and instructional innovation has the additional side benefit of increasing interest in teaching careers among the peer mentors.

Conclusions

Sufficient local incentives must be in place to encourage faculty, new tenure-track faculty, and tenured faculty to become involved in the reform efforts. Promotion and tenure norms must value curriculum and pedagogical change, represented by new curriculum, new instructional and assessment practices, presentations at professional meetings, as well as articles in professional journals.

Efforts at deeper and broader change seem to be enhanced when faculty from mathematics, science, and education work together. Individuals who serve as “boundary spanners” can play critical leadership roles in these change efforts. These new collaborations can transcend debates about the relative importance of “process” versus “content” and result in new conversations and initiatives that can facilitate student learning in mathematics and science and the shared development of future teachers.

Bios

Thomas G. Chenoweth is Professor and Mary K. Kinnick is Professor Emerita in the Department of Educational Policy, Foundations and Administrative Studies, the Graduate School of Education, Portland State University, Portland, Oregon. R. Dan Walleri is Director of Research and Planning, Mt. Hood Community College, Gresham, Oregon.

They served as members of the OCEPT Core Institution Case Study Team from 1999-2002, and shared equally in the development of this article. The individual case studies may be accessed Fall 2003 from the OCEPT website: www.mth.pdx.edu/OCEPT.
References


Abstract

Geosciences for Elementary Educators engages future elementary teachers in a hands-on investigation of topics aligned with the third and fifth grade Earth/Space Science and Scientific Inquiry benchmarks of the Oregon Content Standards. The course was designed to develop the content background of elementary teachers within the framework of the science described in the content standards, to provide an opportunity for future teachers to explore the content area in relation to what takes place in the classrooms of elementary schools, and to initiate a community of learners focused on teaching science to elementary students. The course focused on four themes: the classroom teacher as an activity and curriculum developer using diverse resources to keep the content current and alive; the classroom teacher as educator dealing with the diverse backgrounds of students in a developmentally appropriate manner; the classroom teacher as reflective practitioner exploring the links among pedagogy, content, and student learning; and, the classroom teacher as citizen staying current with emerging policy issues and debates that impact education. In a course where process is extremely important, participants are assessed on what they can do with content and process knowledge through preparing lesson plans, presenting lessons in a simulated classroom environment, and developing a portfolio and journal. Lesson plans demonstrate participant understanding of inquiry, using models, deductive and inductive approaches, links between communication skills and content knowledge, and effective use of technology, including the Internet. For each topic, the mixture of demonstration, experimentation, inquiry, and lecture models are explored through investigation, discovery, and analysis.

Introduction

The introduction of content standards into the debate over reform in American education changed the framework for preparing future elementary teachers [1-4]. As concepts of standards-based education began to work through state and local reform movements, the alignment of practice in undergraduate programs where students receive their content preparation became the focus of efforts by the National Science Foundation to change practice through the Collaboratives for Excellence in Teacher Preparation (CETP).

The status of the earth and space science content area shifted to one of prominence among the science standards and encouraged efforts among the earth and space science
community to respond to the needs of teacher preparation through curricular changes in academic programs and the engagement of professional organizations [5-7]. At Portland State University, the changing status of the earth and space science content area within standards-based education, with funding from the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT), combined to initiate a course for future elementary teachers within the Department of Geology.

In this paper, we review the design, implementation and modification of \textit{G 355: Geosciences for Elementary Educators}. We also report the results of an assessment of course impact on career development of elementary teachers.

\textbf{Need for the Course}

At Portland State University, successful completion of course work and student teaching leads to recommendation by the Graduate School of Education for an Initial License to the Oregon Teacher Standards and Practices Commission. An additional ten-quarter credits are required for completion of a master’s degree and a Continuing Teacher License. Admission to the Graduate Teacher Education Program (GTEP) requires completion of an undergraduate degree and recommendation from an appropriate content-area advisor. The curriculum of the undergraduate degree may be from any of the disciplinary departments or a general studies degree. In addition to undergraduate major requirements, students preparing to be elementary teachers are provided a list of highly recommended courses. Prior to the 1999-2000 academic year, the only science courses included were \textit{General Biology} or three courses offered through the Center for Science Education (\textit{Natural Science Inquiry, Integrated Science Concepts, Context of Science in Society}). In the 1999-2000 PSU Bulletin, introductory geology courses and labs were added to the list.

In 1999, funding provided through OCEPT allowed development of \textit{G 355: Geosciences for Elementary Educators}. Once developed, sustainable course offerings require adequate enrollment to justify a shift of faculty resources. At the time, these resource needs were balanced against the need to develop the content background of elementary teachers within the framework of the science described in the content standards, to provide an opportunity for future teachers to explore the content area in relation to what takes place in the classrooms of elementary schools, and to initiate a community of learners focused on teaching science to elementary students. Annual enrollment of 25-30 students has met the enrollment requirement.
Process of Course Development

Michael Cummings and Denise Monte developed the original course. Monte, an undergraduate student in the B.A. program in Geology, was anticipating admission to the Graduate Teacher Education Program (GTEP) and a career teaching middle school science. Readings on teaching, learning, and geoscience education and weekly discussions were used to define structure, objectives, geoscience topics, and supporting activities. Cummings offered the course for the first time during Spring 1999. Michael Goodrich adopted the course structure and objectives when he became the instructor of record in 2001. Regular discussion, including discussions to prepare this paper, continues as the course evolves. *Foundations of Earth Science* was selected for the textbook because of its coverage of topics in the earth/space science content area [8].

Guiding Concepts for Course Development

Instead of exploring all the roles an elementary teacher plays in the lives of students, schools, and communities, the course focused on four themes: the classroom teacher as curriculum developer using diverse resources to keep the content current and alive; the classroom teacher as an educator dealing with the diverse backgrounds of students in a developmentally appropriate manner; the classroom teacher as reflective practitioner exploring the links among pedagogy, content, and student learning; and, the classroom teacher as citizen staying current with emerging policy issues and debates that impact education.

Table 1

<table>
<thead>
<tr>
<th>Topics Selected for Spring 2000 Offering of G355: Geosciences for Elementary Educators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standards-based education and developmentally appropriate practice</td>
</tr>
<tr>
<td>Standards-based education, Common Curriculum Goals, Content Standards, and Grade 3 and 5 Benchmarks</td>
</tr>
<tr>
<td>Developmentally appropriate practice at the elementary level</td>
</tr>
<tr>
<td>Writing lesson plans</td>
</tr>
<tr>
<td>Understanding minerals and their uses</td>
</tr>
<tr>
<td>Description of minerals and their identification</td>
</tr>
<tr>
<td>Properties of minerals and their uses</td>
</tr>
<tr>
<td>Rocks: the key to interpreting Earth history</td>
</tr>
<tr>
<td>Rock description and classification</td>
</tr>
</tbody>
</table>
The rock cycle and its applications

**Processes that change the Earth’s surface**
- Geologic processes at work at the Earth’s surface
- Geologic hazards associated with surface processes
- Field Study to examine processes that change the Earth’s surface

**Weather and the changing surface of the Earth**
- Weather patterns in the Pacific Northwest
- Basic meteorology

**Earthquakes and volcanic hazards**
- Plate tectonics and plate boundaries
- Hazards related to earthquakes and volcanoes
- Dealing with hazards

**Space science and the solar system**
- Introduction to the solar system
- Activities to explain night and day, the seasons, the changing night sky
- Orbits of the planets and moons

The selection of topics to be covered from the earth and space sciences (Table 1) is the responsibility of the instructor guided by the third and fifth grade benchmarks of the Oregon Education Content Standards [4]. However, once the major topic themes are identified, the exploration of the content is a shared responsibility between participants and instructor. During this exploration, the instructor models various active learning methods that are matched to the characteristics of the content and invites participants to examine the methods and evaluate their potential impact on student learning. The course participants explore content by developing classroom activities that are demonstrated through constructing lesson plans, handouts appropriate for use in classrooms, and presentation in a simulated classroom environment. Peer evaluation of classroom presentations encourages reflection on practice and clarity of content presentation. As the course progresses, participants develop skills in constructing and using knowledge with the instructor’s guidance and modeling and peer evaluation.

The mixture of demonstration, experimentation, inquiry, and lecture used in the presentation of each topic models teaching geosciences as they are practiced through investigation, discovery, and guided analysis. Within this framework, the study of rocks becomes one where examining, describing (writing and sketching), and comparing are primary activities while naming and interpreting are secondary. During the exploration, all participants are placed on an equal footing where common skills can be used and the prior knowledge that may be held by a few does not dominate the activity. Discussion and reflection on the activity emphasizes the
importance of allowing all students to have access to learning without feeling isolated by lack of prior experience or knowledge.

Organization of content knowledge in a useable framework and developing handouts that are appropriate for student use are explored through preparation of lesson plans. Table 1 presents a two-part framework for lesson plans. The first part is prepared from the perspective of the classroom teacher. Each item asks participants to focus on the complex process of developing effective activities aligned with benchmarks and standards. Participants are encouraged to concentrate on the educational objectives of their activities with emphasis on curriculum dimensions (what comes before and what is to follow), development of extensions that are appropriate to a variety of learning styles and levels, and the link between the activity and student inquiry. The second part of the lesson plan is written from the perspective of elementary students. Participants prepare handouts and worksheets for use with their activities and are encouraged to focus on the clarity of presentation, developmental and cultural appropriateness of requested information, effectiveness of the sequence of observations/interpretations, and the correlation between handouts and the fundamental characteristics of the content. For each item on a worksheet or handout, participants are required to justify its use and the educational objectives it addresses.

Participants are assessed on what they can do with content and process knowledge through preparing lesson plans, conducting classroom activities, and developing a portfolio and journal. Lesson plans demonstrate participant understanding of inquiry using models, deductive and inductive approaches, links between communication skills and content knowledge, and effective use of technology including the Internet. Conducting classroom activities demonstrates participant understanding of the use of problem solving approaches and the scientific method, classroom management, developmentally appropriate presentation techniques, understanding of cognitive and ethical development of elementary students, and the importance of sharing classroom materials. Participant-generated lesson plans and plans shared with peers form the nucleus of a professional portfolio.

Experience in elementary classrooms varies among participants. To provide a shared experience and to spark discussions based on classroom practice, participants are required to visit an elementary classroom and to share their observations with all participants. Participants are provided with a crib sheet to help them focus on classroom management techniques, student
responses to teacher prompts, and approaches used by teachers to engage all students in the learning process. The shared experience encourages students to reflect on their own vision of practice and the nature of the learning environment.

Public schools operate in a complex web of cultural, financial, and political influences. Often participants have not explored the impact of these factors on their career opportunities and professional practices. During the course, participants collect news items and discuss the impact of current events on practices in public schools. Near the end of the course, they prepare a synopsis of current events and a reflection.

The Course in Practice

We have adjusted the structure of the course based on assessment of participant background, career goals, response to assignments, and student learning. The adjustments include changes in classroom management, construction and grading of assignments, and participant potential.

In a course where process is extremely important, content is tested and used in a simulated classroom environment. To provide participants with an opportunity to present science lessons, engage other participants in the manipulation of materials, receive feedback from their peers, and practice their skills requires scheduling large blocks of time when, in fact, class time is limited to two, 2-hour class periods. The problem becomes greater as class size increases; current enrollment is between 20 and 25 participants. This classroom management issue has been addressed by allowing each participant the opportunity to make two presentations during the ten-week term. Prior to the first presentation, participants develop a scoring guide. This activity allows them to explore their own understanding of the components of a well-designed classroom activity and encourages reflection on their own practice. The first presentation is short and covers a narrowly focused subject. Participants are expected to incorporate feedback received from the first presentation into the second, a presentation of an entire lesson plan. Although these time saving devices help, this is an unresolved problem.

The task of developing lesson plans and work sheets for use in an elementary classroom is foreign to participants. However, constructing the bridge between content and pedagogy requires that participants engage in this process. Our philosophy is that one learns by doing. Successive lesson plans should demonstrate increasing sophistication not only in the pedagogy
used in the lesson plan, but in the richness of content knowledge. Although this progression of improvement should be evident, it becomes confused after students discover a wealth of classroom activities and lesson plans on the Internet. We encourage students to explore different websites to find resources. However, simply downloading an activity is not acceptable. Internet resources raise the basic question: Does the improvement in the quality of lesson plans during the term reflect an increase in content and process knowledge or increased skill at finding Internet resources? The question faced by instructors is how to evaluate lesson plans when the creative concept, design, and student work sheets may come directly from a website. Three approaches have been developed in areas of content evaluation, lesson plan format, and student worksheet requirements.

Many excellent websites present lesson plans that are developmentally appropriate, contain accurate and appropriate content, and have proven track records with classroom teachers. However, there are other sites that present lesson plans with factual and conceptual errors. Conceptual errors often arise from inappropriate use of analogs to illustrate physical processes in the geosciences. To help participants evaluate websites, lesson plans judged by participants to be appropriate are examined in class. The exercise helps participants evaluate the authorship of the website, the critical review it has received, and their responsibility as teachers to critically review material before introducing it into the classroom. Participants soon recognize the conflict between their own lack of content knowledge and the need to critically evaluate website content.

The format for lesson plans requires participants to respond to items that are rarely addressed on websites. We have identified four items that encourage modification from website lesson plans. The first requires participants to cast the lesson plan in a framework of educational objectives. The second requires consideration of the lesson plan within an earth and space science curriculum. The third explores extensions of the activity to address the learning needs of all students in the classroom. The fourth evaluates the potential of the lesson plan to prompt student inquiry.

The lesson plans must include examples of the written materials that will be given to students and examples of the products students are expected to produce. In the case of worksheets or data sheets, each item of any handout must be annotated to indicate why the item is included, how the item fits into the overall structure of the lesson plan, and the justification for the item in the context of learning objectives and curriculum development.
In addition to these process adjustments, issues related to background preparation and the nature of the earth/space sciences have arisen. How do we develop problem-solving experiences where participants may lack deep experience in this approach? Engaging participants in the analysis of examples of problem solving from everyday life experience is a start, but drawing participants into a deeper understanding of the problem-solving process in the context of the earth/space content requires the depth of content knowledge and problem-solving skills to grow at the same time. The first step lies in clearly distinguishing between observation and description, synthesis and interpretation, and evaluation. The second step engages participants in reflecting upon the process that takes place as they explore a topic. What do I need to know to talk intelligently about this subject? What models can I use to demonstrate the basic concepts of this subject? How do I construct classroom activities that engage students in the problem solving dimensions of this subject? At what point does this activity lead seamlessly into student inquiry? How do I recognize when this point has been reached in my classroom?

Participant understanding of standards-based education may be shallow. The standards and benchmarks are addressed by many earth/space science topics. Although participants are able to list the standards they feel their activities address in the lesson plans, their understanding of the physical linking of content to standards may be weak. One approach to strengthening this link is to engage participants in exploring the course textbook in relation to the standards. Constructing an outline that links textbook topics to specific standards and discussing how the topic specifically addresses the standard helps participants build the necessary content-standards links.

**Course Impact**

Institutionalizing courses specifically designed for the preparation of future teachers in science and mathematics is a goal of OCEPT. Through the support of OCEPT, *G 355: Geosciences for Elementary Educators* was developed in 1999 and subsequently became a regular offering of the Department of Geology. The course not only meets the enrollment requirements for the Department, but is perceived to be a significant benefit to future elementary teachers. In order to assess the benefit of this course for the development of elementary teachers, a survey was developed, approved by the Portland State University Human Subjects Research Review Committee, and administered as paper and web-based instruments to participants in the four offerings of this course. One of the objectives of the survey was to examine changes in attitude with stage of career development. Some participants are completing undergraduate
requirements. Some are currently in GTEP. Others are practicing teachers. The survey asked participants about their backgrounds and current status (Table 2), to rank their experiences in the course using a Likert Scale, to numerically rank the value of different components of the class, and to provide open-ended comments (Table 3).

Table 2
Background Questions

<table>
<thead>
<tr>
<th>Questions</th>
<th>Median</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I heard about <em>Geosciences for Elementary Educators</em> from: PSU course catalog Faculty member Friend or classmate Other source (please write in: _____)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. My ethnicity is: African-American Caucasian (Non-Hispanic) Hispanic/Latino Asian/Pacific Islander Native American/Alaskan Native Other (Please write in: ____ ) Decline to respond</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. My current status is: Undergraduate Student Post-Baccalaureate Graduate student enrolled in Graduate Teacher Education Program Teacher Other (Please write in: ____ )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3
Survey Questions Using Likert Scale, Median (5-point ordinal scale where 5 is highest, 1 is lowest) and Number of Responses

<table>
<thead>
<tr>
<th>Questions</th>
<th>Median</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. This course was a valuable asset in preparing me for a career in education:</td>
<td>5.0</td>
<td>32</td>
</tr>
<tr>
<td>5. This course has strengthened my ability to effectively teach science:</td>
<td>5.0</td>
<td>32</td>
</tr>
<tr>
<td>6. This course increased my knowledge in geoscience:</td>
<td>4.5</td>
<td>32</td>
</tr>
<tr>
<td>7. This course provided me with the skills necessary to construct effective lesson plans for teaching science in elementary school:</td>
<td>5.0</td>
<td>32</td>
</tr>
<tr>
<td>8. I would recommend this class to an aspiring elementary educator:</td>
<td>5.0</td>
<td>32</td>
</tr>
<tr>
<td>9. Please rank the value of the following components for this class between 1 to 5. Please leave blank if not applicable (Note: 5 = very</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The scoring of the survey results produces ordinal data that is subject to non-parametric analysis. SPSS (version 10) was used in this study. The differences in scoring among populations were analyzed using the Kruskal-Wallis test. The Kruskal-Wallis test examines the relation among k-independent variables and is deemed appropriate for comparing the responses to the survey questions. A 95% confidence level was assumed because the population size is small (n=81).

Eighty-one students completed G 355 during four years. Table 4 contains data on the population eligible for the survey. The percent response is calculated for the total number of participants (n=81) and the number of participants presumed to have received the survey (n=71).

<table>
<thead>
<tr>
<th>Table 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data on Participation in the Survey and the Number of Responses</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number completing course</th>
<th>Restricted addresses or deceased</th>
<th>Returned as not deliverable</th>
<th>Number of responses</th>
<th>Percent response</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>3</td>
<td>7</td>
<td>33</td>
<td>41%/46%</td>
</tr>
</tbody>
</table>

Participants were asked to provide information on how they discovered the course, their ethnicity, and current status. Many respondents (51%) indicated that they had discovered the course in the “PSU course catalog.” We can think of no compelling reason why students would browse through the University course schedule to find a course listed in the Department of Geology that deals with teaching geosciences to elementary students. Therefore, we believe the available options did not adequately address the item of interest.
The ethnicity of respondents is summarized in Figure 1. Nine percent of the respondents identified themselves as members of underrepresented populations in science and mathematics (Table 2). At Portland State University, 16.4% of the student population (Fall 2001) is comprised of these groups.

For purposes of analysis, the respondents were placed in five groups depending upon their response to the question on “My current status..” (Figure 2). Thirty percent of the respondents identified themselves as undergraduates at the time they completed the survey. The largest group self-identified as post-baccalaureate students (40%). These students have completed their baccalaureate degree, but may have been part of the applicant pool for admission into a graduate teacher education program at the time the survey was administered. The bulk of survey responses were received at PSU before the pool of students admitted into the spring cohort in the GTEP at PSU was announced. One respondent in this group had applied for GTEP. Two respondents (6%) self-identified as members of a current GTEP cohort. Six respondents (18%) are teachers and one respondent (3%) currently is not in school.
From the perspective of the course instructors, questions 4-7 examine elements of course design and objectives. The median of responses indicates participants “agree” or “strongly agree” that the course was effective in career preparation in these areas (Table 3). A median response of “strongly agree” to question #8, recommending the course to their peers, suggests respondents value the career preparation provided by the course.

On question #9, participants were asked to rank the value of course components. The first five items on the list were present each year the course was offered. Classroom visitation, review of current events in education, and a field trip were not included every year the course was offered. The results for these three items are viewed as inconclusive because of the inconsistent results produced when data are disaggregated relative to participant status. The median responses for the first five items on the list may be interpreted in at least three ways. Participants valued the benefit of preparing lesson plans, conducting classroom activities, and using models more than understanding cognitive development and the scientific method/problem solving. A second interpretation suggests that the current instructional design does not tie the importance of understanding cognitive development and problem solving into the classroom experience as effectively as the first three items. The third interpretation suggests that participants did not recognize the components of the course that addressed cognitive development and problem
solving as clearly as they did the concrete actions associated with developing lesson plans, conducting classroom activities, and using models.

