Reform Teaching Strategies Used by Student Teachers

By

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Abstract

The purposes of this study were to observe the teaching practices occurring in student teachers' science and mathematics K-12 classrooms, compare the student teachers'

perceptions of their teaching with what was actually occurring in their classrooms, and determine what college faculty and/or course impacted the teaching methods used by these student teachers. Data on each student teacher were gathered via field notes of three classes, an observation protocol completed after each lesson, and an interview.

Composites were written for each of the students. The total data set of all composites was examined to see if any patterns generalizable to the whole were evident. Differences between and among grade levels and content areas surfaced and are discussed.

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Introduction

Reform of both science and mathematics curricula and classroom practice has been a focus of many groups for over a decade (AAAS, 1989, 1993; Aldridge, 1989; Grouws & Schultz, 1996; NRC, 1996a, 1996b; NCSESA, 1993; NCTM, 1989, 1991, 1995, 2000). The main elements of these reform practices revolve around a constructivist view of teaching and learning and include practices such as encouraging discourse among students, supporting inquiry and problem solving, and assisting students in thinking about their own learning, among others. These instructional practices require a paradigm shift from the more predominant methods currently used in college teaching, where the common instructional format is lecture (NRC, 1996a; NSF, 1996; NRC, 1999). Thus, if we want to effectuate a change and help preservice teachers move in reform directions at the K-12 level, these students need to see improved teaching practices modeled at all levels of their education, particularly during their college experiences. Some evidence is appearing (Judson & Sawada, 2001) 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.

To address the need to provide preservice teachers with the tools needed to implement reform-based practices, 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 rationale of the NSF CETP program in general and the OCEPT project in particular was that if prospective teachers have first-hand experience in learning mathematics and science through strategies that are reform-oriented, they will develop a stronger appreciation for the value of the coursework and will use this model for more effective pedagogy when they begin their own teaching.

OCEPT was designed to cause systemic change in college and university teaching throughout Oregon by working with a critical mass of interested faculty from two and four-year private and public institutions. OCEPT exposed these instructors, the Faculty Fellows, to a variety of teaching and assessment methodologies and provided stipends for release time for course reform and for professional development opportunities.

In the final year of the OCEPT project, we designed an evaluation of the effectiveness of the program. We examined the kinds of instructional strategies being used in undergraduate mathematics and science classrooms. We also observed the types of reform teaching strategies being used by the student teachers who had taken courses from OCEPT Faculty Fellows.

This evaluation study of student teachers is part of a larger study which examines the classroom teaching of the college-level instructors, as well as the long term effects of their teaching on early career science and mathematics teachers. This particular paper reports on the initial results of a longitudinal examination of the types of reform teaching strategies used by preservice teachers during their student teaching practica following exposure to reformed teaching of science and mathematics college faculty.

Purpose

The purposes of this study were to determine (1) what elements of reform teaching were being utilized by student teachers in their science and/or mathematics teaching, including a qualitative estimate of the frequency with which they are used; (2) the relationship between the student teachers' perceptions of their classroom instruction and the observed classroom practice; and (3) what college faculty or content (mathematics/science) courses student teachers recalled impacting their instructional design and practice.

Sample

While OCEPT was a statewide collaborative which included 34 higher education institutions, we purposely selected our sample from five institutions. These core institutions were chosen because they had been heavily involved in OCEPT activities, had a large pool of OCEPT Faculty Fellows, and together produced large numbers of student teachers. They were representative of the state's teacher education programs, including both public and private institutions; rural, suburban, and urban areas; undergraduate and graduate teacher preparation programs; and teaching and research institutions.

Our sample of student teachers was comprised of students from each of the five core institutions, and consisted of both seniors and fifth year students in a teacher preparation program. The criteria used to select the participants were:

The student teachers were teaching in elementary schools or in science or mathematics classrooms at the middle or high school level.

They must have had at least two undergraduate science or mathematics courses from OCEPT Faculty Fellows.

They volunteered to be a part of this study, to be observed, and to participate in an interview.

In all, seventeen student teachers participated in the study. Nine of these were elementary level student teachers, two were at the middle level (one science and one mathematics), and six were at the high school (three science and three mathematics).

Methodology

Tools

The research team was comprised of four science and/or mathematics education faculty and three graduate students. All seven of the team members were from the five institutions represented in the study sample. A subgroup of three of the faculty members of the research team examined the literature on observing reform teaching practices. A number of researchers and groups had developed classroom observation instruments. The subgroup undertook a critical review of these instruments, specifically those by the Horizon Research Corporation, Inc. (1999), Dana (2000), the NSF CETP group (Lawrenz, Huffman, Appeldoorn & Sun, 2001), and the Arizona Collaborative (Piburn, Sawada & the Evaluation Facilitation Group, 2000). All the scholars studying the task of observing reform teaching practices had the same purpose; that is, trying to define exactly what behaviors illustrate reform teaching in different teaching contents and contexts. For our purposes, the instrument needed to be comprehensive enough to capture the complexities of constructivist teaching but sufficiently streamlined to be used across a relatively large number of classrooms with varying contexts.