The survey results explore changing attitudes among participants who completed the course in different years and who are currently in different stages of career development. For this analysis, the responses were examined for three populations, undergraduates, post-baccalaureate/current GTEP students, and teachers. At the 95% confidence level, the responses from these three groups are not significantly different except for question #7 (p = 0.015), “This course provided me with the skills necessary to construct effective lesson plans for teaching science in elementary school.” For this question there is a significant decline in the ordinal values from undergraduate to post-baccalaureate-GTEP students to teachers. The pattern is believed to reflect the practical experiences of respondents. For the undergraduate students, developing lesson plans is a new experience. Therefore, these students have few reference points to judge what is an effective lesson plan. Teachers, on the other hand, have classroom experience whereby they can judge what constitutes an effective lesson plan. They are likely to judge their skill level at the time they completed the course as inadequate to construct effective plans. However, for question #9 where respondents are asked to rank the value of preparing lessons as a course component, the responses are not significantly different among the three groups. Developing lesson plans as practiced in this course is an effective method to engage participants in the process of thinking about their future teaching practices, but the plans they developed apparently do not hold up under the scrutiny of practice.

Survey results indicate participants found the course valuable in their preparation as elementary teachers. This attitude is summarized by one of the respondents. “This class helped me as a new teacher know how to probe and inspire learning and the thought processes for learning to happen.”

Conclusions
Survey results indicate a high degree of satisfaction with the content and practices used in G 355: Geosciences for Elementary Educators to engage future elementary teachers. There is no significant difference in responses from course participants over the four years the course has been offered with the exception of lesson planning.
The survey results suggest that *Geosciences for Elementary Educators* is an effective element in the continuum of career development that starts by linking content and pedagogy in a disciplinary context and which is enhanced through the GTEP experience and refined through classroom practice.

Preparing lesson plans, conducting classroom activities, and using models are highly valued by respondents as components of the class. However, instructors need to carefully examine their approach to issues related to cognitive development and the use of the scientific method/problem solving to clearly engage participants in these important aspects of student learning.

**References**


METHODS OF SMILE: A SCIENCE SEMINAR COURSE IN “DELIBERATE EDUCATION”

E. DAVIS-BUTTS and R. COLLAY
SMILE Program, Oregon State University
Corvallis, OR 97331-3510
davisbue@smile.orst.edu, collay@smile.orst.edu

Abstract

Oregon State University’s Science and Math Investigative Learning Experiences (SMILE) Program is an enrichment program for minority and underrepresented K-12 students. Through an eight-year iterative process, SMILE has developed and refined a science seminar course that allows undergraduate and master’s degree students to explore science enrichment for youth. Students enrolled in the course are engaged in teaching and learning as a community of learners with a focus on service learning. The intended audience for the course is those students who are interested in working in educational settings with youth—as classroom teachers, science/mathematics professionals engaged in precollege outreach, and the like. The actual audience, though quite broad, represents those students who want to be better prepared as effective science educators in their various career roles. This article provides the context for the course, defines and examines “deliberate education” as illustrated by the structure and activities of the Methods of SMILE seminar course, highlights the elements of an effective community of learners as demonstrated through it, details the specific strategies and activities of it, and summarizes the next steps in identifying its impact in transforming the participants’ college experiences.

Introduction

In reflecting on the Program’s experiences in providing programs for students in grades 4-12, program staff became increasingly aware of the key role of college students in the higher education connections for precollege youth. This has been particularly true during the on-campus challenge events for precollege students. In providing an experience through which college students interacted with and supported the engagement and success of precollege youth, program staff became further aware of the wonderful quality of the experience, both for the precollege students and the college students supporting them.

Through the context of academic enrichment in math and science, the Science and Math Investigative Learning Experiences (SMILE) Program at Oregon State University has developed a model that nurtures the college preparation and entrance of underrepresented minority and other
underserved students participating in its after school clubs. The model offers a deliberate and delicate weaving of student experiences, participant and provider attitudes, and program, club, and community traditions. The structure of activities is one that: enriches the students’ support networks of families, schools, and communities; addresses the students’ perceived barriers to academic success; influences students’ choices; and, offers academic learning opportunities. The outcomes and evaluations of SMILE programming have shown that through their SMILE Club participation, students more readily and more capably find reasons to persist and attain in school, and develop broader visions of their future.

In a 1999 report, the National Task Force for Minority High Achievement (NTFMHA) addressed five factors that have been found to strongly influence educational outcomes for students of different groups: 1) economic circumstances; 2) level of parents’ education; 3) racial and ethnic prejudice and discrimination; 4) cultural attributes of the home, community, and school; and, 5) quality, amount, and uses of school resources [1]. Along with these real influences are students’ perceived barriers to their academic success and educational attainment, their self-efficacy beliefs, and their outcome expectations [2]. NTFMHA concludes its report with a recommendation for a commitment to affirmative development from diverse public and private sector partners.

These research findings inform SMILE’s efforts to address the achievement differences among students from diverse groups. The SMILE Program serves ethnic minority, low-income, and rural students—students underserved in traditional educational settings and underrepresented in higher education, most notably in science, mathematics, engineering, and the biomedical majors and careers. A number of factors influence program design and activities: promoting membership in a safe, supportive community; fostering the development and use of life skills, highlighting the role and use of tools and strategies to aid persistence; enriching students’ intrinsic resources; minimizing extrinsic barriers for students; strengthening resiliency of youth; and, capturing vivid visions for youths’ academic possibilities.

In helping precollege students build their academic visions, program design includes an annual college-connection challenge event. College student mentors are essential to the success of these events. The need to support them in their roles with the SMILE Program led to a unique science seminar course. An underlying question in the development of the course was: What role might university students play in helping to make academic content exciting, higher
education visible and accessible, and career options viable and personal for precollege students? In their study of a project funded through the National Science Foundation to place graduate and advanced undergraduate students in high school science classrooms, Trautman, Avery, Krasny, and Cunningham shared the observed and real, non-academic benefits of having the university students serve as role models for the high school students, communicate an infectious excitement about science, and present the picture that scientists are people as real as the precollege students themselves [3]. With a similar intent, the *Methods of SMILE* seminar course was designed to develop a cohort of students who have reflected on science teaching and learning, their own roles as science educators, and the implications of deliberate education. These students are then prepared to incorporate many of the course elements in their future roles as classroom teachers and science educators in a variety of other settings.

To support the early field experiences of elementary education majors or master’s of arts in teaching students, the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT) provided funding for eligible seminar participants to serve in the dual roles of instructors and counselors at the Outdoor Science Adventure for elementary SMILE students, a field-based college connection event designed for academic enrichment and mentoring. Later, author Collay, as the course instructor, was selected as an OCEPT fellow, supporting SMILE’s involvement in statewide efforts to impact the preparation of science and mathematics teachers. Substantive, ongoing support in the field is a critical element in the retention of classroom teachers [4]. Given this context, how does a seminar course in deliberate science education fit into a broader teacher education agenda?

**Deliberate Education**

Education may have both explicit curriculum outcomes and implicit, hidden outcomes. Each year in preparing for the *Methods of SMILE* seminar course, the authors and, then, co-instructors of the seminar, had numerous discussions and strategizing sessions on how best to address the explicit outcomes of the course and anticipate and reveal the unintended outcomes. The effects of the hidden curriculum, often influenced by a classroom teacher’s behaviors, have been intensely studied and have been shown to put in place barriers that hinder the academic achievement and educational attainment of significant numbers and groups of students [5-7]. As they addressed the need for a broader agenda in school reform, Battistich, Watson, Solomon, Lewis, and Schaps spoke to the danger of relegating some non-academic to the hidden curriculum...
Establishing a teaching and learning environment that nurtures successful experiences for teachers and students requires two critical elements: having clearly defined outcomes and striving to have them realized by each participant; and, implementing and acting on the results of various assessment strategies designed to inform practice and indicate progress toward the realization of outcomes. The authors realized that their own process in considering, adopting, and refining course methods represented significant outcomes for the seminar’s participants—those of recognizing and striving to understand the unintended outcomes in a teaching and learning environment; making choices to change those outcomes; and, being deliberate in providing supportive and relevant experiences that address students’ long-term goals as well as their short-term outcomes.

The authors began to use the phrase deliberate education to signify the intentional and careful attention that they were giving to: (a) fostering the participation and successful engagement of learners by planning for and designing around the desired outcomes; (b) developing multiple strategies for assessing the various learning experiences, the short- and long-term outcomes, and their demonstrated efficacy; and, (c) gaining and employing skills in reflecting on processes and personal efficacy, intentions, and behaviors. Choosing to be a deliberate science educator requires one to recognize that enthusiasm and personal interest in science content alone is not enough to successfully engage students in that science [7]. Effective deliberate science educators will strive to help all students feel comfortable with and connected to science [7]. In general, the goal of deliberate education is to make education matter to all students—to give education a personal, cultural, and real-world context and thus establish a base for literacy and competence.

Deliberate education in the SMILE Program is premised on the disparity in the learning opportunities and the widening achievement gaps among different student groups, especially in the areas of mathematics and science. According to a report from the National Center for Education Statistics, “the values, beliefs, perceptions, and attitudes the students themselves hold regarding mathematics, science and engineering subjects and related careers differ across gender and race/ethnicity.” [9] The report also showed gender differences in self-perceived ability and persistence, with young women persisting less and having lower self-perceived ability.
this context, deliberate education in action requires that teachers and other education providers carefully consider how to create learning opportunities that both improve young women’s self-image and self-efficacy in relation to math and science and also prepare them for careers in these areas.

**Content in a Context of Community**

One of the most powerful elements for the seminar course is implementing tools that help build a community of learners. Creating community and fostering a sense of membership is a way to provide a place where learning is fun, where opportunities abound for community members to engage in higher order thinking and problem solving, and where members have the freedom and encouragement to participate in nonthreatening ways [10]. Building a caring community is essential if educators hope to eliminate the unintended outcomes of reinforcing low self-efficacy and/or self-image, and aiding low levels of students’ intrinsic motivation to learn.

A community of learners is an environment in which members are able to make connections, share resources, bring and receive support, create innovations, and build new collaborations. In any community, members have defined and revealed roles, build a foundation for common understanding, and establish shared goals. In the community, the shared goals include supporting and fostering learning, working as a collaborative team to facilitate the work and accomplishments of individuals and the team, accepting each other’s foibles with patience, and honoring each other’s accomplishments with accolades. It is important for educators to understand that academic achievement is impacted by the social-emotional factors connected to family, school, and the larger community [11]. Any person hoping to positively influence the lives of students will best optimize their impact by understanding interplay of these social-emotional factors and the larger community on students’ academic visions and achievements, as well as their educational attainment.

How does one develop and foster shared goals even as the roles in the community are being defined? Can the experiences for the participants be structured so that each feels comfortable in the process of forming community and supported by the community’s participants? The goals of the community, the context and the content to be explored can be supplanted by the process if care is not taken to ensure that participants are engaged and buy into the values and central tenet of the community. Purposeful intent is needed to help participants develop a sense of place, support, and inclusion in a community [12]. Outcomes of an island
experience used to build collaboration and community among future school counselors revealed that the hands-on learning actually addressed the overarching goals of the program. These goals included: (a) building consensus, cohesiveness, and a sense of community among all attendees; (b) encouraging everyone impacting students to work systemically; and, (c) harnessing this collaborative energy and spirit to further the aims of the comprehensive program [13]. The SMILE Program places great value on the need for, the efforts required to realize, and the benefits of building community among all of its program’s constituents, including the students in the science seminar course. The remainder of this article is devoted to sharing how the design of the course shows a deliberate blending of program mission, research, and the growing program vision for enriching the college student experience.

The Methods of SMILE Seminar Course

At the beginning of each year’s seminar course, participants learn about each other's skills, backgrounds, and interests. In fact, “affirming identity is not contradictory to, but rather a prerequisite for building community.” [14] A favorite seminar activity is one that emphasizes that the course will be different, and who the participants are and what they bring to the course matter. During the “Nonverbal Interviews” opening activity, students are asked to form pairs, share a large piece of poster paper, and introduce themselves through drawings (without using letters or numbers). Students work for ten to fifteen minutes to create their drawings using crayons, markers, and colored pencils. At the end of this time, within each pair, students exchange drawings and spend five minutes looking at and “interpreting” their partner’s drawing. Again, this happens while students are restricted from talking. Finally, each pair of students stands in front of the larger group and, using each other’s drawing, introduces each other. While this could be a very uncomfortable and risky activity, the participants are encouraged to participate and are reassured that at the end of each pair’s introductions, the members of the pair will have the opportunity to correct any misinterpreted information. Consistently, class members find the activity fun and quite different. The course instructors continue to use the activity because it sends a number of important messages that recur throughout the course.

First, the activity is challenging to do! Students find it hard to distill who they are through drawings without words. It is a further challenge for someone else to decipher these drawings and, based on that information, stand in front of a group of mostly unfamiliar faces and introduce someone you’ve just met. Although the activity provokes discomfort among the students, the role of the activity in building a sense of community in the class helps make each
person's participation matter. It is also a very different introduction from what one might otherwise say when asked, "Who are you?" The participants share much more about family, birthplace, religion, hobbies, skills, and interests than one might expect. Each drawing paints a very vivid picture of the participant, and the activity forms a common and challenging experience shared by them all.

At this point course instructors share the purpose and objectives of the seminar course. The purpose of the Methods of SMILE seminar course is to develop a diverse population of qualified and interested college students who are committed to expanding their skills in and appreciation for teaching and learning and who may choose to work with the SMILE Program in its education and outreach activities in the local community. Specific course objectives include:

- Promoting awareness of the issues impacting education of rural and minority youth
- Fostering the development of community building skills
- Encouraging awareness of social issues surrounding the diversity of cultural and ethnic groups in the United States
- Investigating the role of modeling as a teacher and lifelong learner in the educational setting
- Providing a forum through which students may absorb, analyze and synthesize ideas relating to science teaching using a multicultural education approach
- Providing an arena for students to develop science teaching strategies to address diverse ways of learning
- Providing opportunities for developing skills in science curriculum creation addressing the issues of diversity
- Modeling the SMILE approach to education

Specific strategies used by course instructors, in addition to building community are: (a) practicing communication skills and science teaching strategies that reflect overall course objectives; (b) modeling pedagogical strategies that promote learning for diverse learners; and, (c) allowing flexibility in teaching to address students' needs.

Another central tenet of the course is the use of various strategies to share information. The students' first class paper is the "Student Information" sheet. This form is structured to
provide basic contact information, as well as elicit from students their reasons for taking the course, the experiences they bring to the community, and most importantly, the outcomes they hope to realize through the course. The instructors read these and begin course modification to ensure that the course reflects those things the students say they want to learn, while maintaining the intent and integrity of the course.

Seminar participants are expected to be reflective practitioners, and the instructors model the strategies, share writings and readings, and provide support and encouragement to help students develop their skills in this area. This mentoring is seen as a key element in helping novice reflective practitioners move through the developmental process [15]. Students are asked for specific reflections in two ways. They reflect on the implications of the course readings and the experiences in which they are engaged on how they may choose to relate to youth as science educators. In addition, students are asked to reflect on their ideas about learning and learners, and how these ideas might shape their practice as science educators. As the course progresses to week five and again to week nine, students participate in outreach events at two local elementary schools. These family nights give students opportunities to try out science activities, explore their roles as science educators doing outreach, and provide a service for and make a connection with community members. In a supportive atmosphere, students apply what they have been engaged in throughout the course.

**Evaluation**

A realization of the synergistic interaction of evaluation and program design is embedded in the *Methods of SMILE* seminar course. Instructors consciously and consistently ask about and reflect on each class. Each discussion and reflection provides a piece of the puzzle that examines the effectiveness and impact of course format and experiences. The course goals and instructor flexibility make it possible to make changes in what was planned and how the class unfolds during the evening. When it becomes clear during the two hours that objectives are not being met and/or materials are not sufficient for the next step, the deliberate educator assesses the points of disconnect and embarks on a different path, using different strategies and materials to help participants achieve the desired outcomes.

An example is taken from the preparation for the first outreach presentation. The class members work through each of the activities they will teach at the Family Math and Science Night. Knowing that the focus of the event is engaging students and their families in fun math
and science activities, students need to understand the logistics and feel competent in the content of each activity and recognize that a course outcome for them is focusing on the process of teaching. Sometimes it becomes apparent that seminar participants have had fun in planning and rehearsing the activities and learned about the intent of and goals for the event, but they have spent little, if any, time reflecting on the teaching. Through a combination of discussion and questions, instructors are able to help students refocus on their practice as educators and guide them through formulating questions to ensure that the event addresses the community members being served and the college student participants as they define themselves as deliberate science educators.

The final presentation is an evening of evaluation. Students present their final class projects in the context of a desert potluck; food, as a powerful social messenger, helps set the stage for community closure. Students prepare and deliver their final projects. Students are asked to create and present a five-minute program on what they learned from the class. They can present it in any fashion they choose, from art to readings, to activities to songs. Students have chosen a wide range of strategies and styles to use over the years. What is clear is that the students feel supported in their own process by the structure and by other class members. Class members are encouraged to write notes about each presentation; they share these at the end of all presentations. Each presenter receives the notes written by others to know that she or he has contributed to the community and impacted the lives of the other members. While a number of presentations stand out, all of them represent the students’ personal reflections on a process and their own journey into teaching and learning.

At the end of the evening, they fill out both the SMILE-designed evaluation and the Department of Biology evaluation. From the students’ written comments, themes have emerged. The class is one of a kind. Students state it is hard for them to compare their experiences in the SMILE seminar course to those in their other courses because of the stark differences in format, goals, and student involvement and engagement. Students often rate the course as one of the best of their college experience. The factors that support their responses include purposeful attention to creating a sense of community, the team-based approach to their hands-on learning, and real evidence of affirming and valuing each participant. These responses make it clear that the seminar participants have been engaged in a learning environment that was supportive, inclusive, challenging, and enriching.
The course has influence consistent with its design. A number of seminar participants have made career decisions based on their experiences of being in the course and working with the SMILE Program in its activities for club members. One science major, working on his master's degree, took the class because a friend brought him along. The student then worked for the SMILE elementary outdoor science camp and decided that his calling in life was to teach young people. Soon after, he enrolled in an MAT program and is now a middle school science teacher.

Another seminar participant served in numerous roles with SMILE—resident advisor for three middle school summer science camps, instructor/counselor for four elementary camps, and team mentor for several on-campus events for middle and high school students. After completing her degree in environmental science, she realized that her long-term volunteering with SMILE was her attempt to address her desire to be integrally involved in the education of youth. She made a career change. She entered and completed an MAT program, became a fourth grade teacher, and served as an elementary SMILE Club advisor. She has since transferred from the district with the SMILE partnership, but she is still a classroom teacher.

The Next Steps

As researchers did for the Science Outreach Program at George Fox University, the Methods of SMILE instructors need to conduct further action research “to document, analyze, and interpret the experiences of the participants” in the seminar [16]. On a longer time scale, an important question to ask is what students perceive as the influences from the course that persist in their careers as teachers and science educators, and their views about and efforts to build community where they live and work.

One of the desired outcomes for the course is to encourage students of color to take the class and, hopefully, get involved with SMILE activities. While some minority students participate, they have never emerged as a majority of seminar participants. Effort and attention are needed to look at the reasons the participation of minority students is so low. Pat Gurin, a social psychologist, found that students who experience the most racial and ethnic diversity in and out of their classrooms showed the greatest engagement in active thinking processes, growth in intellectual engagement and motivation, and growth in intellectual and academic skills [14]. How might the participation of minority students be increased so that the full benefits of engagement in a diverse community are realized for all seminar participants?
With the emphasis on science education reform and the call for greater collaboration between university science faculty and teacher education faculty, what role does a seminar course in deliberate science education play? [17] How might this seminar course become a more integral partner in institutional efforts to build stronger science teacher education collaborations, provide education outreach experiences for science majors, and promote a lifelong value for and commitment to science education and outreach? Is it possible to make a definite link between the nontraditional content and strategies of the Methods of SMILE seminar course and the academic benefits attributable to service learning? [18] The responses of the participants in the seminar warrant finding ways to address these questions and build a case and established place for the SMILE course in focused efforts to redesign teacher education at Oregon State University.

References


THE OCCURRENCE OF REFORM TEACHING PRACTICE IN UNDERGRADUATE MATHEMATICS AND SCIENCE CLASSES: THE STUDENTS’ PERSPECTIVE

P.D. MORRELL and J.B. CARROLL
School of Education, University of Portland
Portland, OR 97203
morrell@up.edu; carroll@up.edu

Introduction

It is a widely accepted adage that teachers teach the way they were taught [1]. Lortie states that what pre-service teachers experience in classrooms has a strong impact on the pedagogical choices they make as they move into their own classrooms [2]. Thompson, focusing on mathematics teachers, concurs, believing that after years of receiving traditional instruction, it is very difficult for teachers to conceptualize teaching mathematics differently [3]. If we want mathematics and science to be taught in public schools in a more meaningful way, then pre-service teachers need to be exposed to the teaching of these areas in a more meaningful way.

Reform of both science and mathematics curricula and classroom practice has been a focus of many groups for over a decade. Related to science teaching, various initiatives present a common series of suggestions for reformed approaches in science teaching: Project 2061; Scope, Sequence, and Coordination of Secondary School Science of the National Science Teachers Association; the National Research Council; and, the National Committee on Science Education Standards and Assessment [4-8]. Similar work in mathematics has been generated by the National Council of Teachers of Mathematics and initiatives funded by the National Science Foundation [9-13]. Uniformly, the suggested approaches are more constructivist in nature and demonstrate a need for students to reflect on their own learning. Coble and Koballa outline recommendations for reform in order to improve teaching, stressing the areas of learning facilitator, assessor of learning, reflective practitioner, and pedagogical content knowledge expert [14].

Research has shown that pedagogical knowledge may be more important than pure content knowledge in being an effective mathematics or science teacher. This demonstrates the need to focus attention to Schulman's concept of pedagogical content knowledge in both mathematics and science education [15].
Helping pre-service teachers move in reform directions remains problematic. For reform to occur, students need to see improved teaching practices at all levels of their education, particularly during their college experiences. Some evidence is appearing that training of college level content faculty may have a positive impact on the instructional strategies selected by first year teachers coming from those programs [1].

In August 1997, the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT) was funded for five years as part of the Collaborative for Excellence in Teacher Preparation (CETP) program of the National Science Foundation. The main goal of the program was to strengthen teacher preparation in science, mathematics, engineering, and technology. One major way OCEPT identified to achieve that goal was to engage faculty currently teaching undergraduate science and mathematics courses in a critical examination of their instructional practices. As the reform movement entered the consciousness of college-level instructors, OCEPT sought to assist the change of teaching methodologies. Through a variety of interventions, OCEPT hoped to encourage among these faculty members the use of particular kinds of instructional practices advocated by various state and national educational reform reports.

Purpose

The purposes of this study were two-fold: 1) to measure the degree to which pre-service teachers perceive reform classroom practices occurring in their undergraduate college mathematics and/or science courses; and, 2) to determine if there has been a shift in these perceptions over time (pre-1990 to the present).

Methodology

Instrument — To gather information about the mathematics and science backgrounds of students entering teacher preparation programs in Oregon, a survey was developed by a group of college math, science, and education faculty involved in the OCEPT program. A portion of that instrument was designed to measure students’ perceptions of the instructional strategies they experienced in undergraduate science and mathematics classrooms.
The Classroom Experience section consists of twelve items that describe reform teaching and assessment practices (see Appendix A). The items were designed based on the national mathematics and science standards for teaching, instruments used by other CETP projects, and an instrument developed by the American Association for the Advancement of Science Project 2061 [5,7,9-11,16]. Students were asked to indicate how frequently they experienced each of the items in their undergraduate mathematics and science classes using a rating of 1 (not at all) to 5 (often).

The instrument was piloted across the state of Oregon (n=330) in 1997. After the initial administration, some questions were reworded for greater clarity. Content validity of the instrument was determined by a panel of college mathematics, science, and education faculty familiar with national and state mathematics and science reform efforts. A factor analysis on the items demonstrated a high degree of correlation among eleven of the twelve items, indicating a single factor represents approximately 50% of the variance among the items. The only item not correlated with the rest is “used computer technology in ways that enhanced my ability to learn.” This is the sole item of the twelve that is dependent on outside resources (e.g., equipment), which may influence if and how frequently this classroom experience is used. To gain some measure of reliability, a group of eighteen post-baccalaureate, pre-service students were given the survey twice over the course of a month. Paired t-tests showed no significant differences in the students’ responses [17].

Besides the twelve classroom experience statements, additional items were included on the survey instrument for the students to indicate in what time period they completed the majority of their mathematics and science undergraduate course work. The choices were: before 1990, between 1990 and 1994, and between 1995 and the present. These time divisions were chosen to represent the periods prior to the push for the current mathematics and science teaching reforms, the initial widespread dissemination of the NCTM, NRC, and AAAS guidelines for reform, and closer to the inception of the OCEPT project.

Sample — There are sixteen institutions of higher education in Oregon which have teacher preparation programs. In Fall 1998, 1999, 2000, and 2001, copies of the questionnaire, instructions for administration, and informed consent forms were sent to all sixteen institutions. Faculty members were asked to administer the survey to all students admitted to teacher education programs between June and December of the corresponding year; that is, undergraduate seniors and post-baccalaureates. Over the course of the four years of administration, 2,141 surveys were collected. Because not all institutions participated in the
survey administration, we do not have the data needed to determine what proportion of the total population is represented in our findings. Sampling data are presented in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Student Responses</th>
<th>Number of Participating Institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>503</td>
<td>14</td>
</tr>
<tr>
<td>1999</td>
<td>624</td>
<td>13</td>
</tr>
<tr>
<td>2000</td>
<td>421</td>
<td>11</td>
</tr>
<tr>
<td>2001</td>
<td>593</td>
<td>12</td>
</tr>
</tbody>
</table>

Analysis — The data from all surveys were analyzed using StatView. Means and standard deviations were calculated for each item, by content area and by time period. Analysis of variance was run for the aggregate data for each item, using the item rating as the dependent variable and the time block the courses were taken as the independent variable. A Scheffe post-hoc analysis was performed when indicated.

Mathematics Results

The means and standard deviations of the student responses to twelve items concerning their perceived experiences in mathematics classrooms are listed in Table 2. The data are reported by the time period block that students completed the majority of their mathematics coursework. Also indicated on the table are the time periods for each item that had significant differences between the reported perceptions. Table 3 shows the corresponding data concerning science classroom experiences.
Table 2
Means and Standard Deviations and Results of ANOVA Analyses for each Item Indicating Students' Perceptions of Mathematics Classroom Experiences (Rating Scale of 1 “not at all” to 5 “often”)

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre-1990 Mean (SD) N=280</th>
<th>1990-1994 Mean (SD) N=337</th>
<th>Post-1994 Mean (SD) N=1,408</th>
<th>Significant Differences (p&lt;.0001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encouraged me to work on problems and projects with others</td>
<td>2.1 (1.2)</td>
<td>2.7 (1.3)</td>
<td>3.5 (1.3)</td>
<td>1,2 2,3 1,3</td>
</tr>
<tr>
<td>Used a variety of approaches to help me and other students learn</td>
<td>2.1 (1.2)</td>
<td>2.5 (1.2)</td>
<td>3.3 (1.3)</td>
<td>1,2 2,3 1,3</td>
</tr>
<tr>
<td>Provided a variety of ways for me to demonstrate what I learned</td>
<td>1.9 (1.1)</td>
<td>2.2 (1.2)</td>
<td>2.9 (1.3)</td>
<td>1,3 2,3</td>
</tr>
<tr>
<td>Helped me to make connections between the course material and the “real world”</td>
<td>2.2 (1.2)</td>
<td>2.4 (1.2)</td>
<td>3.2 (1.2)</td>
<td>1,3 2,3</td>
</tr>
<tr>
<td>Provided frequent feedback on my work that helped me improve my learning</td>
<td>2.6 (1.2)</td>
<td>2.7 (1.3)</td>
<td>3.4 (1.2)</td>
<td>1,3 2,3</td>
</tr>
<tr>
<td>Made learning goals very clear</td>
<td>3.1 (1.3)</td>
<td>3.2 (1.2)</td>
<td>3.7 (1.1)</td>
<td>1,3 2,3</td>
</tr>
<tr>
<td>Emphasized my understanding of “big ideas” or concepts rather than isolated facts and information</td>
<td>2.4 (1.2)</td>
<td>2.7 (1.2)</td>
<td>3.3 (1.2)</td>
<td>1,3 2,3</td>
</tr>
<tr>
<td>Expressed the belief that I could learn and be successful in their classes</td>
<td>2.7 (1.2)</td>
<td>2.9 (1.3)</td>
<td>3.6 (1.2)</td>
<td>1,3 2,3</td>
</tr>
<tr>
<td>Provided opportunities for me to “be” a mathematician (posing my own questions, investigating problems, analyzing data, developing theories)</td>
<td>1.9 (1.1)</td>
<td>2.1 (1.2)</td>
<td>2.9 (1.3)</td>
<td>1,3 2,3</td>
</tr>
<tr>
<td>Used computer technology in ways that enhanced my ability to learn</td>
<td>1.5 (1.0)</td>
<td>1.8 (1.1)</td>
<td>2.3 (1.3)</td>
<td>1,3 2,3</td>
</tr>
<tr>
<td>Required me to reflect on my learning through writing, journaling, etc.</td>
<td>1.3 (0.9)</td>
<td>1.4 (0.9)</td>
<td>2.2 (1.4)</td>
<td>1,3 2,3</td>
</tr>
<tr>
<td>Shared with the class their reasons for choosing their teaching strategies</td>
<td>1.5 (1.0)</td>
<td>1.7 (1.1)</td>
<td>2.4 (1.4)</td>
<td>1,3 2,3</td>
</tr>
</tbody>
</table>
Table 3
Means and Standard Deviations and Results of ANOVA Analyses for each Item Indicating Students’ Perceptions of Science Classroom Experiences (Rating Scale of 1 “not at all” to 5 “often”)

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre-1990 Mean (SD)</th>
<th>1990-1994 Mean (SD)</th>
<th>Post-1994 Mean (SD)</th>
<th>Significant Differences (p&lt;.0001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encouraged me to work on problems and projects with others</td>
<td>2.9 (1.3)</td>
<td>3.4 (1.3)</td>
<td>3.6 (1.1)</td>
<td>1,2, 2, 3, 1, 3</td>
</tr>
<tr>
<td>Used a variety of approaches to help me and other students learn (group work, lecture, field-based work, hands-on labs, demonstrations, etc.)</td>
<td>3.0 (1.2)</td>
<td>3.4 (1.2)</td>
<td>3.7 (1.6)</td>
<td>1,2, 2, 3, 1, 3</td>
</tr>
<tr>
<td>Provided a variety of ways for me to demonstrate what I learned</td>
<td>2.4 (1.2)</td>
<td>2.8 (1.2)</td>
<td>3.0 (1.1)</td>
<td>1,2, 2, 3, 1, 3</td>
</tr>
<tr>
<td>Helped me to make connections between the course material and the “real world”</td>
<td>3.0 (1.2)</td>
<td>3.4 (1.2)</td>
<td>3.6 (1.5)</td>
<td>1,2, 1, 3</td>
</tr>
<tr>
<td>Provided frequent feedback on my work that helped me improve my learning</td>
<td>2.7 (1.2)</td>
<td>2.9 (1.2)</td>
<td>3.2 (1.2)</td>
<td>2, 3, 1, 3</td>
</tr>
<tr>
<td>Made learning goals very clear</td>
<td>3.2 (1.2)</td>
<td>3.4 (1.0)</td>
<td>3.6 (1.0)</td>
<td>2, 3, 1, 3</td>
</tr>
<tr>
<td>Emphasized my understanding of “big ideas” or concepts rather than isolated facts and information</td>
<td>2.9 (1.2)</td>
<td>3.2 (1.1)</td>
<td>3.4 (1.1)</td>
<td>1, 2, 2, 3, 1, 3</td>
</tr>
<tr>
<td>Expressed the belief that I could learn and be successful in their classes</td>
<td>2.9 (1.3)</td>
<td>3.1 (1.2)</td>
<td>3.5 (1.6)</td>
<td>2, 3, 1, 3</td>
</tr>
<tr>
<td>Provided opportunities for me to “be” a mathematician (posing my own questions, investigating problems, analyzing data, developing theories)</td>
<td>2.5 (1.2)</td>
<td>2.9 (1.3)</td>
<td>3.2 (1.3)</td>
<td>1, 2, 2, 3, 1, 3</td>
</tr>
<tr>
<td>Used computer technology in ways that enhanced my ability to learn</td>
<td>1.6 (1.0)</td>
<td>2.0 (1.2)</td>
<td>2.5 (1.3)</td>
<td>1, 2, 2, 3, 1, 3</td>
</tr>
<tr>
<td>Required me to reflect on my learning through writing, journaling, etc.</td>
<td>1.7 (1.0)</td>
<td>1.9 (1.2)</td>
<td>2.2 (1.3)</td>
<td>2, 3, 1, 3</td>
</tr>
<tr>
<td>Shared with the class their reasons for choosing their teaching strategies</td>
<td>1.6 (0.9)</td>
<td>1.8 (1.0)</td>
<td>2.2 (1.3)</td>
<td>2, 3, 1, 3</td>
</tr>
</tbody>
</table>

Students tended to keep their ratings in the middle of the 1-5 scale. No items had a mean rating of 4 or above; several items were rated below 2. Three items were rated consistently as the lowest, and these were the same for both the mathematics and science classrooms; namely, use of computers to enhance learning, reflecting on one’s learning, and sharing reasons for choosing...
teaching strategies. The frequency of occurrence, as perceived by the students, increased significantly from prior to 1990 to 1995 and the present (p<.001) for each of the items in both content area classrooms.

**Discussion**

Looking at the comparisons between time periods, most striking is that science and mathematics instruction is perceived by students to be significantly more in alignment with new standards of teaching than it was just seven years ago. The differences are even more pronounced with a comparison of perceived instruction of twelve or more years in the past. Considering the conservative nature of change in education, this represents an encouraging trend.

Several items were rated at 3.5 or higher in the most recent time block. Three were common to both content area classrooms. All students felt that mathematics and science instructors had clear learning goals and felt they could be successful in the classes. Additionally, group work was a frequently used strategy. In science classrooms, students additionally felt the instructors used a variety of instructional approaches and helped to make the course content relevant.

Less encouraging is the number of items in the most recent time category with means at or below the midpoint of the response scale (2.5). In both mathematics and science, these practices are: “used computer technology in ways that enhanced my ability to learn,” “required me to reflect on my learning through writing,” and “shared with the class their reasons for choosing their teaching strategies.” Mathematics had two additional items: “provided a variety of ways for me to demonstrate what I learned” and “provided opportunities for me to be a mathematician.”

The item on technology may reflect a number of issues. The availability of technology in science and mathematics classrooms is not uniform in the institutions participating in the study. Low scores may reflect that the technology simply was not available. Alternatively, the question was worded to begin to address technology as a generative learning tool, and respondents may have been unable to imagine the technology they did use as enhancing their ability to learn [18].

Apparently, using written reflection is one of the strategies least likely to have made its way into college level math and science courses as an instructional tool. As noted above, in all classes group work was used frequently. By its nature, discussion among peers often requires
revisiting learning, and collaboration may be providing experience for this kind of reflection. College faculty may not be familiar with journaling, may not have experienced it first-hand, and/or may feel it is an unnecessary time burden for themselves and/or their students. A substantial literature base now identifies reflection as necessary in knowledge construction. We need to determine whether it is truly being omitted in these college level courses or whether it is just not required in a formal manner.

Sharing reasons for choosing teaching strategies is the only item that represents a need related to the discipline of education. All the other items are effective strategies to enhance learning in the fields of math and science—and most others. Openly articulating instructional reasoning is necessary to help students move toward enhanced teaching rather than enhanced abilities within math or science. Because most content courses are not geared just to pre-service teachers, and because most instructors (those in teacher education included) are not in the habit of vocalizing their thinking processes about planning and executing a lesson, it is understandable that the scores for this item do not indicate frequent use.

Particular to mathematics classrooms, students felt they infrequently experienced a variety of assessment techniques. Traditionally, mathematical assessments have consisted of solving closed problems, where one applies the correct algorithm(s) to arrive at the correct answer. Broadening mathematical thinking to include conceptual understanding necessitates a broadening of assessment techniques. It may be possible that college level instructors do not yet feel comfortable designing alternative assessment tools and/or do not have a variety of these tools readily available for their use.

Another item rated as experienced infrequently in mathematics classrooms is being provided with the opportunity to be a mathematician. Again, this is not surprising as most people have no concept of what a mathematician is or what a mathematician does.

Conclusions and Implications

The data collected indicate that undergraduate instruction in mathematics and science classes is moving toward the models recommended by the teaching reform movement. Basic teaching principles, such as providing clear learning goals and helping students feel they can be successful, are being implemented with more regularity. Group work is frequently being used in
the classroom. Some areas are still weak (e.g., written reflection), but all reform-based teaching practices are being utilized more often than they have been in the past.

Although there is no direct evidence to connect this positive trend to the efforts of the OCEPT project, it would appear that the types of interventions used by OCEPT should continue. College-level instructors need an organized way to be introduced to a variety of teaching and assessment methodologies. Collaboration and coordination among mathematics and science faculty and education faculty need to be encouraged and facilitated. Many instructors have already tried a variety of presentation and assessment strategies, and dialogue needs to occur as to what works, what has not, and to brainstorm future endeavors. College faculty need to be made aware of national, state, and local standards and be introduced to resources that are available to assist them in strengthening their instruction. They need to know (beyond the scope of their course evaluations) what students perceive as encouraging and impeding their learning. In addition, they also need to realize that non-majors and majors alike may eventually become our future teaching force.

There are several major limitations to this study that must be considered. The first is that not all institutions of teacher preparation participated in this study and data are not available to calculate a response rate. We made the assumption that the sample is representative of the population. Another concern is we are relying on students’ memories to describe their content classes’ classroom experiences. The time lapse between when they completed the coursework and when they completed the questionnaire may certainly have affected the ratings. Also, the students are giving one rating for all mathematics or science classes. It is hard to give one rating to a number of classes, and those most recent classes or classes with strong memories may have influenced the final score. Finally, as is the case with many Likert-type scales, the ends are defined, but the middle rankings are more nebulous. It is unlikely that all students viewed a score of 2, for example, in the same manner.

If we accept the premise that we teach as we have been taught, it is reasonable to assume that as we implement reform in college level mathematics and science classes, these changes will begin to be implemented in the lower grades, as well. Two questions are raised by this research. How accurate are the students’ perceptions of the classroom experiences in their college courses, and will changing college level teaching actually affect how pre-service teachers will teach once they are in their own classrooms? The answers to these questions will help to focus where efforts should be most effectively directed in promoting science and mathematics literacy for all.
Acknowledgments

The writing of this paper was supported by WRITE ON! a writing retreat facilitated by the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT), and funded by National Science Foundation grant DUE-9653250.

References


Appendix A

Items Found on Survey Relating to Classroom Experiences

Encouraged me to work on problems and projects with others
Used a variety of approaches to help me and other students learn (group work, lecture, field-based work, hands-on labs, demonstrations, etc.)
Provided a variety of ways for me to demonstrate what I learned
Helped me to make connections between the course material and the "real world"
Provided frequent feedback on my work that helped me improve my learning
Made learning goals very clear
Emphasized my understanding of "big ideas" or concepts rather than isolated facts and information
Expressed the belief that I could learn and be successful in their classes
Provided opportunities for me to "be" a mathematician (posing my own questions, investigating problems, analyzing data, developing theories)
Used computer technology in ways that enhanced my ability to learn
Required me to reflect on my learning through writing, journaling, etc.
Shared with the class their reasons for choosing their teaching strategies
PART II: REGULAR JOURNAL FEATURES

Virginia Mathematics and Science Coalition
Abstract

There are few instructional tools available to teach basic nuclear reactions to beginning students. The activity described in this paper can be used to help students visualize and write basic nuclear reactions such as alpha, beta, and positron decay, as well as electron capture. These reactions are represented using the technology of thermochromic paints, which either change color or turn colorless depending upon the temperature. By using a special thermochromic paint that turns colorless upon heating, students are able to visualize nuclear interactions. For instance, when positron decay occurs, the object depicting a proton will "decay" into a neutron by the application of heat. In order to avoid confusion, the heating instrument is referred to as a "time gun." This paper includes the details of preparing and incorporating the activity into the classroom environment.

Introduction

Nuclear chemistry is an interesting topic with many opportunities for real-world application and discussion in a general chemistry class [1-5]. Inclusion of nuclear chemistry topics has been encouraged in the undergraduate and high school chemistry curriculum since the late 1980s [6-8]. A published review, "Teaching Aids for Nuclear Chemistry," contains a number of articles that can be used as resources when incorporating nuclear chemistry topics into the classroom [9]. In addition, several activities and labs are available for modeling decay, or half-life, of nuclear particles [10-16], radioactive dating [17], experiments involving properties of isotopes [18-19], and simple radon measurements [20]. However, there are very few instructional tools available to teach basic nuclear reactions to beginning students [21-22]. Nucleogenesis, an instructional game, requires students to be able to quickly evaluate several possible decay reactions, as well as recognize unstable atoms with every player's turn [23].

Nuclear chemistry is a very abstract topic for students to comprehend. Confusion sets in when students discover that the particles that they used to identify specific atoms and elements when learning atomic chemistry can "decay" causing the identity of the atom to change. Not only
do the particles decay, they do so in such a manner that a proton can become a neutron and a neutron can become a proton. Also, students are introduced to the concept that electrons can be ejected from the nucleus during decay or that an orbiting electron can be captured by a proton to cause a nuclear reaction. These concepts can be very bewildering to students. Therefore, a more basic instructional tool can be useful in introducing students to the nature of nuclear reactions. The activity described below can be used as an instructional tool to introduce students to visualizing and writing basic nuclear reactions such as alpha, beta, and positron decay, as well as electron capture.