None of the existing tools met our needs. Building primarily on the work of Piburn, et al. (2000) and Lawrenz, et al. (2001), the subgroup designed and piloted the OCEPT Classroom Observation Protocol (OTOP), found in Appendix I. We felt the protocol met the following criteria: (a) it was externally validated by experts in science and mathematics education; and (b) items contained sufficient descriptive information to reliably train observers. Information concerning the specific development of the instrument, along with validity and reliability data is described in Wainwright, Flick, and Morrell (2003). The group also designed an interview protocol (OCEPT Teacher Interview Protocol—OTIP) based directly on the OTOP (see Appendix II). Using the OTIP along with the OTOP acts to validate the observational data and adds an in-depth description of the instructor's perspective.

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. Further validation and reliability checks were carried out by pairs of researchers observing actual classrooms at the elementary, middle, high school, and college levels.

<u>Data Collection</u>

Each student teacher in the sample was asked to supply the research team with dates and times of possible observation visits. This ensured that each research team member was able to observe an "active" mathematics or science lesson, as opposed to a non-targeted content course in the case of elementary student teachers, a testing situation, a full-period video, and the like. Most participants were observed teaching on three occasions. Field notes were taken during each observation, and the OTOP instrument was completed at the end of each class observation. After the series of observations, the student teachers were individually interviewed using the interview protocol. Typically, the interviews lasted about 30 minutes. The interviews were audio-taped and transcribed.

Analysis

We collected a total of 50 sets of observational field notes, 50 completed OTOP instruments, and 17 interview transcripts. To assist in analyzing this volume of data, the observers wrote a composite case study for each participant summarizing data from the field observations, the OTOP instruments, and the OTIP transcribed interview. The composites specifically included:

1. A table listing the student teacher's OTOP rating for each item for each observation
2. A graph showing the sets of OTOP 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 (3 consecutive days, etc.)
   - description of students and make up of the class (e.g. sophomore and juniors in an elective class)
   - size of class
   - institution (public v. private, etc.)
   - important constraints (e.g. room set up, equipment limitations)
4.

A description of the observed behaviors that led to the OTOP scores for each observation

5.

Patterns and interpretations of the total data set, relying on observations, OTOP 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 (Bogdan & Biklen, 1998). Because of the low numbers of middle school student teachers and because their content background would be similar, we formed one group of middle and high school student teachers. We grouped the data by grade level (elementary, middle/high school) and then by content areas (science, mathematics). In addition, we collapsed the categories of numerical data from the OTOP instruments. Observers used the OTOP numbers as estimates of frequency ranging from "not observed" to "characterize the lesson." We reduced the five point scale to three categories: "not observed" (N/O on the scale), "infrequent" (1 and 2 on the scale) and "frequent" (3 and 4 on the scale).

Unlike several other observation protocols (for example, see MacIsaac & Falconer, 2002) that rate the teaching experience and total the numerical ratings, the OTOP was viewed as a descriptive tool. We designed the OTOP to generate a profile of what was happening across instructional settings rather than assigning a score to a particular lesson. In other words, we treated the ratings on the OTOP items as nominal data rather than interval data. This differs from the way the R-TOP has been used in recent reports (Piburn et al., 2000). We see the OTOP results in combination with interviews and field notes from classroom visits as a prelude to theory building.

We recognized from the outset that the OTOP items, if used reliably across observers to mean the same thing, would not produce a rating that was interpretable without knowing the teaching context. Experience suggested that some aspects of reform teaching in the OTOP would be more evident in some modes of instruction than others. For example, laboratory activities typically afford more small-group work and student-to-student discussion than lectures. We recognized that this study required a qualitative dimension that preserved context. Our understanding of how the items of the OTOP performed in classroom observations had to be informed by the class context and the student teacher's perspective.

Results with Discussion

Observed Classroom Teaching Practices

The first purpose of this study was to determine what types of teaching practices were being used by student teachers (see Tables 1, 2 and 3). The analysis is based on 26 elementary observations and 24 middle/high level observations. Looking first at the elementary level student teachers, we see that four of the OTOP items typify the instruction that was observed (Figure 1). (A practice was considered "typical" if it was observed with a frequency of 3 to 4 on the OTOP scale in at least 50% of the observed lessons.) These four categories are student discourse and collaboration (item 3), attending to preconceptions/ misconceptions (item 5), pedagogical content knowledge (item 9), and use of multiple representations (item 10). Some evidence of items 9 and 10 were seen to some extent in all observations.