Alpha, beta, and positron decay, and electron capture are presented using the technology of thermochromic paint. Thermochromic paint has color changing properties that are dependent upon temperature. Some thermochromic paints may change colors while others turn colorless with an increase or decrease in temperature. By using a special thermochromic paint that turns colorless upon heating, students are able to visualize nuclear interactions. For instance, when positron decay occurs, the object depicting a proton will "decay" into a neutron by the application of heat. Although heat is the factor that makes this activity possible, instructors should be advised not to suggest that the decay occurs as a result of the heat. We have successfully avoided this potential problem by presenting the heat gun as a "time gun." The details of preparing and incorporating the activity are described below.

**Materials and Preparation**

Blue thermochromic pigment and acrylic base can be obtained from Middlesex University Teaching Resources (see Appendix A). One 5ml tube is ample for this activity. Blue, orange, red, black, and white acrylic paints can be purchased at any local arts and crafts store. One tube of 2-4 fl oz each is sufficient. Other light colors may be substituted for the orange. Wooden plugs (1/2"), flat or rounded, can also be obtained at an arts and crafts store or woodworking store. A total of nine plugs are needed per group. Hairdryers or heat guns are used for applying heat. Masking tape (2" width) is useful for holding the plugs in place during the activity.

Prior to using the paints, they need to be prepared for certain shades and consistencies. The regular orange acrylic paint should be mixed with a little white to brighten its color. The blue thermochromic pigment should be mixed with the acrylic base (approximately 1.75g of base
for every 1 g of pigment). The pigment must be mixed with the base in order to obtain an easily applicable form of the pigment that will be transparent upon heating (see Appendix B). The regular blue acrylic paint should be mixed with white, red, and black as needed to obtain the same shade of blue as the thermochromic paint mixture.

To prepare the materials for use in the activity, five wooden plugs are painted with orange acrylic paint. Only one side of the plug is painted because the other side will remain face down during the activity. Once the painted plugs are dry, one of the orange plugs is painted again with the blue thermochromic paint. A soft, camel hair paintbrush can be used to prevent the paint from streaking. This thermochromic blue plug is demarcated by placing an “X” on the back of it using a permanent marker. It is the color of this thermochromic plug that must be matched by the regular blue acrylic paint. As stated previously, the blue paint can be mixed with white, red, and black paints, as needed, to obtain the same shade of blue as the thermochromic paint mixture. Compare the colors when the painted plugs are dry. Once the correct shade of blue is obtained, it is used to paint four plugs. This supplies one set of plugs for the activity: four orange, four blue, and one orange covered with thermochromic paint. The paint can be used to make additional sets according to the number of students or groups that will complete the activity.

Procedure

In the activity, students build representations of nuclei using the blue and orange plugs as protons and neutrons. A piece of masking tape should be folded in a loop with adhesive side out and placed flat on the table. Students should group the particles of each nucleus close together on the masking tape so that heat can be applied evenly to all the plugs. The heating instrument should be referred to as a “time gun.” Instructors should be careful not to mislead students that heat is necessary for the decay to occur. When the particles are heated, the blue (X) plug turns orange corresponding to the opposite particle type. Students make observations before and after heating their particles and then write corresponding nuclear reactions. Different nuclei are used to represent different types of nuclear reactions. A copy of the handout that accompanies this activity is provided. Prior to beginning the activity, students only need to be familiarized with the proper notation needed for writing nuclear reactions: mass number as superscript, and number of protons as subscript in front of the atomic symbol.
Using this Activity as an Instructional Tool

There are four basic types of reactions covered in this activity: alpha, beta, and positron decay, and also electron capture. The reactions used as examples in the activity are given below in the order that they appear in the activity.

\[
\begin{align*}
\text{Alpha Decay} & : & {^7}_3\text{Li} & \rightarrow & {^4}_2\text{He} & + & {^3}_1\text{H} \\
\text{Positron Decay} & : & {^8}_5\text{B} & \rightarrow & {^8}_4\text{Be} & + & 0_e \\
\text{Electron Capture} & : & {^7}_4\text{Be} & + & 0_e & \rightarrow & {^7}_3\text{Li} \\
\text{Beta Decay} & : & {^3}_1\text{H} & \rightarrow & {^3}_2\text{He} & + & 0_e
\end{align*}
\]

Each part of the activity introduces a different nuclear reaction. Students are taken through four steps for each reaction. The steps are outlined below.

**Step 1:** Use the particles to make a representation for the nucleus. Sketch a representation of the nucleus in your notes.

**Step 2:** Observe the reaction by moving particles (alpha decay) or using the time gun (positron/beta decay and electron capture).

**Step 3:** Identify the new atom based on the particles that remain. Sketch a representation in your notes.

**Step 4:** Write a reaction corresponding to the changes that have just taken place by using the skeleton provided.

By beginning with the alpha decay, students can easily observe how an alpha particle can be removed from lithium-7 by displacing two blue and two orange plugs. In order to do this, students must know that an alpha particle is equivalent to the nucleus of a helium atom. After counting the particles and identifying the two new daughter atoms, students can fill in the reaction using the proper notation. Precise accounting of particles on each side of the equation will help students write the remaining reactions.
When students move on to the positron decay of boron-8 the steps are the same, but the reaction takes place when the “time gun” is used. One of the blue (darker) protons will change to an orange neutron because of the thermochromic properties of the blue paint used on that plug. Students then note their observations and write the reaction by using the appropriate skeleton. By using the concepts learned during the alpha decay, students are able to write the reaction for the positron decay without first knowing the notation for a positron. This pattern continues for the other nuclear reactions. Figure 1 shows an example of positron decay by boron-8.

Figure 1. Visualization of positron decay

Conclusion

This activity is appropriate for use in both high school and introductory undergraduate classrooms. Students are given the opportunity to manipulate particles in a hands-on fashion in order to familiarize themselves with the nature of basic nuclear reactions. This is accomplished in a discovery format where no previous knowledge of nuclear reactions is necessary. By completing the activity, students are able to write and describe the basic nuclear reactions of alpha, beta, and positron decay, as well as electron capture. A good foundation in writing and understanding these reactions provides the necessary skills to study more complex fission, fusion, and bombardment reactions that are to follow.

Acknowledgments

The authors would like to thank Dr. Lope Max Diaz, North Carolina State University, College of Design, for his help in determining how to mix and apply the paint.
References


Appendix A

SUPPLIES

Middlesex University Teaching Resources — The blue pigment (order #IT9004 – blue thermochromic pigment) comes in 5ml syringes and must be mixed with the acrylic base. Other colors are available, but blue has the best coverage for use in this activity; the black thermochromic pigment was not tried. The acrylic base comes in a 400ml container (order #IT9011). Information on these materials is available at the following URL: http://www.mutr.co.uk/SmartCol/Smartcol.htm.

Acrylic Paints — The authors used Daler-Rowney System3 Zinc Mixing White and Liquitex® Phthalocyanine Blue and Cadmium Red (Light Hue), which is orange. However, any deep blue, orange, and white acrylic paints will be sufficient in preparing the activity. The red and black paints were inexpensive acrylic craft paints.

Appendix B

METHODOLOGY

The thermochromic pigment is mixed with a white paste for distribution. When heated, the blue goes colorless and leaves behind a white paste that is not transparent. When mixed with the appropriate amount of acrylic base, the mixture will be transparent upon heating. The authors recommend that the base be added in small increments to avoid mixtures that become too thin. A testing plate can be prepared by painting a small piece of white cardboard with the orange paint and allowing it to dry. A small spot of the thermochromic paint mixture on this plate should be tested. The spot is allowed to dry and then heat is applied. When the heated mixture is transparent enough for the orange to show through clearly, then enough base has been added.
In order to begin this activity you first need to become familiar with how the particles are being represented. For the first three parts of the activity the blue wooden plugs are the protons and the orange plugs are the neutrons. ALWAYS USE THE ONE BLUE PLUG THAT HAS AN "X" ON THE BACK OF IT. A blowgun or hair dryer is supplied as a source of time or a "time" gun.

**Alpha Decay**

1. Let's begin by constructing a simple nucleus. Using your particles make a representation for the nucleus of Lithium-7. Place the particles on masking tape to stabilize them. Sketch a representation of this in your notes.

2. Now we are going to make observations of an alpha decay. During an alpha decay an alpha particle is lost from the nucleus. An alpha particle is equivalent to the nucleus of a helium atom. So, using your plugs representing the nucleus of Lithium-7, remove an alpha particle.

3. What is the new identity of the atom based on the particles that are left? Sketch a representation in your notes.

4. Write a reaction corresponding to the alpha decay that has just taken place by using the skeleton provided below.

   \[ ^{7}_{3}\text{Li} \rightarrow ^{4}_{2}\text{He} + ^{3}_{1}\text{H} \]

   Note that the superscripts and subscripts on the product side of the reaction add up to the superscripts and subscripts on the reactant side. THIS WILL ALWAYS BE TRUE!

**Positron Decay**

5. Using the appropriate number of particles, construct the nucleus of boron-8. Place them on masking tape. Sketch a representation in your notes.
6. Now we are going to observe positron decay. Use the "time" gun.

7. Make immediate observations. What is the new identity of the atom based on the particles you now observe? Sketch a representation in your notes.

8. Write a reaction corresponding to the positron decay that has just taken place by using the skeleton provided below. Remember superscripts and subscripts should be equal on both sides.

\[ \text{ED}^- + \text{ED}^+ \rightarrow \text{ED}^- + e^- \]

**Electron Capture**

9. Using the appropriate number of particles, construct the nucleus of beryllium-7. Place them on masking tape. Sketch a representation in your notes.

10. Now we are going to observe electron capture (EC). Use the "time" gun.

11. Make immediate observations. What is the new identity of the atom based on the particles you now observe? Sketch a representation in your notes.

12. Write a reaction corresponding to the beta decay that has just taken place by using the skeleton provided below.

\[ \text{ED}^- + e^- \rightarrow \text{ED}^- \]

**Beta Decay**

NOW ALLOW THE ORANGE PLUGS TO BE PROTONS AND THE BLUE PLUGS TO BE NEUTRONS!

13. Using the appropriate number of particles, construct the nucleus of tritium (hydrogen-3). Place them on masking tape. Sketch a representation in your notes.

14. Now we are going to observe beta decay. Use the "time" gun.

15. What is the new identity of the atom based on the particles that are left? Write a reaction corresponding to the positron emission. Sketch a representation in your notes.
16. Write a reaction corresponding to the beta decay that has just taken place by using the skeleton provided below.

\[ \text{[ ]} \rightarrow \text{[ ]} + e^{-} \]

Questions

1. Give the notation for an alpha particle and briefly describe what occurs during alpha decay.
2. Give the notation for a positron particle and briefly describe the process of positron decay.
3. Give the notation for an electron and briefly describe what occurs during an electron capture.
4. Give the notation for a beta particle and briefly describe what occurs during a beta decay.
THE USE OF TRADITIONAL AND CONTEMPORARY INSTRUCTIONAL STRATEGIES AND MATERIALS IN THE ELEMENTARY MATHEMATICS CLASSROOM

J.E. RILEY

Dept. of Education, Longwood University
Farmville, VA 23909
jriley@longwood.edu

Abstract

Elementary school teachers were surveyed about the strategies and materials they use to teach elementary school mathematics. A list of twenty strategies and materials derived from the Changes in Content and Emphasis sections of the National Council of Teachers of Mathematics (NCTM) Curriculum and Evaluation Standards for School Mathematics were examined [1]. These strategies represent both contemporary and traditional approaches to the teaching of mathematics. Teachers were asked to respond to each survey item by indicating how often these strategies were used in their classrooms.

The findings were compared to the goals of the NCTM Standards to assess how much progress has been made in the effort to influence elementary school mathematics instruction. Compared to these goals and the call for change in instructional strategies by the Standards, results seem to be mixed with progress in some areas and not in others. Teacher-centered, whole-group instruction remains the dominant pedagogical form, but approaches using concrete materials seem to be on the increase.

Introduction

Over the past few decades, much attention has been focused on changing the way mathematics is taught. Nationwide programs, as well as state and local initiatives, have been launched to effect these changes. One wonders how much these efforts have impacted the way elementary school mathematics is taught.

It has been more than a decade since the publication of the NCTM Standards [1]. Has there been change in the way mathematics is taught in the nation’s classrooms? The answer seems to be "yes ... somewhat," but there is little research that would indicate how much. In 1992, NCTM conducted a pilot study titled, “The Road to Reform in Mathematics Education: How Far Have We Traveled?” [2]. This pilot study found that about half of the teachers said that state or district testing programs dictate what they teach. In addition, the study found that more than half of the teachers organize their curriculum around the textbook. Only in grades K-4 did more than half of the teachers
responding indicate that the use of manipulative materials was one of their frequently used activities. So, how far have we come? How much impact has all of this effort had on mathematics instruction in the elementary classroom? This study is an attempt to discover which of the many traditional and contemporary strategies and materials are currently used in elementary school mathematics instruction [2].

The Sample

The population for this study was the elementary classroom teachers (grades 1-6) in a mid-Atlantic state. A sample of 381 returns were needed [3]. Based on a projected return rate of approximately 70%, a simple random sample (n = 600) of this population was requested from the Office of Information Reporting and Technology Services of the State Education Department [3]. The initial sample of 600 was reduced to 500 by randomly selecting and removing 100 names. These names were held in reserve to be used as replacements for teachers who responded that they did not teach mathematics or for surveys that could not be delivered.

Data Collection

Data were collected by means of a mailed survey questionnaire. Dillman's Total Design Method was used in the data collection process in an effort to achieve the necessary return rate [4]. A total of 529 surveys, including replacements for teachers who did not teach mathematics, were mailed. Of those, sixteen were returned because they were undeliverable. Of the remaining 513 surveys, 438 were returned from teachers in the sample for a return rate of 85.4%. Of those returned by teachers, 413 taught mathematics. This number served as the basic n for the statistical procedures in this study.

The Survey Instrument

The survey instrument consisted of a list of nineteen materials and strategies. This list included items that represent both traditional and contemporary materials and instructional strategies. Table 1 shows the materials and strategies, and their designation as contemporary or traditional. In Tables 2-5, the list is coded with (C) for contemporary or (T) for traditional to assist the reader with identification. There were also a number of demographic items.

The items comprising the list of materials and strategies were initially derived from the Summary of Changes in Content and Emphasis sections of the Curriculum and Evaluation
Standards for School Mathematics [1]. Teachers responded to these items by making the appropriate choice from a Likert scale that best described the frequency with which they used the indicated strategy or material. The Likert scale selections were: 1) not at all; 2) rarely; 3) sometimes; 4) often; and, 5) very often.

Table 1
Designation of Strategies and Materials

<table>
<thead>
<tr>
<th>Contemporary Strategies</th>
<th>Traditional Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manipulative (concrete) materials</td>
<td>Teacher-centered, whole-class instruction</td>
</tr>
<tr>
<td>Problem solving instructional approach</td>
<td>Worksheets/workbooks/skillbooks</td>
</tr>
<tr>
<td>Cooperative learning</td>
<td>Computational skills instructional approach</td>
</tr>
<tr>
<td>Integration of mathematics with other subjects</td>
<td>Mathematics textbook</td>
</tr>
<tr>
<td>Extended problem-solving tasks</td>
<td>Memorization of number facts and algorithms</td>
</tr>
<tr>
<td>Computers</td>
<td>Competitive activities among students</td>
</tr>
<tr>
<td>Journal writing</td>
<td>Timed tests of number facts</td>
</tr>
<tr>
<td>Class presentations by students</td>
<td>Grouping by ability</td>
</tr>
<tr>
<td>Portfolio assessment</td>
<td>Calculators</td>
</tr>
<tr>
<td>Student interviews</td>
<td></td>
</tr>
</tbody>
</table>

Treatment of Data

Frequencies, means, and standard deviations were calculated to ascertain the extent to which teachers reported using each of the listed strategies and materials. These descriptive statistics were calculated for several configurations of the set of teachers who responded to this survey. These configurations consisted of the complete set of teachers, primary teachers, and intermediate teachers.

A number of traditional divisions of the elementary grades exist. Grouping the levels as primary and intermediate is perhaps one of the most common. With this in mind and upon examination of these results, it was decided to perform the same set of calculations on these two different configurations: teachers of primary (1-3) and intermediate (4-6) grades, as well as the whole set (grades 1-6). The set was also divided into individual grade levels, calculating descriptive statistics for each grade level (1-6) separately.
Reported Use of Strategies and Materials

Table 2 shows the extent to which teachers reported using each of the listed strategies and materials. The last two columns were created from the data in order to show two levels of use by classroom teachers. The first of them, titled “Use—at least moderate” (moderate), is intended to provide an indication of the percentage of teachers using the strategy or material at least in a marginal way. This column was computed by adding the percentages for “sometimes,” “often,” and “very often.” The second of these columns, titled “Use—Frequent” (frequent), is intended to provide an indication of the percentage of teachers using the strategy or material in an important way. This column was computed by adding percentages for “often” and “very often.” Generally speaking, most teachers responding to this survey reported substantial use of some contemporary strategies. Manipulative materials were reported to be used at least moderately by 93.1% of the teachers. Frequent use was reported by 59.4% of the teachers. An instructional approach based on problem solving was reported to be used at least moderately by 96.1% of the respondents, while 62.2% reported using this strategy frequently. Cooperative learning was reported to be used at least moderately by 94.9%, and frequently by 53%. Respondents reported using integration of mathematics with other subjects moderately at the 91.5% value, and frequently at the 52% value. Extended problem-solving tasks were reported to be used moderately by 86.5%, and frequently by 48.2% of the subjects.

Teachers did not report substantial use of some of the other contemporary strategies and materials. Journal writing, student presentations, portfolios, calculators, and student interviews were all used frequently by less than 23% of the respondents, even though these strategies are favored by the current movement in mathematics education [1].
## Table 2
Mean, Standard Deviation, Percentage of Moderate Use, and Percentage of Frequent Use for Teachers in Grades 1-6, Listed in Descending Order by Mean

<table>
<thead>
<tr>
<th>Strategy or Material</th>
<th>M</th>
<th>SD</th>
<th>% Use at Least Moderate</th>
<th>% Use Frequent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher-centered, whole-class instruction (T)</td>
<td>4.19</td>
<td>0.80</td>
<td>98.0</td>
<td>81.0</td>
</tr>
<tr>
<td>Worksheets/workbooks/skillbooks (T)</td>
<td>3.99</td>
<td>0.94</td>
<td>94.1</td>
<td>69.8</td>
</tr>
<tr>
<td>Manipulative (concrete) materials (C)</td>
<td>3.83</td>
<td>0.96</td>
<td>93.1</td>
<td>59.4</td>
</tr>
<tr>
<td>Problem solving instructional approach (C)</td>
<td>3.78</td>
<td>0.82</td>
<td>96.1</td>
<td>62.2</td>
</tr>
<tr>
<td>Computational skills instructional approach (T)</td>
<td>3.70</td>
<td>0.78</td>
<td>95.4</td>
<td>60.0</td>
</tr>
<tr>
<td>Mathematics textbook (T)</td>
<td>3.69</td>
<td>1.41</td>
<td>80.5</td>
<td>63.9</td>
</tr>
<tr>
<td>Cooperative learning (C)</td>
<td>3.64</td>
<td>0.83</td>
<td>94.9</td>
<td>53.0</td>
</tr>
<tr>
<td>Integration of mathematics with other subjects (C)</td>
<td>3.55</td>
<td>0.84</td>
<td>91.5</td>
<td>52.0</td>
</tr>
<tr>
<td>Extended problem-solving tasks (C)</td>
<td>3.47</td>
<td>0.96</td>
<td>86.5</td>
<td>48.2</td>
</tr>
<tr>
<td>Memorization of number facts and algorithms (T)</td>
<td>3.29</td>
<td>1.09</td>
<td>79.1</td>
<td>42.1</td>
</tr>
<tr>
<td>Computers (C)</td>
<td>2.92</td>
<td>1.25</td>
<td>66.4</td>
<td>31.0</td>
</tr>
<tr>
<td>Competitive activities among students (T)</td>
<td>2.79</td>
<td>1.08</td>
<td>62.7</td>
<td>23.7</td>
</tr>
<tr>
<td>Timed tests of number facts (T)</td>
<td>2.75</td>
<td>1.27</td>
<td>57.4</td>
<td>29.8</td>
</tr>
<tr>
<td>Journal writing (C)</td>
<td>2.57</td>
<td>1.30</td>
<td>49.6</td>
<td>22.2</td>
</tr>
<tr>
<td>Class presentations by students (C)</td>
<td>2.55</td>
<td>1.10</td>
<td>52.3</td>
<td>19.1</td>
</tr>
<tr>
<td>Grouping by ability (T)</td>
<td>2.42</td>
<td>1.18</td>
<td>45.7</td>
<td>16.2</td>
</tr>
<tr>
<td>Portfolio assessment (C)</td>
<td>2.40</td>
<td>1.27</td>
<td>45.5</td>
<td>20.8</td>
</tr>
<tr>
<td>Calculators (C)</td>
<td>2.40</td>
<td>1.11</td>
<td>49.6</td>
<td>15.0</td>
</tr>
<tr>
<td>Student interviews (C)</td>
<td>2.09</td>
<td>1.04</td>
<td>32.6</td>
<td>8.9</td>
</tr>
</tbody>
</table>

Scale of 1 to 5

It would seem from these results that strategies such as manipulative materials, problem-solving instructional approaches, cooperative learning, integration with other subjects, and extended problem-solving tasks have become an important aspect of the instructional process in many elementary mathematics classrooms. In a climate of high stakes testing that exists even in elementary classrooms, teachers have become more selective about the strategies they use. Perhaps this is an indication that the strategies named above have value to teachers preparing students for high stakes testing. However, instruction utilizing journal writing, student presentations, portfolios, calculators, and student interviews has not found an important place in elementary classrooms.
Perhaps teachers are unfamiliar with or untrained in the use of these strategies. It is more likely, however, that teachers do not view them as productive in the current climate.

Two traditional strategies—teacher-centered, whole-class instruction and worksheets/workbooks/skillbooks—were reported to be used most frequently of all the strategies in this study. Teacher-centered, whole-class instruction was reported by far to be the most frequently used instructional strategy. A very high 98% of the participants indicated using this approach at least moderately and 81% said that they used it frequently. The other tactic, worksheets/workbooks/skillbooks, is one which contemporary curriculum initiatives encourage teachers to use less frequently; however, it is indicated as the second most frequently used approach. A high level, 94.1%, of participating teachers said that they employed worksheets/workbooks/skillbooks at least moderately, and 69.8% said they used them frequently.

An initial reaction to the picture of a teacher-centered elementary mathematics classroom focused on paper and pencil practice is discouraging. If these results are an indication that change takes place slowly, then we need to continue efforts to produce change. If these results indicate a reaction to the current testing climate, then we need to examine the nature of the assessments and the way teachers and administrators have interpreted them. If it is true that testing (or how testing is perceived) drives instruction, perhaps more creative and thought provoking assessments will foster more creative and thought provoking instruction.

Table 2 depicts data collected for teachers in grades 1-6. This presents an overall picture of the elementary school; however, it is possible that teachers in individual grades or groups of grades think differently about the materials and strategies used in mathematics instruction. Schools are frequently organized as primary (1-3) and intermediate (4-6) schools. Teachers are frequently grouped as primary (1-3) and intermediate (4-6) teachers. Since the primary and intermediate configuration exists in many school organizations, it was decided to examine the data when separated into these categories. Table 3 shows the extent to which primary (grades 1-3) teachers reported using the listed strategies and materials. Table 4 presents the extent to which intermediate teachers reported using the listed strategies and materials. The statistics in the “use at least moderate” and “use frequent” columns have been derived in the same way as described for Table 2. The means and standard deviations are those calculated for the separated groups.
Table 3
Mean, Standard Deviation, Percentage of Moderate Use, and Percentage of Frequent Use for Teachers in Grades 1-3, Listed in Descending Order by Mean

<table>
<thead>
<tr>
<th>Strategy or Material</th>
<th>M</th>
<th>SD</th>
<th>% Use at Least Moderate</th>
<th>% Use Frequent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher-centered, whole-class instruction</td>
<td>4.17</td>
<td>0.78</td>
<td>98.8</td>
<td>79.7</td>
</tr>
<tr>
<td>Manipulative (concrete) materials</td>
<td>4.14</td>
<td>0.86</td>
<td>97.9</td>
<td>73.3</td>
</tr>
<tr>
<td>Worksheets/workbooks/skillbooks</td>
<td>3.99</td>
<td>0.92</td>
<td>94.5</td>
<td>65.7</td>
</tr>
<tr>
<td>Problem solving instructional approach</td>
<td>3.79</td>
<td>0.85</td>
<td>95.8</td>
<td>61.1</td>
</tr>
<tr>
<td>Integration of mathematics with other subjects</td>
<td>3.69</td>
<td>0.81</td>
<td>94.1</td>
<td>60.2</td>
</tr>
<tr>
<td>Computational skills instructional approach</td>
<td>3.67</td>
<td>0.79</td>
<td>93.7</td>
<td>58.5</td>
</tr>
<tr>
<td>Cooperative learning</td>
<td>3.62</td>
<td>0.84</td>
<td>94.4</td>
<td>51.2</td>
</tr>
<tr>
<td>Extended problem-solving tasks</td>
<td>3.44</td>
<td>0.99</td>
<td>84.0</td>
<td>46.7</td>
</tr>
<tr>
<td>Mathematics textbook</td>
<td>3.39</td>
<td>1.56</td>
<td>70.4</td>
<td>56.4</td>
</tr>
<tr>
<td>Memorization of number facts and algorithms</td>
<td>3.21</td>
<td>1.12</td>
<td>75.4</td>
<td>39.4</td>
</tr>
<tr>
<td>Computers</td>
<td>2.94</td>
<td>1.22</td>
<td>67.4</td>
<td>30.5</td>
</tr>
<tr>
<td>Journal writing</td>
<td>2.68</td>
<td>1.34</td>
<td>52.5</td>
<td>24.1</td>
</tr>
<tr>
<td>Timed tests of number facts</td>
<td>2.61</td>
<td>1.33</td>
<td>50.9</td>
<td>27.6</td>
</tr>
<tr>
<td>Competitive activities among students</td>
<td>2.61</td>
<td>1.05</td>
<td>57.3</td>
<td>16.6</td>
</tr>
<tr>
<td>Portfolio assessment</td>
<td>2.57</td>
<td>1.28</td>
<td>52.1</td>
<td>24.6</td>
</tr>
<tr>
<td>Class presentations by students</td>
<td>2.5</td>
<td>1.11</td>
<td>48.7</td>
<td>16.5</td>
</tr>
<tr>
<td>Grouping by ability</td>
<td>2.35</td>
<td>1.11</td>
<td>43.7</td>
<td>13.6</td>
</tr>
<tr>
<td>Student interviews</td>
<td>2.14</td>
<td>1.06</td>
<td>34.4</td>
<td>10.2</td>
</tr>
<tr>
<td>Calculators</td>
<td>2.11</td>
<td>1.06</td>
<td>38.1</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Scale of 1 to 5

A comparison of Table 3 with Table 4 revealed some of the similarities and differences regarding the use of the listed strategies and materials between primary and intermediate teachers. The most striking observation was the prevalence of teacher-centered whole-class instruction. This approach topped the list for both groups. Primary teachers reported using the teacher-centered technique moderately at 98.8%, and frequently at 79.7%. Intermediate teachers reported using the whole-class style moderately at 96.5%, and frequently at 82.7%.
Table 4
Mean, Standard Deviation, Percentage of Moderate Use, and Percentage of Frequent Use for Teachers in Grades 4-6, Listed in Descending Order by Mean

<table>
<thead>
<tr>
<th>Strategy or Material</th>
<th>M</th>
<th>SD</th>
<th>% Use at Least</th>
<th>% Use Frequent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher-centered, whole-class instruction (T)</td>
<td>4.22</td>
<td>0.83</td>
<td>96.5</td>
<td>82.7</td>
</tr>
<tr>
<td>Mathematics textbook (T)</td>
<td>4.06</td>
<td>1.06</td>
<td>92.5</td>
<td>72.4</td>
</tr>
<tr>
<td>Worksheets/workbooks/skillbooks (T)</td>
<td>4.00</td>
<td>0.96</td>
<td>92.6</td>
<td>74.2</td>
</tr>
<tr>
<td>Problem solving instructional approach (C)</td>
<td>3.76</td>
<td>0.79</td>
<td>96.5</td>
<td>63.2</td>
</tr>
<tr>
<td>Computational skills instructional approach (T)</td>
<td>3.75</td>
<td>0.76</td>
<td>97.7</td>
<td>62.1</td>
</tr>
<tr>
<td>Cooperative learning (C)</td>
<td>3.66</td>
<td>0.82</td>
<td>95.4</td>
<td>54.6</td>
</tr>
<tr>
<td>Extended problem-solving tasks (C)</td>
<td>3.51</td>
<td>0.93</td>
<td>89.7</td>
<td>50.0</td>
</tr>
<tr>
<td>Manipulative (concrete) materials (C)</td>
<td>3.41</td>
<td>0.93</td>
<td>86.2</td>
<td>40.2</td>
</tr>
<tr>
<td>Memorization of number facts and algorithms (T)</td>
<td>3.41</td>
<td>1.04</td>
<td>84.5</td>
<td>46.0</td>
</tr>
<tr>
<td>Integration of mathematics with other subjects (C)</td>
<td>3.35</td>
<td>0.84</td>
<td>87.9</td>
<td>40.8</td>
</tr>
<tr>
<td>Competitive activities among students (T)</td>
<td>3.03</td>
<td>1.07</td>
<td>70.1</td>
<td>32.7</td>
</tr>
<tr>
<td>Timed tests of number facts (T)</td>
<td>2.92</td>
<td>1.18</td>
<td>65.5</td>
<td>32.7</td>
</tr>
<tr>
<td>Computers (C)</td>
<td>2.89</td>
<td>1.29</td>
<td>64.9</td>
<td>31.6</td>
</tr>
<tr>
<td>Calculators (C)</td>
<td>2.78</td>
<td>1.06</td>
<td>65.5</td>
<td>24.1</td>
</tr>
<tr>
<td>Class presentations by students (C)</td>
<td>2.60</td>
<td>1.09</td>
<td>56.9</td>
<td>22.4</td>
</tr>
<tr>
<td>Grouping by ability (T)</td>
<td>2.51</td>
<td>1.27</td>
<td>48.2</td>
<td>19.5</td>
</tr>
<tr>
<td>Journal writing (C)</td>
<td>2.41</td>
<td>1.24</td>
<td>45.4</td>
<td>19.5</td>
</tr>
<tr>
<td>Portfolio assessment (C)</td>
<td>2.18</td>
<td>1.22</td>
<td>36.8</td>
<td>16.1</td>
</tr>
<tr>
<td>Student interviews (C)</td>
<td>1.99</td>
<td>1.01</td>
<td>29.2</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Scale of 1 to 5

Another strategy and material reported to be used frequently by both primary and intermediate teachers, as well as the whole group, was worksheets/workbooks/skillbooks. This method was third on the list for both groups of teachers. Intermediate teachers reported the use of these drill and practice tools moderately at 92.6%, and frequently at 74.2%. Primary teachers reported their use at moderate (94.5%) and frequent (65.7%).

Before excessive criticism is heaped on the teacher-centered, practice-oriented mathematics classroom, it is important to recognize the nature of the skills and content taught at the elementary level. For much of the content and many of the skills, a high level of teacher input and guided practice represents good pedagogy. It is hoped, however, that the high levels for teacher-centered
classroom and workbooks do not indicate that these strategies are used when more thought provoking and student-centered strategies would be more appropriate and productive.

Interesting findings were represented by those approaches that data showed to be used with different frequencies by primary and intermediate teachers. The mathematics textbook was such a case. Use of the text was reported second on the intermediate list and tenth on the primary list. Intermediate teachers reported using the textbook moderately at 92.5%, and frequently at 72.4%. Primary teachers, however, reported using the book moderately at 70.4%, and frequently at 56.4%. It was also worth noting that the standard deviation for use of the mathematics textbook on the primary list was 1.56. This standard deviation was the largest of any listed in Tables 3, 4, or 5. This large standard deviation indicated considerable variability in the use of this material.

### Table 5

**Rank Order of Strategies and Materials for Whole Group and Each Grade Level**

<table>
<thead>
<tr>
<th>Strategy or Material</th>
<th>Gr1</th>
<th>Gr2</th>
<th>Gr3</th>
<th>Gr4</th>
<th>Gr5</th>
<th>Gr6</th>
<th>Gr 1-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher-centered, whole-class instruction (T)</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Worksheets/workbooks/skillbooks (T)</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Manipulative (concrete) materials (C)</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Problem solving instructional approach (C)</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Computational skill instructional approach (T)</td>
<td>7</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Mathematics textbook (T)</td>
<td>10</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Cooperative learning (C)</td>
<td>8</td>
<td>7</td>
<td>11</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Integration of mathematics with other subj. (C)</td>
<td>3</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>11</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Extended problem-solving tasks (C)</td>
<td>9</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Memorization of number facts &amp; algorithms (T)</td>
<td>14</td>
<td>11</td>
<td>4</td>
<td>6</td>
<td>10</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>Computers (C)</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>12</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Competitive activities among students (T)</td>
<td>15</td>
<td>15</td>
<td>14</td>
<td>13</td>
<td>13</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Timed tests of number facts (T)</td>
<td>19</td>
<td>14</td>
<td>12</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Journal writing (C)</td>
<td>13</td>
<td>13</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Class presentations by students (C)</td>
<td>16</td>
<td>16</td>
<td>15</td>
<td>16</td>
<td>16</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Grouping by ability (T)</td>
<td>17</td>
<td>18</td>
<td>17</td>
<td>18</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Portfolio assessment (C)</td>
<td>12</td>
<td>17</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>Calculators (C)</td>
<td>20</td>
<td>20</td>
<td>18</td>
<td>15</td>
<td>15</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>Student interviews (C)</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
The math book could almost be considered a classroom tradition. It seems difficult for teachers to conceive of teaching without it. So it is not surprising that it is ranked near the top of the list, particularly by intermediate teachers. The interesting aspect of textbook use is the great variability of use in the primary grades indicated by the large standard deviation (SD = 1.56). It appears that many primary teachers cling to the textbook tradition. It also appears that many primary teachers have found an alternative. An examination of Table 5, where strategies and materials are ranked in order of use for each grade level, gives an indication of what that alternative might be. The use of manipulative materials is ranked as the most frequent approach in both first and second grade. It is possible that many early primary teachers build their math program on a foundation of concrete experience. It is interesting that the use of concrete materials drops sharply in grade 3 (see Table 5) and continues to decline to grade 6. Perhaps this trend is reflective of the changing nature of the skills and content taught. It is more likely, however, that this trend reflects a change in teachers' beliefs about the effectiveness of concrete experience as an instructional strategy. One wonders if teachers, when faced with high stakes testing which begins in grade 3 in many states, return to the traditional strategies of controlled drill and practice.

The memorization of number facts and algorithms presented a different kind of pattern. This approach seemed to be marginally used except at grades three and four, where there was a rise in its reported use. The technique was ranked from tenth to fourteenth by grades 1, 2, 5, and 6. Its reported use peaked at grades 4 and 3 where it was reported sixth and fourth, respectively. When analyzing this trend, it is important to keep in mind the skills and content taught at these levels. This increase in reported use is consistent with the traditional expectation that students memorize their multiplication tables in grades three and four.

**Conclusions**

The NCTM standards and the various new state learning standards have encouraged teachers to use contemporary approaches more frequently and use less effective traditional approaches less frequently. A clear indication of progress in these areas would be welcome. It must be noted, however, that change in the use of strategies and materials for teaching elementary school mathematics is very difficult to assess. No other study of the strategies and materials used by elementary school teachers was found. The tenor of such documents as the 1989 NCTM Standards, the various state learning standards, and the core curricula for mathematics coupled with national efforts such as the 1992 NCTM study provide the only basis upon which to make comparisons.
Based on the results of this survey and the conditions indicated by these documents, progress in these areas is mixed.

It is also difficult to determine the impact of perceptions teachers and administrators have about high stakes testing. It is possible that teachers would use more varied instructional approaches in a climate where passing the test was not the central focus. The prevalence of the teacher-centered classroom, the textbook, and the workbook seems to indicate that teachers have chosen the traditional approach.

There are, however, a number of contemporary approaches that appear to have made encouraging gains. Specifically, manipulative materials, problem solving, cooperative learning, and integration of mathematics with other subjects seem to be well on their way to becoming standard classroom practices. There is also encouragement in the finding that strategies such as rote memorization of facts and algorithms are used appropriately instead of pervasively. It is also indicated here that some of the less effective traditional approaches seemed to be on the decline. Specifically, timed tests of number facts and grouping by ability were not reported to be important classroom strategies.

The way elementary school mathematics is taught is very important to all mathematics learning. Early experiences form the attitudes that older students and adults have about the nature of mathematics and their ability to learn it. It is important to continue to strive for an elementary classroom that fosters understanding and excites all young students about learning mathematics.

References


UNDERSTANDING TEACHER REFLECTION AS A SIGNIFICANT TOOL FOR 
BRINGING REFORM-BASED TEACHING TO COLLEGE MATHEMATICS

K. JEON
Institute for Mathematics and Science Education
University of Illinois at Chicago
Chicago, IL 60607
kjeon72@hotmail.com

Abstract
This paper describes a senior mathematics professor’s effort to change his teaching practice in a mathematical analysis course for secondary pre-service teachers in alignment with the current reform movement. Data include semester-long observations and interviews with the professor and his students. The data were analyzed by the use of reflection as the most significant tool for examining his experience of bringing about change. The reflection was used as a bridge from theory to practice by serving as a significant point for the professor to experience the process of professional development in a real sense. Discussions include the role of teacher reflection, teacher beliefs about good teaching and their manifestation in practice, the role of students in a reform-based classroom and the professor’s effort for changing pedagogy of the mathematics course and his search for continuing the effort. The researcher includes her own reflection of the processes of understanding the change process. Her views on inconsistency between the professor’s beliefs and his practice, the role of reflection as a hallmark of professionalism, and the importance of environment and support for the change to be sustainable are addressed.

Introduction
As a teacher myself, I have always struggled to understand what it means to teach. As a mathematics teacher educator, I have struggled to understand how teachers understand their teaching and how they improve teaching practice. Fundamentally, I always wonder what constitutes good teaching practice? And how can I learn and teach it that way? The work by Lampert and Ball on their own studies of teaching and learning for elementary pre-service teachers clearly illustrates that learning to teach was a function of practice and experience [1]. I also realized that even to these expert teachers, teaching to practice was a complex matter. In fact, my inquiry about teaching has provided me with more unresolved questions rather than answers. As a member of a research and evaluation team, I had the opportunity to study other faculty members’ teaching practices. Sometimes, I was a one-time visitor and came back with much mixed thinking about teaching as practice. Other times I did an in-depth case study thanks to

collaboration efforts with faculty. One could easily imagine how challenging it might have been to study about teaching practice, especially someone else’s. This paper is about the teaching practice of a senior mathematician, Professor L, under reform. The emphasis will be on what a journey of change looked like.

Among many faculty members that I visited, Professor L was one of the most impressive teachers that I have met. Not only did he have 39 years of teaching experience, but he was also aware of the need for change in teaching practice at the university level. While writing this reflection paper about my work with Professor L, I came to a thought that teaching must be a journey of many different routes. This relates to what Fullan points out: change is a journey, not a blueprint [2]. The journey that I witnessed in Professor L’s classroom for a semester was nonlinear and it was loaded with uncertainty and excitement. I express my deepest thanks to Professor L, who spent an enormous amount of time with me talking about his day-by-day lessons, plans and changes, his thinking about student learning, his observations and thoughts about his classroom teaching.

What follows is an attempt to organize my understanding about Professor L’s teaching practice represented by reflection. The word “reflection” is understood as Grant interprets John Dewey’s work [3]. In the early part of this century, John Dewey made an important distinction between human action that is reflective and that which is routine. According to Dewey, routine action is behavior that is guided by impulse, tradition, and authority. He defines reflective action, on the other hand, as behavior which involves active, persistent, and careful consideration of any belief or practice in light of the grounds that support it and the further consequences to which it leads. According to Dewey, reflection involves a way of meeting and responding to problems [3]. Based on this definition of reflection, discussions will include many issues like the role of teacher reflection, teacher beliefs about good teaching and their manifestation in practice, the role of students in a reform-based classroom and a senior professor’s effort for changing pedagogy of a mathematics course, as well as his search for continuing the effort, through the eyes of a researcher, with the inclusion of her own understanding and those of his students.

Professor L’s Change Project

I first met Professor L in the fall of 2001. At that time, he was planning to launch a change project for his teaching practice of a mathematical analysis course for 21 secondary pre-service teachers for the semester. In the summer of 2001, he had participated in a series of
professional development activities. His plan included mathematical activities that would develop qualitative properties of functions. His plan was originally to work with one unit about function concepts. However, it was expanded to pursue a semester-long effort to change his teaching practice for a broader theme, “curricular and instructional improvement in calculus focusing on oral and written communication of mathematics and numerical methods.” I became a regular member of his class for the entire semester as a participant observer, and Professor L regularly visited me more than twice a week during the semester.