The following OTOP items were typical of the middle/high school level observations (Figure 2). These items were numbers metacognition (item 2), student discourse and collaboration (item 3), attending to pre/misconceptions (item 5), pedagogical content knowledge (item 9) and use of multiple representations (item 10). Items 2 and 10 were seen to some extent in all observations at these levels.

When we compare the elementary level with the middle/high school level of teaching observations (Figure 3), we see that four of the OTOP categories were frequently seen at both levels. Regardless of teaching level, the student teachers taught lessons which were typified by student discourse and collaboration (item 3), probing of existing student knowledge and preconceptions (item 5), possession of a solid grasp of the subject matter content and how to teach it (item 9), and use of a variety of means to represent concepts (item 10).

Although many of the reform practices that typified the observed classrooms were common to all levels, there were some differences between elementary and the higher levels. Pedagogical Content Knowledge (item 9) was always evident to some extent in the elementary levels, but there were some instances in the middle/high classes where this item was not observed (8% of the time). However, PCK was seen more frequently in the middle/ high school classes than in the elementary classes, along with metacognition (item 2) and student discourse and collaboration (item 3). One might reason that because middle and high school student teachers are “content specialists” and have specific subject matter and methods coursework, they may be more adept at knowing their area and how best to teach it than an elementary level generalist.

At the elementary level, multiple representations (item 10) was more frequently seen than at the middle/high levels. The developmental levels of elementary-aged students often require the use of multiple methods and materials to explain a concept than with older students.

Neither group of student teachers had lessons typified by habits of mind/problem solving (item 1), challenging of ideas (item 4), conceptual understanding (item 6), divergent thinking (item 7) and interdisciplinary connections/relevance (item 8). These are areas that need further examination. Within the context of this study, these results raise questions about the frequency of these features in the instruction these teachers themselves have experienced. Without explicit modeling, student teachers may have difficulty in exhibiting these behaviors in their own teaching.

If we examine OTOP scores by content area, several other patterns emerge. At the elementary level, 15 of the lessons observed were in mathematics while eight were in science (Figure 4). Three lessons included in the overall analysis of elementary level student teachers were integrated science/language arts lessons. However, because the main emphasis of these observed lessons was language arts, they were not included in the analysis for science lessons. Three OTOP items typified the lessons observed for both content areas.

These were student discourse and collaboration (item 3), pre/misconceptions (item 5) and multiple representations (item 10). In science classes, two additional reform practices were typically seen: interdisciplinary connections/relevance (item 8) and pedagogical content knowledge (item 9). It may be that it is easier for teachers to make interdisciplinary connections and provide a statement of relevance in science as opposed to mathematics. It is interesting that PCK was more typical of a science than a mathematics lesson in these elementary classes. Given that all of the student teachers in this study had a full year of Mathematics for Elementary School Teachers course work, this seems almost counterintuitive. However, it may be that because of the high frequency scores for interdisciplinary connections/relevance and multiple representations, taken in concert, the incidence of PCK observations is "inflated." Additionally, elementary-aged students tend to be curious about science and thus more likely to engage in classroom discourse. Students may be more willing to pose questions in science than mathematics classes and may be more engaged in the lesson. These factors may also aid in strengthening the appearance of PCK in science over mathematics courses.

Looking at OTOP values by content areas for the middle/high school level student teachers (Figure 5), we observed 11 mathematics classes and 13 science classes. Three items typify the teaching in both areas: student discourse and collaboration (item 3), pre/misconceptions (item 5) and PCK (item 9). In mathematics classes, habits of mind/problem solving (item 1) and metacognition (item 2) are more evident. It may be that there are more obvious problem solving opportunities presented in a typical secondary mathematics class than in a science class. Given the emphasis on problem solving in mathematics, this is not surprising. Typical science classes may tend to have fewer questions of all types than a typical mathematics class. The same holds true with metacognition. Because communication is stressed in mathematical problem-solving, teachers tend to encourage mathematics students to explain how they worked a problem. Science classes still tend to be dichotomous between information giving (lecture type classes) and concept formation/problem solving (laboratory activities). Finally, checking for preconceptions and misconceptions is more prevalent in mathematics classes. Because mathematics is taught in such a step-wise, scaffolded manner, it is not unusual for mathematics teachers to check on the previous day's lesson before continuing with the current day's planned content.

In contrast, several items were more typical of a middle/high science lesson than a mathematics lesson. Science classes tended to make greater use of multiple representations than middle/high school mathematics classes. This may be explained by the number of models and demonstrations that are common to science classes. Student discourse and collaboration (item 3) was more typical of science classes, as well. Laboratory activities and group presentations may account for this. But, another question is raised. The observation protocol is not designed to examine the qualities of the student collaborative activities. Group laboratory activities are not always collaborative especially when one student dominates the group. How reform oriented were the observed collaborations and student discourse?