In my initial conversations with him, Professor L described himself as a typical mathematician who taught mathematics courses for college students. He said that this was going to be a challenge for him because he used to be quite a conservative teacher in the past. I found the opportunity extremely valuable. I was aware of the kind of limitation that William Kyle, Jr. mentioned about an unfortunate dearth of teacher education research at the college level in comparison to much effort on educators’ understanding of teaching and learning in K-12 learners [4]. Anderson and Mitchener also described that the big advances in understanding about student learning have not been matched by equivalent advances in understanding about teaching [5]. Due to Professor L.'s recognition of the importance of reform-based mathematics teaching in the college classroom for the well-being of the mathematics community, I found myself in the middle of a unique setting for observing university mathematics teaching.

Being critical about his past way of teaching that he called “theorem-proof,” he initiated a new way of teaching that he named, “qualitative understanding.” He strongly believed that in the past, his teaching was not necessarily focusing on conceptual understanding of the mathematical content. He speculated that there existed qualitatively different ways of teaching the same contents. Over the semester, I often found Professor L struggling to find his next steps for teaching the course. For example, one day after doing an activity-based lesson using a beaker problem from the professional development activities, he wondered what would be the best way to evaluate students' learning. He believed that the conventional methods of evaluation would not work, but he had not thought of new methods yet. He did not know which problems would be good to assess the qualitatively different learning that he expected his students to experience. In the meantime, I found Professor L becoming more reflective because he recognized a need for an alternative to the traditional assessment method. He was not guided by tradition. Instead, he took a careful consideration of alternatives in light of the grounds that support his goal for teaching for
qualitative understanding. Later, he came back to me with his plan to give the students an essay question. This was the first time that he asked his students to write about mathematics.

His world of teaching required a constant interplay between constraint and choice. As a result, the position was taken that it was necessary for Professor L to be reflective. He took our conversations related to his questions to his rethinking and reshaping process and then brought it out to his practice in the classroom. I, as well, needed to reflect on what he said that actually went on in his mind so that I came to understand the process of his reshaping and its manifestation in practice. The following are examples of the kinds of change that Professor L made from my point of view. These changes are the results of the process of rethinking, reshaping, and manifestation in practice that he tried to communicate with me.

- *Instruction and assessment influenced by student responses:* Designing tentative exams, he modified them based on his understanding of students and the course. He thought hard on how to design activities for the other topics in his syllabus. He and his students started using the word assessment rather than exam and there was a shared feeling for the use of the word.

- *Utilizing collegial network to look for ideas and insights:* He realized the need for technological help, such as a visual presenter, for the first time in his teaching and sought assistance. He also needed more resources, especially mathematical activities that he might consider using in the later part of the course. He then went to other faculty members in the university who were experts in these areas.

- *Becoming flexible with the course syllabus and content:* I often heard him say, “Everything I am doing is building up.” He was not constrained by the syllabus. Rather, he redefined the syllabus not as a collection of chapters to cover, but as teaching for conceptual understanding.

- *Changing his implicit theory on students’ learning of mathematics:* The change happened from not seriously thinking about how students might learn mathematics to thinking deeply about the difference in the way students learned mathematics. As a result, he tried to listen to students. He realized that students learned mathematical concepts in a different way than a mathematician might learn. Therefore, they might take a different route for understanding some concepts that would not look reasonable to the mathematician’s eye. The more he listened to the students, the more he heard from them in and outside of the classroom.
• **Facing challenges with assessment:** Assessment was an unresolved matter even though he tried many new ways of assessing the students. While emphasizing conceptual understanding, he noticed that his students did not do well on the formal definition part of the final exam. He was concerned about the result and wondered whether he balanced the two, conceptual understanding and formal aspect of mathematics learning, in his words. Professor L’s plan for the following year is to pursue the balance although he does not know exactly how he will be able to achieve it.

Once Jalongo suggested that educators’ stories about teaching and their reflections upon them are a deceptively simple way of addressing significant issues about what it means to teach and learn [6]. His suggestion was, needless to say, applicable to both Professor L and me. I found reflection was the most significant tool for Professor L so that he could continuously keep motivating himself to pursue his change project successfully. Reflection was being utilized by Professor L because he wanted to bring change. Professor L and I both understood reflection in the way John Dewey described it: reflection as a way of meeting and responding to problems by making active, persistent, and careful consideration of belief and practice, and the further consequences [7]. The opportunity for reflecting on teaching experience was significant enough to shape a teacher’s belief system that affects teaching and learning [8]. As reflection allowed him to perceive his practice as problematic, initiation of reflection became easier for him. The reflection provided a link between his daily teaching practice and the development of his ability to reflect on his teaching. Most of all, this method of reflection addressed Professor L’s personal experiences as a teacher and their influence on shaping his beliefs about good teaching practice.

Very often, reflection resulted in more and deeper questions. Professor L often started out talking about a topic that he felt comfortable to talk about with me. Then, he came up with a connection to another topic that turned out to be the “real” issue to him in implementing his change project. He discussed how he could design problems for the midterm assessment so that he could really assess the students’ qualitative understanding of the function concepts rather than asking them to do theorems and proofs. While he often engaged me in discussions on various issues in teaching and learning, he sometimes ended the discussion without making a specific decision. After spending more time on reflecting on those issues, he always came back to me with, he believed, exciting plans for further steps for the course. After reflecting on his teaching for several weeks, for example, he said, “My mind is developing.”
As Fang pointed out about teachers, Professor L also started possessing his own theoretical orientations that organize and trigger his instructional behaviors over the semester [8]. For example, his theory that students learned mathematical concept differently than mathematicians was expanded to another theory that all of his students were learning in a different way. Naturally, he solicited for different approaches to an answer. With a problem for getting the area of a small pond that Professor L assigned as a project, he listened to eighteen different students who all gave different approaches to the problem. Professor L’s reflection process was often used as a prompting moment when he became aware of conflicting aspects of his thinking and actions to be planned for the course. He realized that what he believed to be right for the students was not necessarily conveyed to them after paying more attention to his students’ voices from the classroom, their homework, or their group discussions. His reflective action, however, kept him open to new choices that took into account students’ views and understanding.

**Changes in Professor L’s Students**

Professor L taught the students differently from other mathematics professors that they had. I heard the students frequently saying to him, “What do you want us to do?” especially in the beginning of the course. Almost all students seemed to feel that they needed a structure. Professor L tended to stop talking and wait for student thinking and responses. Yet, the students were trained to depend on professors for good grades and they did not know how to make sense of this new kind of setting where responsibilities for learning should be shared by both the teacher and themselves. As Canning mentioned, student teachers had a voice, but they had learned to withhold it [9]. Particularly in the beginning, the students had a contradictory view of a mathematics teacher. They described their past mathematics professors as masters of subject matter content knowledge who delivered information and partially decoded the information. Therefore, it was not the responsibility of the students to make connections and understand concepts while being in the classroom. However, when they were exposed to Professor L’s teaching which emphasized thinking processes and conceptual understanding rather than memorization, they resisted. They often argued that they needed to be told what to study for on the exams, and they asked for clear definitions of concepts and specific steps for proving theorems.

His students, however, changed. After the midterm assessment, a student said, “I did not know what to expect. But it seems this professor has a good sense of coming up with good problems. They are not too easy, not too difficult… challenging enough.” Another student said,
“It didn’t test something like cramming, memorization. It really tested what I learned and understood. I think I will be able to write the same as I did today in a week.” Those who felt the most uncomfortable about the fuzziness of their tests and assignments started capturing their expected roles in this teaching and learning process. They were finding out the importance of their responsibilities. They started actively asking questions in the classroom. Professor L’s focus was mainly on teaching, not on students’ learning. But once he started reflecting on his teaching, he began to incorporate students’ learning into his reflection. This illustrates Rhine’s argument about using students’ thinking as a source for personal reflection as exemplified in Professor L’s case [10].

**My Reflection**

What was my role for Professor L? I believe I tried to provide daily feedback on his teaching so that he was able to offer instruction which was consistent with his beliefs concerning good teaching practice. At the same time, I tried to understand how he could apply his beliefs and philosophies within the constraints imposed by the complexities of his classroom life. His thinking about his role as a teacher (a facilitator for students’ active involvement in the process of teaching and learning) and the beliefs about the nature of mathematics (emphasizing conceptual understanding as well as doing theorem and proof), helped shape his pedagogical decisions. Professor L’s implicit theories about students, the subjects they teach, and their teaching responsibilities influenced his reactions to students and their teaching practice [11]. As Canning suggested, Professor L found reflection an intra-personal experience leading to insight about himself as an actor in his world [9]. It prompted changes in self-concept, changes in perception of an event or a person(s), or plans for a change in some behavior.

Another important part of Professor L’s journey of change was the issue of consistency between his professed beliefs in the dialogue with me and his teaching practice in the classroom. A study by Readence, Konopak and Wilson with elementary and secondary teachers on reading indicated that the relationship between beliefs and instructional practices varies from very consistent to very inconsistent [12]. This issue of consistency in Professor L’s beliefs and practice became more complicated along the timeline. In his class with the beaker problem, not only was his instruction found to be consistent with his beliefs about the nature of mathematics, but his interactions with the students were also coherent with his beliefs about mathematics learning.
But in the classes after the unit long project was over, it seemed Professor L’s beliefs and his actual instructional practices lacked consistency. This inconsistency between beliefs and practice seemed to stem from two factors: assessment and resources. He did not have enough knowledge about assessing students in the way he designed his instructional change process. Also, he did not have enough mathematical activities that could support him in teaching the other concepts of mathematics, such as limits and formal proofs as he did for the function concepts. This inconsistency between Professor L’s beliefs and his practice was not unexpected, but the problem for me as a researcher was that the inconsistency was happening in one person at different time points. A future study is being planned as an effort to better understand this issue of inconsistency with Professor L for this year when he will teach the same course.

It is notable that Professor L believed that the informal and qualitative aspects of learning mathematical concepts is important. He also believed that mathematical activities are a vehicle through which students construct meaning in a rich way. In many ways, it seemed that he was one of the reform-oriented mathematics teachers. On the other hand, he believed that the mastery of concepts, (i.e., theorem-proof) must be learned before the meaning of the concepts can be qualitatively understood by the students. Fang pointed out that the instructional techniques utilized in the classroom were not mutually exclusive. Asking people to choose one lesson plan as opposed to another imposes the researcher’s categories on those who do not normally utilize them [8]. Therefore, the problem might have resided in me because I expected in some sense that Professor L’s change process could be well shaped in a semester-long effort. Anyway, this issue of possessing two comparable perspectives along with the issue of inconsistency became critical to me in understanding the role of a teacher’s beliefs and practice.

Regardless of the unanswered issues that I posed, this opportunity to work with Professor L, unlike many other studies on beliefs and practice in their separate way, captured what was actually done in the classroom rather than what should be done. And I reached at least one conclusion about the identity of a teacher: A teacher is a reflective professional whose teaching practice develops in a profoundly different way when reflection becomes active. A supporting argument comes from Schon’s view on reflection not only as a way of thinking, but as a hallmark of being a professional [13]. The reflection process was a time intensive process both for the researcher and the professor. However, as Wenzlaff and Cummings suggested, the ability to think about what one does and why, and assessment of past actions, current situations, and intended outcomes, is vital to intelligent practice—practice that is reflective rather than routine [14]. The
method of reflection provided a bridge from theory to practice by serving as a beginning point for the mathematics professor himself to experience the process of professional development in a real sense.

As a researcher, I learned the importance of the environment and support for a university faculty member to learn to be reflective about his teaching and about his students’ learning. During the reflective process, he became thoughtful so that he could reflect on his own professional thinking and continue as a lifelong learner. The reflective process served as an encouragement and structure for the change to happen in his teaching practice. Finally, reflection was an effective process for making Professor L’s teaching a continuously evolving process. An implication of this study is that incorporating this teacher reflection process may be a way to provide university faculty members with a richer knowledge about the complex nature of teaching and possible methods for change and improvement in their practice. Once they have an understanding of the nature of teaching via reflection, then they may seek better ways to organize their practice and eventually to begin to change their practice. I, then, wonder whether the two of us have a shared meaning for the word reflection? Another plan for this year is for the two of us to communicate the meaning of reflection in a more visible way. I will consider adopting different ways of collecting classroom data other than my observations and interviews, such as videotaping the lessons. I also wonder about the role of interactions between Professor L and me in his process of change. Professor L and I spent a great amount of personal time outside of the classroom and this seems to be critical for him as opportunities for being more reflective and analytical about his practice.

References


RECRUITING MORE MATHEMATICS TEACHERS USING COLLABORATION AS THE MAIN INGREDIENT: AN EFFECTIVE MODEL FROM MISSOURI

L. KAISER
Dept. of the Dean of Education, University of Missouri–Columbia
Columbia, Mo 65211-2400
Kaiserl@missouri.edu

Abstract
A National Science Foundation grant was designed to develop a series of courses to connect mathematics concepts taught in middle school classes with actual class materials used at the middle school level; however, a second component of the grant focused on efforts to recruit more teachers into the field of mathematics. By collaborating with several groups across Missouri, several strategies were developed that were shown to have positive results, both in increasing awareness of mathematics teacher shortage issues, and in encouraging attendance in Missouri mathematics education programs. The strategies developed were easy to implement and low in cost. The Missouri team encourages others to duplicate or adapt this recruitment model in their own regions.

Introduction
Waiting to see who shows up on the doorstep of the math department is no longer an option when considering the serious shortage of mathematics teachers throughout the country. The statistics are sobering: the No Child Left Behind website states that “just 41% of teachers of mathematics had math as an area of study in school.” [1] Other reports estimate that about 30% of mathematics teachers lack state certification in their field [2-3]. Districts make valiant efforts to employ fully certified mathematics teachers, but in many cases find that those individuals do not exist. Consequently, they call upon alternative teachers or full-time teachers certified in other areas to teach mathematics.

Despite the best efforts of teachers employed in such cases, the research shows that lack of a solid background in mathematics can have a negative impact on student achievement. The National Assessment of Education Progress reports that eighth grade students of teachers with mathematics majors or minors perform higher than students of teachers without mathematics majors or minors [4].
In Missouri, the shortage is evident. Approximately 500 mathematics teaching vacancies are posted annually while fewer than 200 middle and secondary mathematics teaching certificates are issued each year by the Missouri Department of Elementary and Secondary Education from all 34 college mathematics education programs combined [5].

That's not going to cut it. The new federal No Child Left Behind Act calls for all teachers in schools receiving federal funds to be “highly qualified.” That is, teachers must hold a bachelor's degree and meet state certification requirements—they cannot have certification requirements waived or be on an “emergency, provisional, or temporary” certificate. These requirements are mandatory by the 2005-06 school year. Each state's department of education is in the process of writing rules that incorporates the law into its certification process. The Missouri Department of Elementary and Secondary Education has mandated that teachers with any kind of certification (including temporary or provisional) will be counted as "highly qualified." Nevertheless, the need for excellent math teachers will remain a challenge as student test scores continue to receive ever greater scrutiny.

So what is the answer? Like any complex equation, simple formulas are not likely to work. An extended, cooperative effort on many fronts is needed. Activities from an NSF-funded grant called Connecting Middle School and College Mathematics or (CM)² have made great attempts to identify, recruit, and train new mathematics teachers for Missouri schools. The steps below describe the plan of action implemented in Missouri, but we believe these low-cost efforts can be duplicated and adapted for other regions.

Step One: Forming the Team

One of the first steps taken was to coordinate a statewide meeting with mathematics faculty from all the public institutions in Missouri. The result was an active exchange of ideas for promoting the field of mathematics teaching. From there, the ideas generated were sorted and further developed into workable projects. Using the financial backing from the (CM)² grant, a recruitment team began to actively work on the project ideas for promoting the field of mathematics teaching to potential markets. The team involved mathematics faculty, mathematics education faculty, and graduate assistants and staff with experience in recruitment and teacher placement.
Statewide meetings continued for two years, with two meetings each year, where everyone was updated on the status and results of the recruitment projects. Territorial issues disappeared as a spirit of collaboration took hold and the statewide meetings became important occasions to share information among colleagues.

**Step Two: Develop a Website**

A website identifying a faculty member at each four-year public institution in Missouri was established to distribute information and opportunities [6]. The goal of the website was to promote mathematics teaching as a career choice while simultaneously promoting the mathematics education programs at each institution. One of the universities donated server space to host the site and graduate assistants skilled in web design developed the site.

**Step Three: Partner with High School Mathematics Teachers**

Many college students have told us they chose teaching as a career because they were influenced by a teacher they had in school. To make use of this powerful army of “ambassadors,” we asked high school mathematics teachers around Missouri to help us identify strong mathematics students in their classrooms. We received a good response and developed a database of potential future mathematics teachers. A brochure was mailed to each identified high school student encouraging them to consider the field of mathematics teaching and letting them know the name of the teacher that recommended them. Over a period of two years, close to 1,300 high school students received a teacher recommendation and brochure.

The brochure we used was a focused communication piece to “get the good word out” about mathematics teaching as a career. The field of teaching as a whole has negative stereotypes related to salary, which at times can overshadow a talented student’s desire to help others through teaching. We specifically focused on providing accurate information about starting salaries and student loan forgiveness, while also promoting the “make a difference” appeal that teaching offers. The brochure pointed interested students to the website where contact information on all the Missouri mathematics education programs could be found. A copy of the brochure and letter was loaded onto the website [6].
Step Four: Partner with College Admissions Offices

It is commonly known that once students enroll in college, the choice of major is subject to change. Relying on this assumption, we further targeted new students at the University of Missouri-Columbia who had strong ACT subscores in mathematics and undecided majors. Using a list of names and addresses obtained from the college admissions office, we promoted mathematics teaching through the use of a brochure (the same brochure used for high school students) and a letter encouraging students to consider the field of mathematics teaching as a possible career.

Step Five: Partner with School Administrators

School administrators are no stranger to the mathematics teacher shortage issue—they struggle with hiring situations in this area every year. They sometimes feel, however, that they struggle alone. Many school administrators have a deep pile of elementary applications, but no openings in elementary education. At the same time, they are desperately trying to fill math teaching positions for which there are no qualified applicants. It is no wonder that the cry is sometimes heard, “What are you college people doing? Don’t you know what we need here?” In addition, hiring officials in school districts frequently come into contact with individuals interested in teaching, but lacking appropriate certification. Connecting with school administrators can be an important step in promoting mathematics education programs.

In Missouri, school administrators participate in a variety of regional and statewide meetings at different times of the year. To reach this important group, we proposed meeting topics and conference presentations to several related professional organizations across the state. Each time a proposal was accepted, it gave us an opportunity to communicate our efforts at recruiting more mathematics teachers, and inform school administrators about mathematics education programs in the state. The result was twofold: school administrators began to see that we were listening to their needs and actively working to address the issues, and the availability of traditional and non-traditional teacher training programs was promoted.

Step Six: Partnership with Journalism Students

The most challenging goal of the recruitment effort was to reach career changers, as well as to market the field of mathematics teaching on a national level. For assistance, we turned to the journalism department at the University of Missouri-Columbia. The University’s journalism
students are required to complete a capstone project near the end of their program. By contacting a faculty advisor in the advertising sequence, we were able to be designated a “client” for a capstone project. We were assigned three senior-level journalism students who conducted market research. They developed a full-scale campaign, specifically targeted to career changers, that promoted mathematics teaching as a career choice. The financial commitment was small: we covered expenses for the students in terms of copying, phone calls, photos, and supplies. In return, we received ready-to-go advertisements for print ads such as magazines and billboards, as well as suggested scripts for radio and television. Grant funds have been identified that will allow us to use the designed materials.

Results

Obviously, recruitment is not “business as usual” for college mathematics educators. No one told us this would someday be a part of our function as mathematics faculty or college staff members. However, the efforts have paid off with positive results. First, there is an increase of awareness of mathematics teacher shortage issues among college mathematics faculty, high school faculty, and administrators at both levels. Secondly, there is a spirit of comradery that comes from working together to address the shortage of mathematics teachers. A special session focusing on the mathematics teacher shortage is now a regular part of the annual meeting of the Missouri Council of Teachers of Mathematics. Third, the University of Missouri-Columbia noticed a 40% increase in mathematics education enrollment last fall. It is hard to determine exactly what led to such a dramatic increase, but we believe our recruitment efforts played at least some part in the phenomenon.

Ultimately, we believe a continued partnership among colleges and schools can make a difference in meeting the teaching needs of students. The methods we use to recruit more mathematics teachers in Missouri are simple, easy to implement, and low in cost. We encourage other areas to duplicate or adapt these strategies to address teacher shortages in their own areas. Collaboration is the key to addressing the complex problems of teacher staffing and with No Child Left Behind deadlines rapidly approaching, there is no time like the present to get started.
References


The first paper in this section describes work that was undertaken by three students from Saint Catherine’s School in Richmond, Virginia, in a class offered in the school’s minimester. The name of the course was The Return of Hard Problems – The Sequel.

The second paper was written by Wendy Griffin who is a teacher and Chair of the Department of Mathematics at Liberty Middle School in Hanover County, Virginia. This paper was written while she was on a leave at Virginia Commonwealth University as a National Science Foundation GK-12 Fellow.

**MATHEMATICS FROM CHINA TO VIRGINIA BY WAY OF SINGAPORE**

H. KIM, C. WU, and A. XUE  
*St. Catherine’s School*  
*Richmond, VA 23226*  
J. BOYD  
*St. Christopher’s School*  
*Richmond, VA 23226*

**Abstract**

Our article follows from an interesting concurrence of mathematical and educational lines. At least the concurrence seems so to us and we hope that those who read on will agree. The lines or streams are a joint minimester program at St. Catherine’s and St. Christopher’s Schools, an interest in problem solving, and a Singapore connection. We shall describe the lines first and then describe the mathematics that we found at their intersection.

**Minimester at St. Catherine’s and St. Christopher’s Upper Schools**

The academic session at our two schools is divided into three trimesters and a two-week minimester. The minimester takes place during the two weeks in late February and early March between the end of the second trimester and the start of spring break. All girls in the St. Catherine’s Upper School and all seniors, as well as some juniors from St. Christopher’s, participate in the minimester program. Regular academic courses (with the exception of certain Advanced Placement courses) for minimester students are suspended. Participants may choose
two-week activities from a varied and impressive array of options which includes independent projects and study, academic and recreational courses, workshops in literature and the arts, travel, community service, and internships sponsored by local businesses and professional groups.

The yearly cycles of weather, psychology, and academic stamina seem in phase at their dismal low points as winter nears its end. Spring and the vacation which signals its advent are blocked by a succession of tests and due dates for term papers and projects; and, for upperclassmen, the stresses which attend the college applications process are heightened. Thus by its timing, minimester is intended to provide recreation and refreshment for the students of the two schools and for their teachers as well.

Every minimester activity must have an academic component, and credit for acceptable participation in activities and completion of courses is recorded on each student’s transcript. Outstanding performances by students are honored and noted on their transcripts as well, while credit is withheld when performances are not satisfactory. In certain of the activities and courses, academic rigor may be properly relaxed a bit in light of the acknowledged intent that the program provide pleasure during a period of academic doldrums. However, each student must participate in at least one rigorous course or activity.

The major planning and direction for the minimester come from St. Catherine’s. Courses, workshops, and other activities are led by St. Catherine’s teachers, visiting faculty, and to a lesser extent, St. Christopher’s teachers. Each year for the past three years (2000, 2001, 2002), the Department of Mathematics at St. Christopher’s has offered a course focused on problem solving. In 2000, problem solving and learning to use Mathematica were strongly tied together, and subsequently Mathematica has been used when appropriate in a natural manner. Posing problems has always been a part of the courses; and clear, unambiguous statements of problems and expositions of their solutions have been emphasized. Hence, the writing of mathematics has been an important component of the work.

Throughout participation by the St. Christopher’s mathematics faculty, writing has been an integral part of the mathematics course. In 1989, Virginia Mathematics Teacher published an article which grew out of that year’s spring minimester study of several problems famous in the history of mathematics [1]. Also from time to time, that journal has published in its “Problem Corner” problems which were posed and solved in one or another minimester class.
Problem Solving

The title of the course for 2001 was *Hard Problems* and the title of the 2002 course was *The Return of Hard Problems—The Sequel*. Despite the forbidding titles, students did sign up for the classes, and the first three authors of this article comprise the class for the sequel of 2002; the fourth author was the teacher.

The opening paragraph of the published course description attempts to justify the course and to say something about what mathematicians and mathematics teachers mean when they talk about “problem solving,” as opposed to working “the odd-numbered exercises at the end of the chapter.”

Every mathematician has his or her own personal mathematical frontier. No matter where that frontier is located, the mathematician will find challenging problems along that boundary which separates what is known from what is not yet understood. Such boundaries are, of course, somewhat fuzzy. By attacking such problems, the mathematician will advance his or her personal frontier. If the mathematician is working at the boundary of his or her discipline, the mathematician advances the frontier of mathematics itself.

The distinguished Canadian mathematician and problemist Murray Klamkin possesses far more clout than do the present four authors. Thus, it seems a good idea to cite his remarks to clinch the matter. He wrote:

> . . . problems and questions beget more problems and questions in an unending cycle. These problems and questions are the lifeblood of mathematics. Smaller problems lead to larger problems which in turn lead to substantial mathematical research [2].

Just as baseball is a game of failures, so is problem solving. A real problem solver knows that he will never solve all of the problems that he or she considers. If the sole criterion for success is a correct and complete answer at the bottom of a page, then good solution averages over many attempts would probably approximate the batting averages of good major league hitters who experience failure roughly two-thirds of their times at bat. But the real problemist does not keep score. Learning new mathematics, gaining better understanding of old mathematics
by testing one’s knowledge against new configurations of what is given and what is to be found, and the establishment of connections between seemingly disparate parts of the body of mathematical theory are the true rewards of problem solving.

Posing and writing good problems are at least as important as solving them. Mathematics is filled with conjectures and theorems named for the proposer rather than the solver. That proposers become eponyms recognizes that they were the ones who alerted the mathematical world to the significance of some idea. In a similar way, the problem editors of journals also recognize the importance of developing good problems. If one’s problem is accepted for publication, the proposer’s name appears when the problem is first published. His or her name is repeated with the restatement of the problem when the solution is published in a later issue of the journal. If the editors choose to reproduce the proposer’s own solution, his or her name is given again. As a result, the proposer’s name appears two or three times while the names of the other solvers appear only once.

“Problem solving” does have a particular meaning and can be taken as a specialized pursuit within mathematics. It must be acknowledged that the statement, “He is a problem solver” with an implied “only” between the “is” and the “a” should not be taken as a compliment. When a mathematician uses the description as a “put-down,” it probably means that the mathematician feels that a colleague or competitor is missing “the big picture” and is wasting time and energy on relatively trivial matters. Problem solving is an important activity that produces fun as well as results, while it adds a game-like, competitive aspect to learning mathematics. However, it can be overdone at the expense of the systematic development of the various major branches of mathematics. Thus, a two-week minimester course seems an ideal setting for a fairly intense engagement in problem solving.

The Singapore Connection

Mr. Willie Yong of the SCT Publishing Company of Singapore produces a lovely journal, *Mathematics and Informatics Quarterly* (informatics is a synonym for information science used chiefly in Great Britain). This journal is largely devoted to problem solving at an advanced secondary level. It is published in English, but receives problems and manuscripts from all over the world. The names of some of the contributors would be familiar to those who read the problem sections in popular American journals. The last author of this article has the privilege of serving on the editorial board of Mr. Yong’s journal, and one of his responsibilities is to provide
smoothly flowing versions of often elegant and challenging problems, solutions, and articles submitted by non-native speakers of English. Some of the problems even arrive at St. Christopher’s written in the contributors’ own languages; but, the mathematical notation usually makes the content of the problems clear. Thus from far away places and via Singapore, there has come to St. Christopher’s a large supply of problems to challenge the minimester mathematicians of recent years.

Mr. Yong often includes in his packets of material to be read and rewritten items that he thinks will be of interest to the students of St. Christopher’s and St. Catherine’s. One of these items caught the special attention of the minimester class. It was a single sheet of paper covered for the most part with diagrams and equations, but also containing a small amount of text written in Chinese characters. It is reproduced below as Figure 1. The hand written notations on the page were made by Mr. Yong. Mr. Yong’s last suggestion—“Have fun”—might well serve as a motto for his journal.

The class agreed upon a project. The students would translate the text, and the students and teacher together would attempt to understand the mathematics. Then, if the results of the project seemed of sufficient interest, a manuscript describing the class and the mathematics from Singapore would be prepared and submitted for publication in an appropriate journal.
Given a wire of length $a$ construct the following cross-sections and determine the maximum area.

$\square$ Chinese equivalent of numerals

**Figure 1**

**MATHEMATICS FROM SINGAPORE**
Mathematics from China by Way of Singapore

Translation from the Chinese reveals that the page is a record of “Exercise III.” It represents a series of student calculations most likely intended to support and motivate a well-known problem in the calculus of variations. A piece of wire of length $a$ is bent to form the incomplete boundary of a plane, convex figure. That is, a segment would have to be added between the ends of the wire to close the figure. The problem is to discover how to bend the wire to define the plane figure of largest area.

American students and teachers sometimes refer to an equivalent problem as the “gutter problem,” although a far more romantic name is “Dido’s problem.” Suppose that a gutter is to be created from a long strip of metal which has uniform width $a$. The top of the gutter is open, and the quantity of water that the gutter can carry away is proportional to its cross sectional area. In this version, the problem is to discover the shape of the cross section that will maximize the cross sectional area of the gutter, subject to the condition that the length of the cross sectional curve has the fixed value $a$.

It may be that the results obtained by the different pupils in the mathematics class in China are being presented to the class as a whole or, perhaps, to visitors to the classroom. Anyway, the text above the first set of diagrams represents what the teacher says to introduce the presentation: “Let the representatives of each group explain their plans to the entire class. The creativity of the students has been amazing. The students have suggested the following plans.” Then Plans 1 through 8 are developed.

The sense of the calculations is obvious from the diagrams and students should observe an almost uniformly increasing area as the curve more nearly approximates a semicircle. A sample of several of the computations will be given in the next section. Students who have performed these calculations and been led by their teacher to ponder their meaning will most certainly have gained an understanding of a famous problem. A lovely proof by contradiction that the semicircle is the curve that yields the largest cross sectional area for a fixed length is given by Ivan Niven in *Maxima and Minima Without Calculus* [3]. The proof hinges upon the well-known theorem that an angle inscribed in a semicircle is a right angle. Niven also explains why the problem bears the name of Dido, Queen of Carthage.
Calculations — The calculations below are referenced to the diagrams as numbered in Figure 1. One must imagine the class discussion which accompanied these calculations and the conclusions to which the young students were led. Each diagram possesses the symmetry of a reflection across its vertical center line, and the fixed length of the wire in each instance is $a$.

**Diagram 1** — The wire forms three sides of a rectangle with altitude and base of lengths $a/4$ and $a/2$ units, respectively. If the rectangle represents the cross section of a gutter, it presents a cross sectional area of $a^2/8 = 0.125a^2$ sq. units to water flow.

**Diagram 2** — The wire forms two sides of a triangle. The lengths of the two sides are $x$ and $a - x$, and the angle between the two sides has measure $\theta$. Therefore, the area of the triangle is $x(a - x)\sin\theta/2$. The area is largest when $x = a/2$ and $\theta = 90^\circ$. It is interesting that this largest area $(0.125a^2)$ has the same value as the area of the rectangle immediately above.

**Diagram 3** — The wire forms the base and non-parallel sides of an isosceles trapezoid. Each of the non-parallel sides is $a/4$ units long and the base is $a/2$ units long. The angle between an altitude and each of the non-parallel sides is $\theta$. The area of the trapezoid is 

$$a(a + a \sin\theta/2)\cos\theta/8.$$ 

A series of computations indicates that the area will attain its maximum value of approximately $0.138a^2$ near $\theta = 20^\circ$. The methods of differential calculus yield a critical value of $21.4707^\circ = 21^\circ 28'$ for angle $\theta$. In the next diagram, the wire is bent so that the three given sides of the trapezoid are all congruent.

**Diagram 4** — In this figure, each segment of the wire is $a/3$ units long. The area of the trapezoid becomes $a^2(1 + \sin\theta)\cos\theta/9$. An angle $\theta = 30^\circ$ yields a maximum area of $0.144a^2$ as may be verified by differential calculus.

The trapezoid in this case is half of a regular hexagon, and in the case illustrated by the sixth diagram, the figure is half of a regular octagon. By now, students ought to anticipate that the area of the figure will increase as the shape of figure approaches that of a semicircular region. The final diagram to be considered in detail is that which appears next to last in Figure 1.

**Diagram 7** — The figure is half of a regular decagon which may be partitioned into five isosceles triangles with base $a/5$ and altitude $a(\tan72^\circ)/10$. Thus, the area of the figure is 

$$(1/2)5(a/5)(a(\tan72^\circ)/10) = a^2(\tan72^\circ)/20$$ 

which has the approximate value of $0.154a^2$ sq. units.

The exercise concludes with the computation of the area of a semicircle of length $a$. The radius of such a semicircle is $a/\pi$ and its area is $(1/2)\pi(a/\pi)^2 = a^2/(2\pi)$ which is approximately $0.159a^2$. 


It seems clear that students who participate with goodwill in these exercises and pay attention to the meaning of their results will learn a great deal of geometry.

Conclusion

One needs to ask whether or not the minimester excursions into problem solving have been successful. Total student enrollment has not been large—roughly fifteen students over the past three years. However, those who participated did so enthusiastically. Students and teachers not directly involved have derived benefit as well. There really is truth to the old adage about “casting one’s bread upon the waters.” By means of the minimester course, ideas were set afloat that do not find expression in the general mathematics curricula of the two schools. Ideas floated on a sea of young minds do have their eventual return.

If the question is asked, the answer is “Yes.” If the question is not asked, the answer not given is still “Yes.” At St. Catherine’s and St. Christopher’s, a convenient time in crowded schedules was available for the class, there was already in place an interest in problem solving, and there was a seemingly inexhaustible source of problems from Singapore to consider. All that was needed was the addition of enthusiasm and hard work.

References


THE PERFECT PERSPECTIVE: A MATHEMATICAL ANALYSIS OF PERSPECTIVE USING TOOLS AVAILABLE TO MIDDLE SCHOOL STUDENTS

W. GRIFFIN

Liberty Middle School, Hanover County Schools
Ashland, VA 23005
wgriffin@hanover.k12.va.us

Abstract

This paper examines the basic properties of perspective drawings, the history of perspective drawings, and the basic mathematics of perspective. Using a side view and a top view of a three-dimensional projection, similar triangles can be used to find distances from the axes and vanishing point in a projection. By breaking the three-dimensional projection into two, two-dimensional planes, one can recreate projections based on actual figures, or create placements of figures in real space based on a projection. Using this method, one can change a projection based on the changing position of the vanishing point. This simple approach to perspective makes it accessible to students of different ability levels, as well as creating a strong connection between art and mathematics.

What is Perspective?

We do not often look at a photograph or a realistic painting and think of it as being a projection of our surroundings. However, this is precisely what a picture is. In a sense, it is flattening our world so that we can carry it with us. Both mathematicians and artists agree that perspective is representing the three-dimensional world in which we live on a two-dimensional plane [1,2].

Linear perspective assumes that the world exists behind a flat rectangular pane of glass. It is a simplification of how we view the world in that it relies on fixed rather than constantly shifting viewpoints and on straight lines to a vanishing point rather than the curvilinear ones that exist [2].
Brief History of Perspective

Perspective as we know it has evolved over thousands of years. In early civilizations and then for thousands of years following, artists often portrayed all of the objects in a picture as being the same size [2]. This early strategy made paintings very easy to understand and clear. When size was introduced initially, it was used to emphasize importance rather than relation to other objects. For example, the focal point of a painting would be the largest part of the work regardless of its position in respect to the other objects.

This Egyptian record depicting life in the Nile Valley does not use perspective. Notice the men in the background and foreground are the same size. [3]

The Bayeux Tapestry dating back to the 11th century depicts the Battle of Hastings. Notice how the king is much larger than anything else in the tapestry portraying his importance. [4]

In the late thirteenth century, a mindset of scientific naturalism began to take hold. These ideas of naturalism gave birth to perspective in art [2]. This study of perspective was mastered during the Renaissance period. During this time, artists were not only experimenting with perspective, but rules for the subject were being developed as well. The father of perspective was
not an artist or a mathematician for that matter, but rather a goldsmith named Filippo Brunelleschi [2]. He produced a couple of works done with accurate perspective, but he is best known for his design of buildings. None of his writings on perspective exist today and, in fact, it is possible that he may not have written anything in his time on the subject.

The first actual writings that we have today were done by a learned humanist named Leon Battista Alberti (1404-1472) [2]. As artists perfected this method on canvas, many artists and mathematicians alike created and perfected the method of finding true perspective.

Different Scenarios of Perspective

The horizon line or eye level line in a perspective drawing is the line where the sky meets the ground or the line that the eye falls on naturally when looking straight at the drawing [1]. Somewhere on that line, you will usually find the vanishing point or points in the painting.

The vanishing point is the point in which any two or more lines of the painting converge in the plane [1]. As illustrated in the simple diagrams below, you can see that there can be one vanishing point. When there is only one vanishing point, the drawing has one-point perspective. Another scenario illustrated below shows two vanishing points. When a painting has two or more vanishing points, it is said to have two-point perspective.

![One-Point Perspective](image1.png)

![Two-Point Perspective](image2.png)
Finding the Projected Coordinates

In my research, I have chosen to focus on one-point perspective paintings. Although this problem can be solved using the equation of lines in three-space and where they intersect different planes, I have chosen instead to focus on how to solve the problem using mathematics accessible to middle school students [5]. Although the process has many steps, curriculum could be developed from this research that could lead students through the method. The majority of the mathematics used in this project includes visualizing in three-space, and using proportions to find the lengths of corresponding sides of similar triangles.

In my initial problem, I had a rectangular prism that I wanted to recreate using one-point perspective. I knew the size and position of the prism; I chose the position of the vanishing point, and the position of the projection plane. My task was to find the coordinates of the cube in the projection plane. I first placed my prism on graph paper and found the three-dimensional coordinates of each of the six vertices. Since I could set the vanishing point to be anywhere, I chose to place it (0,0,0). I then chose to place my projection plane between the object and the vanishing point.

Since I was thinking and graphing points in three-dimensions, I needed to find a system to simplify the process. I chose to look at the setup from two separate two-dimensional planes and then combine them to get the three-dimensional coordinates. In order to do this, I followed a few steps:

1. Draw the side view of the setup. The base of the triangle is the distance from the front of the figure to the vanishing point. The triangle then has a leg that extends the height of the front of the figure. The hypotenuse is a segment extending from the top of the face of the prism to the vanishing point. This view
will allow you to find the y- and z-coordinates. (As usual, $z$ is the distance from
the vanishing point toward the object. The vertical distance is $y$ and $x$ measures
the horizontal distances parallel to the object.)

2. Draw the top view of the setup. The vanishing point is one of the vertices of the
triangle and the other two vertices are found on either side of the front of the
object. It is very likely that you will need to draw an altitude in this triangle.

3. Use similarity ratios to find lengths of each segment.
Similar triangles have corresponding angles that are congruent and corresponding sides that are proportional. The triangles we are looking at are similar because they have the same angle that has a vertex at the vanishing point. Parallel lines form the other two angles in each triangle. Since corresponding angles cut by parallel lines are congruent, we know that we have three congruent angles in our triangles. Because we have congruent angles, we know that the triangles must be similar, thus allowing us to set up proportions to solve for missing side lengths.

In our situation, we have drawn a perpendicular line through the vanishing point that goes through the projected plane and the real position of the figures. We can measure perpendicular distances from this line to any point in the projection. We also know how far the projection is from the vanishing point because we set these two positions. We are now in a position to set up our proportions.

- Distance from the perpendicular line to the projected y-value = Distance from the perpendicular line to the figure's y-value
- Distance from the perpendicular line to the projected x-value = Distance from the perpendicular line to the figure's x-value
- Distance from the vanishing point to the projected z-value = Distance from the vanishing point to the figure's z-value

**Example 1**

Step 1: Draw the side view of the entire projection.
Step 2a: Draw the top view of the projection.

Step 2b: Draw the top view of the projection.
Step 3: Use proportions of similar triangles to find lengths and positions of points.

Let's first find the coordinates of G'. Looking at the side view, we can determine the y- and z-values in our projection. The z-value from the vanishing point to the projection plane is 7 units long. The z-value from the vanishing point to the side of the box is 20 units. We also know that from the y-axis to the top of the box is 12 units. We do not know how far it is from the y-axis to the position of the top of the box in our projected plane. We can set up a proportion to find that distance.

\[
\frac{7}{20} = \frac{G'}{12} \quad 63 = 20G' \quad 3.15 = G'
\]

Since we are finding the distance of this segment from the y-axis, the value that we got is the actual coordinate. We only have to check to see if it is above or below the axis and in this case, it is below so the y-coordinate for this point is -3.15. Using this process, we can find all of the y-coordinates in this projection.

<table>
<thead>
<tr>
<th>Projection points</th>
<th>y-coordinates</th>
<th>z-coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>A'</td>
<td>-3.15</td>
<td>7</td>
</tr>
<tr>
<td>B'</td>
<td>-8.4</td>
<td>7</td>
</tr>
<tr>
<td>C'</td>
<td>-1.97</td>
<td>7</td>
</tr>
<tr>
<td>D'</td>
<td>-5.25</td>
<td>7</td>
</tr>
<tr>
<td>E'</td>
<td>-1.97</td>
<td>7</td>
</tr>
<tr>
<td>F'</td>
<td>-5.25</td>
<td>7</td>
</tr>
<tr>
<td>G'</td>
<td>-3.15</td>
<td>7</td>
</tr>
<tr>
<td>H'</td>
<td>-8.4</td>
<td>7</td>
</tr>
</tbody>
</table>

Our diagram includes the points E', F', G' and H', but since we are working with a cube that is positioned parallel to the projection plane, we can reason that there are two points that share the same y-values. Using this deduction, A', B', C', and D' can be found.

Notice that all of the z-values are the same. This is indicating that the projection is contained in one plane that runs perpendicular to the z-axis.

Once we have the y- and z-values, we just repeat the above process using the top view to find the x-values.
To find $A'$, we first find the perpendicular distance from the vanishing point to the projected plane which is 7 units. Then, we find the perpendicular distance from the vanishing point to the point on the figure which is 20 units. The next distance that is needed is the perpendicular distance from the z-axis to the point on the figure which is 8 units. This distance is unknown in the projection.

\[
\frac{7}{20} = \frac{G'}{4} \quad \frac{7}{20} = \frac{A'}{8}
\]

\[
28 = 20G' \quad 56 = 20A'
\]

\[
1.4 = G' \quad 2.8 = A'
\]

Again, we need to observe whether this distance is to the right or left of the x-axis and in this case, it is to the right making the coordinate positive. We can repeat this process to find the rest of the coordinates in the projection.

<table>
<thead>
<tr>
<th>Projection points</th>
<th>x-coordinates</th>
<th>y-coordinates</th>
<th>z-coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>A'</td>
<td>2.8</td>
<td>-3.15</td>
<td>7</td>
</tr>
<tr>
<td>B'</td>
<td>2.8</td>
<td>-8.4</td>
<td>7</td>
</tr>
<tr>
<td>C'</td>
<td>1.75</td>
<td>-1.97</td>
<td>7</td>
</tr>
<tr>
<td>D'</td>
<td>1.75</td>
<td>-5.25</td>
<td>7</td>
</tr>
<tr>
<td>E'</td>
<td>-0.875</td>
<td>-1.97</td>
<td>7</td>
</tr>
<tr>
<td>F'</td>
<td>-0.875</td>
<td>-5.25</td>
<td>7</td>
</tr>
<tr>
<td>G'</td>
<td>-1.4</td>
<td>-3.15</td>
<td>7</td>
</tr>
<tr>
<td>H'</td>
<td>-1.4</td>
<td>-8.4</td>
<td>7</td>
</tr>
</tbody>
</table>

This is what the projection would look like in our example.
In our case, these distances are very easy to find since we have set the vanishing point to the origin. We can use the given coordinates rather than having to subtract two coordinates to find the distance. If the vanishing point were not the origin, then you would have to subtract the line's position from the position of the point in question. It is also important to remember that you are working with one specific triangle at a time since the similarity ratio will vary for different triangles. The distances that you are finding can then be added or subtracted from the axes to find the coordinates of each point.

**Finding the Coordinates of the Figure**

When you are given a projection, you can find the coordinates of the figure, as they would be positioned in real life. First, you must set the distance from the vanishing point to the projection. It is logical when working with a painting as a projection to use an arm's length for this distance since the vanishing point in this instance would be the artist's eye, the projection his or her canvas, and the objects being painted would be behind the canvas. Once this point is set, you must also know the real length of one of the objects in the projection.

To find the vanishing point of the picture, find the intersection of the major lines of the painting. Once you find this point, you can use it as the origin and draw the x- and y-axis on the projection plane. You can then measure distances perpendicular from these axes and use the set z-value that corresponds to the placement of the projected plane to find the coordinates of each point. Using these points, the origin and the information that you know about the figures, you can find real-life placements from the painting.

**Example 2**

Using the same prism as above, we will find the position of each of the coordinates in the real figure given only the projected coordinates and the knowledge of the distance between two of the points in real space.
<table>
<thead>
<tr>
<th>Projection points</th>
<th>x</th>
<th>y</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>A'</td>
<td>2.8</td>
<td>-3.15</td>
<td>7</td>
</tr>
<tr>
<td>B'</td>
<td>2.8</td>
<td>-8.4</td>
<td>7</td>
</tr>
<tr>
<td>C'</td>
<td>1.75</td>
<td>-1.97</td>
<td>7</td>
</tr>
<tr>
<td>D'</td>
<td>1.75</td>
<td>-5.25</td>
<td>7</td>
</tr>
<tr>
<td>E'</td>
<td>-0.875</td>
<td>-1.97</td>
<td>7</td>
</tr>
<tr>
<td>F'</td>
<td>-0.875</td>
<td>-5.25</td>
<td>7</td>
</tr>
<tr>
<td>G'</td>
<td>-1.4</td>
<td>-3.15</td>
<td>7</td>
</tr>
<tr>
<td>H'</td>
<td>-1.4</td>
<td>-8.4</td>
<td>7</td>
</tr>
</tbody>
</table>

Step 1: Graph a top view of the points in the projection plane.
Step 2: Sketch a top view of the position of points in real space and fill in any information given.
Step 3: Set up proportions to find missing distances.

Use the distance formula to find the distance from the VP to $G'$,

$$d = \sqrt{(-1.4)^2 + (-3.15)^2 + 7^2}$$

$$d = \sqrt{60.8825}$$

$$d = 7.803$$

7.803 units is the distance from VP to $G'$.

Using that distance, find the distance from the VP to $G$.

$$\frac{\text{Distance from } A' \text{ to } G'}{\text{Distance from } A \text{ to } G} = \frac{\text{Distance from VP to } G'}{\text{Distance from VP to } G}$$
\[
\frac{4.2}{12} = \frac{7.803}{x} \\
4.2x = 93.636 \\
x = 22.29
\]

22.29 is the distance from \( VP \) to \( G \).

Use the distance found to set up another proportion.

\[
\frac{\text{Distance from } VP \text{ to } G'}{\text{Distance from } VP \text{ to } G} = \frac{\text{Distance from the } z\text{-axis to } G'}{\text{Distance from the } z\text{-axis to } G}
\]

\[
\frac{1.4}{x} = \frac{7.803}{22.29} \\
7.803x = 31.206 \\
x = 3.999
\]

3.999 is the distance from the \( z\)-axis to \( G \).

If the distance from the \( z\)-axis to \( G \) is 3.999, then the distance for the \( z\)-axis to \( A \) is 12-3.999=8.001.

Use the distance found to set up another proportion.

\[
\frac{\text{Distance from } VP \text{ to } w}{\text{Distance from } VP \text{ to } r} = \frac{\text{Distance from } VP \text{ to } G'}{\text{Distance from } VP \text{ to } G}
\]

\[
\frac{7}{x} = \frac{7.803}{22.9} \\
160.3 = 7.803x \\
20.54 = x
\]

The distance from the vanishing point to \( r \) (adjacent point on the \( z\)-axis) is 20.54.

Therefore, the known coordinates for \( G \) are \( x = -3.999, z = 20.54 \), and the known coordinates for \( A \) are \( x = 8.001 \) and \( y = 20.54 \).
We now need to set up the side view of the projection. This is easier than the first calculations because we already know the distance from the vanishing point to the figure.

Notice that from the side view, A and G are at the same height. One portion will find the missing length.

\[
\frac{\text{Distance from } VP \text{ to } W}{\text{Distance from } VP \text{ to } Q} = \frac{\text{Distance from } W \text{ to } A'}{\text{Distance from } Q \text{ to } A}
\]

\[
\frac{7}{20.54} = \frac{3.15}{x}
\]

\[
7x = 64.701
\]

\[
x = 9.234
\]

The distance from Q to A is 9.234 units.

Therefore, the ordered triples for the two points are \( A = (8.001, 9.243, 20.54) \) and \( G = (-3.999, 9.243, 20.54) \).
We can repeat this process to find all of the coordinates in this case because we are working with a cube. The cube creates a special case. The above process will vary slightly for each new situation based on what is known, but the process and technique remains essentially the same.

When objects are projected from two-space to one-space, certain features are lost. The same is true when a projection is made from three-space to two-space. With the transition from two-space to three-space, many placements can be made as they originally were in the figure. This reverse projection is a tool that can be used to recreate positions, but not to reproduce every detail of the original object.

**From a Different Point of View**

Once we know the real position of the figures in the projection, we can change the vanishing point and create a new projection plane. This will alter what the picture looks like in the projection, but will still hold true for the properties of perspective. The process will work exactly as it did in Example 1 except the vanishing point is not at the origin so additional calculations will be needed to get coordinates.
Example 3

We will use the same figure and projection plane as in the first example, but change only the vanishing point to (5, 10, -3).

Step 1: Draw the top view of the projection.

Step 2: Use proportions to find missing distances.

\[
\frac{10}{23} = \frac{A'}{8} \quad \frac{10}{23} = \frac{G'}{4} \quad \frac{10}{35} = \frac{C'}{8} \quad \frac{10}{35} = \frac{E'}{4}
\]

\[
80 = 23A' \quad 40 = 23G' \quad 80 = 35C' \quad 40 = 35E'
\]

\[
3.45 = A' \quad 1.74 = G' \quad 2.29 = C' \quad 1.14 = E'
\]

The x-coordinate for A' and B' is 5 + 3.45 = 8.45
The x-coordinate for G' and H' is 5 - 1.74 = 3.26
The x-coordinate for C' and D' is 5 + 2.29 = 7.29
The x-coordinate for E' and F' is 5 - 1.14 = 3.86

This is not the distance from this object to the x-axis, but rather to the line that runs through x = 5. To get the coordinates, you must add and subtract values from 5.
Step 3: Draw the side view of the projection.

Note that these distances represent not the y-coordinates, but rather the distance from the perpendicular line running through y=10. In order to get the coordinates, these distances need to be added or subtracted from 10.

*Notice that each y-coordinate corresponds to two points in our figure.

Step 4: Use proportions to find the missing distances.

\[
\begin{align*}
\frac{10}{23} &= \frac{A'}{22} & \frac{10}{23} &= \frac{B'}{34} & \frac{10}{35} &= \frac{C'}{22} & \frac{10}{35} &= \frac{D'}{34} \\
\end{align*}
\]

The y-coordinate of A' and G' = 10 - 9.57 = .43
The y-coordinate of E' and C' = 10 - 6.29 = 3.71
The y-coordinate of H' and B' = 10 - 14.78 = -4.78
The y-coordinate of F' and D' = 10 - 9.71 = .29

Since the z-values stayed the same (same projection plane), we now have all of our coordinates for the new projection.

<table>
<thead>
<tr>
<th>name</th>
<th>x</th>
<th>y</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>A'</td>
<td>8.45</td>
<td>.43</td>
<td>7</td>
</tr>
<tr>
<td>B'</td>
<td>8.45</td>
<td>-4.78</td>
<td>7</td>
</tr>
<tr>
<td>C'</td>
<td>7.29</td>
<td>3.71</td>
<td>7</td>
</tr>
<tr>
<td>D'</td>
<td>7.29</td>
<td>.29</td>
<td>7</td>
</tr>
</tbody>
</table>
Below, you can compare what the projection looks like with the original vanishing point compared to the new vanishing point.

**Botticelli's *Adoration of the Magi***

I chose to work with a painting by Sandro Botticelli, a Renaissance artist. He was born in Florence in 1445 and showed a talent for painting from an early age. Although he did get many famous commissions during his lifetime, his greatest recognition as a Renaissance master came centuries after his death. During his lifetime, the arts were flourishing and many wealthy people were commissioning portraits and other artwork for their estates. A wealthy merchant commissioned a religious work by Botticelli, but also wanted it to contain portraits of the de Medici family and the group of artists of which Botticelli was a member. The piece was called *Adoration of the Magi*, and featured portraits of Lorenzo, Piero, Giovanni, and Giuliano de Medici, as well as artists Poliziano and Pico della Mirandola. Botticelli is pictured in the lower
right corner wearing a yellow cloak, and looking outward. In addition to this painting, he produced many other famous works, including *The Birth of Venus*, *Virgin and Child*, *The Annunciation*, and many more [6].

Finding Real-Life Distances

When you are given a painting as a projection, no calculations are needed to find the coordinates of each point. You should first find the vanishing point by following the major lines of the painting to their intersection point. This point can be called (0,0,0). Since we are working on a plane, we can draw perpendicular lines through the origin to create the s- and y-axes. The coordinates of each point can be found by measuring to the left and right of these axes.

To find the actual position of the objects in real space, the next step is to set the distance from the vanishing point to the projection. A logical distance would be an arm’s length from the projection [8]. The artist most likely stood this distance away from his or her canvas as the projection was created. I have chosen to set this distance at 24 inches. Next, an assumption must be made about the painting, such as the length of a foot, the width of a hand, etc. I have chosen to assume that a foot in the painting is twelve inches long. As always, it is good practice to draw the scenario.
Use the distance formula to find the distance from the vanishing point to B'.

\[ d = \sqrt{(-7.3125)^2 + (-7.75)^2 + (24)^2} \]

\[ d = 26.26in \]

Set up proportions of similar triangles from the top view to find the other missing distances.

\[ \frac{1}{12} = \frac{26.26}{w} \quad \frac{26.26}{315.12} = \frac{24}{24 + z} \quad \frac{6.3125}{x} = \frac{24}{288.02} \]

\[ 1w = 315.12 \quad 315.12 = 26.26(24 + z) \quad 1818.13 = 24x \]

\[ w = 315.12 \quad z = 264.02 \quad x = 75.76 \]

Set up proportions of similar triangles using the side view and what was found from the top view to find the missing distances.
\[
\frac{24}{288.02} = \frac{7.75}{y} \\
24y = 2232.155 \\
y = 93.006
\]

Therefore, the coordinates to the toe and heel in real space would be:

Heel \((-87.76, -93.006, 288.02)\)  
Toe \((-75.76, -93.006, 288.02)\)

Use the same steps as described to find the coordinates of the foot in the painting. Using this coordinate, you can also find any object’s position that lies in the same x, y, or z plane. For example, it is possible to find the height of the object, any object that is placed on the same horizontal surface, or any object that is in the same perpendicular plane. In this case, I have also decided to find the height of the man.

\[
\frac{24}{288.02} = \frac{.75}{s} \\
24s = 216.015 \\
s = 9.0006
\]

Based on the assumption that his foot is twelve inches long, his height is 93.006+9.0006=102.007 inches or about 8.5 feet.
His actual height kneeling, based on the assumption that his foot is twelve inches long, is 102.007 inches. The assumption made is not reasonable since a fifteenth century man is probably not over eight feet tall. I chose to recalculate his height using the assumption that his foot is eight inches long. This new assumption made his height 68.007 inches, which is about five and a half feet tall. This second calculation is much more reasonable. This example speaks to the challenges that arise when trying to recreate the position of three-dimensional objects based on a two-dimensional projection.

Summary

As you can see using a series of relatively simple steps, it is possible to recreate the actual location of objects as they appear in a painting. You can also place three-dimensional objects in a two-dimensional plane without the use of a camera. This mathematical process, in conjunction with technology, has given birth to advancements that are changing the way we live. Filmmaking, computer graphics, modern creative media, and virtual reality are a few examples of what is possible due to our understanding of perspective [8].

Acknowledgment

The funding for this project was provided by the National Science Foundation DGE 0086320.

References


AIMS & SCOPE

Articles are solicited that address aspects of the preparation of prospective teachers of mathematics and science in grades K-12. The Journal is a forum which focuses on the exchange of ideas, primarily among college and university faculty from mathematics, science, and education, while incorporating perspectives of elementary and secondary school teachers. The Journal is anonymously refereed, and appears twice a year.

The Journal is published by the Virginia Mathematics and Science Coalition.

Articles are solicited in the following areas:

• all aspects of undergraduate material development and approaches that will provide new insights in mathematics and science education

• reports on new curricular development and adaptations of ‘best practices’ in new situations; of particular interest are those with interdisciplinary approaches

• explorations of innovative and effective student teaching/practicum approaches

• reviews of newly developed curricular material

• research on student learning

• reports on projects that include evaluation

• reports on systemic curricular development activities
The Journal of Mathematics and Science: Collaborative Explorations is published in spring and fall of each year. Annual subscription rates are $20.00 US per year for US subscribers and $22.00 US per year for non-US subscribers.

All correspondence, including article submission, should be sent to:

Karen A. Murphy, Editorial Manager  
The Journal of Mathematics and Science: Collaborative Explorations  
Virginia Mathematics and Science Coalition  
VCU Mathematics  
1001 W. Main Street, Room 2069  
Richmond, VA 23284-2014  
FAX 804/828-7797  
e-mail VMSC@vcu.edu

- For article submission, send three copies of the manuscript.
- The body of the paper should be preceded by an abstract, maximum 200 words.
- References to published literature should be quoted in the text in the following manner: [1], and grouped together at the end of the paper in numerical order.
- Submission of a manuscript implies that the paper has not been published and is not being considered for publication elsewhere.
- Once a paper has been accepted for publication in this journal, the author is assumed to have transferred the copyright to the Virginia Mathematics and Science Coalition.
- There are no page charges for the journal.

Copy editor: E. Faircloth
METHODS OF SMILE: A SCIENCE SEMINAR COURSE IN "DELIBERATE EDUCATION"
E. Davis-Butts and R. Collay

THE OCCURRENCE OF REFORM TEACHING PRACTICE IN UNDERGRADUATE MATHEMATICS AND SCIENCE CLASSES: THE STUDENTS' PERSPECTIVE
P.O. Morrell and J.B. Carroll

PART II  Regular Journal Features

VISUALIZING BASIC NUCLEAR REACTIONS
D. Allen and M.T. Oliver-Hoyo

THE USE OF TRADITIONAL AND CONTEMPORARY INSTRUCTIONAL STRATEGIES AND MATERIALS IN THE ELEMENTARY MATHEMATICS CLASSROOM
J.E. Riley

UNDERSTANDING TEACHER REFLECTION AS A SIGNIFICANT TOOL FOR BRINGING REFORM-BASED TEACHING TO COLLEGE MATHEMATICS
K. Jeon

RECRUITING MORE MATHEMATICS TEACHERS USING COLLABORATION AS THE MAIN INGREDIENT: AN EFFECTIVE MODEL FROM MISSOURI
L. Kaiser

STUDENT WORK SECTION, R. Howard, Section Editor

MATHEMATICS FROM CHINA TO VIRGINIA BY WAY OF SINGAPORE
H. Kim, C. Wu, A. Xue, and J. Boyd

THE PERFECT PERSPECTIVE: A MATHEMATICAL ANALYSIS OF PERSPECTIVE USING TOOLS AVAILABLE TO MIDDLE SCHOOL STUDENTS
W. Griffin
PART I  Oregon Collaborative for Excellence in Teacher Preparation (OCETP)

OREGON COLLABORATIVE FOR EXCELLENCE IN THE PREPARATION OF TEACHERS – AN OVERVIEW
    M. Enneking 1

PEER-LED TEAM LEARNING IN INTRODUCTORY BIOLOGY AND CHEMISTRY COURSES: A PARALLEL APPROACH
    A. Tenney and B. Houck 11

THE DEVELOPMENT OF INSTRUMENTS FOR ASSESSMENT OF INSTRUCTIONAL PRACTICES IN STANDARDS-BASED TEACHING
    C.L. Wainwright, L. Flick and P. Morrell 21

A DESCRIPTIVE COMPARISON OF ONE UNIVERSITY INSTRUCTOR’S INSTRUCTION DURING PRE-SERVICE MATHEMATICS COURSES AND THE SUBSEQUENT MATHEMATICS AND SCIENCE INSTRUCTION OF THREE OF HIS STUDENTS DURING THEIR STUDENT TEACHING EXPERIENCE
    S. Blair 47

LESSONS LEARNED IN A MATH EXCEL WORKSHOP: THE IMPORTANCE OF MAINTAINING HIGH COGNITIVE DEMANDS
    T. Dick 65

MAKING UPPER DIVISION MATHEMATICS COURSES RELEVANT FOR PRE-SERVICE TEACHERS
    G. Hill 75

PERSISTENCE IN MATHEMATICS BY UNDERREPRESENTED STUDENTS: EXPERIENCES OF A MATH EXCEL PROGRAM
    C.M. Hake, M.L. Crow, and T. Dick 87

LESSONS LEARNED FROM EFFORTS AT INSTITUTIONAL CHANGE: CASE STUDIES OF SIX OCEPT INSTITUTIONS
    T.G. Chenoweth, M.K. Kinnick, and R.D. Walleri 103

GOESCIENCES FOR ELEMENTARY EDUCATORS: A COURSE ASSESSMENT
    M.L. Cummings, M. Goodrich, and D. Burmester 127

(Contents continued inside)