In both the mathematics and science content areas, two items were not seen frequently. These areas of concern are encouraging divergent thinking (item 7) and rigorously challenging ideas (item 4). Given the emphasis on problem solving in mathematics classes and the need for inquiry in science, the fact that these reform techniques do not typify student teachers' lessons calls for further examination and exploration. Previous studies of classrooms have noted that teachers reduce cognitive demands in the face of student difficulties or under other pressures of the classroom. Is that what is occurring in these student teachers' classrooms?

<u>Consistency of Perceptions with Observations</u>

The second purpose of this investigation was to compare the student teachers' perceptions of their teaching with what we actually observed. Based on interview data and observational data, the students seem to be fairly accurate in describing their instructional strategies and their limitations. For example, one secondary mathematics student teacher was observed to consistently check for students' misconceptions and prior knowledge through an individual warm up or questions at the beginning of each lesson and before introducing new concepts. The questions, however, tended to be lower level, factual type questions. The student noted in his interview:

I suppose questioning would be the best way to do that (check for mis/ preconceptions)… I found that the best way was simply just asking questions. Obviously as a new teacher, I am finding that asking good questions is challenging. And eliciting good feedback is difficult, too.

A middle school mathematics science teacher was not seen to make interdisciplinary connections or explicitly show the relevance of what was being taught. When responding to the interview question concerning this item, she stated it was hard for her to do this:

Especially common multiple and greatest common factors. Where are we ever going to use this? So that stuff, I tried to bring in, if I really thought of something that would work in terms of a real world example, I would bring it in. But that is another area that would help the conceptual, if I knew a lot more of real world uses for things.

A secondary science student teacher who was seen using a variety of ways to explain a concept noted that she used manipulatives, drawings, etc. because it was necessary to help with students' understanding:

We have done what are isomers (in readings and discussion) and a lot of things that are kind of abstract and hard to understand. So making sure they have several shots to figure out what is going on and different ways of explaining it (is why she varies a variety of instructional tools).

There were, however, some instances of overstating claims of instructional skills. For example, when asked about making interdisciplinary connections and promoting divergent thinking, this elementary teacher was quite positive.

In fact, yes. In a previous unit, we worked in a workbook a great deal. And I've found out since, that we are learning a lot more in math when I have them writing. So at the end of every day, and I continued this even after the unit was over for awhile, have them write about steps that they went through.

Two observations of this teacher indicated "not observed" or very low frequency of these kinds of activities in mathematics. As another example, an elementary teacher stressed that self-reflection was an important way he gets his students to "move from lower levels to higher levels" and writing what they have learned and how they have learned is important to him. It helps students "find their own mistakes, figure it out and apply it to new situations." However, although we observed both mathematics and science classes, students were never observed doing any writing in those content areas.

Clearly our observation protocol will under-sample certain kinds of teaching behaviors depending on the specific lessons observed. This is a limitation that we must keep in mind as we interpret the entire data set. Conversely, certain kinds of teaching behavior that are considered a natural part of the teaching environment, for example, collaboration in laboratory activities, may be over-reported.

Reported Impact of College Teaching

The last question addressed in this study was what college faculty and/or content courses impacted the student teachers' instructional design and practice. Only one of the 17 student teachers commented that s/he learned more from the cooperating teacher than any college course. Most were quick to identify college experiences that influenced their teaching. Several mentioned specific teacher preparation courses as being influential. Because the interview question posed focused on mathematics and science content courses, we usually received direct comments about their undergraduate college content preparation. Most elementary student teachers felt their mathematics for elementary teachers courses were very beneficial, more so than their mathematics content courses. Many science content course instructors were credited with showing student teachers at all levels reform practices in action. Specifically, concerning all college courses, students felt they experienced and found valuable the following reform teaching methodologies: collaborative activities, inquiry-based laboratories, visuals, demonstrations, concept mapping, and reflections. The students also credited the content courses and mathematics for elementary teachers with providing a strong knowledge base.

> I think that when I took (Prof. X'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…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. (elementary student teacher)

> I can remember one of my professors using jigsaws a lot. He actually was the one who taught me how to use jigsaws…I have taken that with me and I love jigsaws now…I just thought if college students can learn better through groups, why can't high school students? (secondary science teacher)

> I have seen a lot of the concept mapping going on. You know, processes where they draw arrows to show from one step to another, and I take that and give it to my students because I think without those arrows they are going to get lost. (secondary science teacher)

Besides commenting on instructors and courses, student teachers also volunteered factors that they felt interfered with how they really wanted to teach. Most of these comments concerned limitations imposed by practica experiences. While this is outside the scope of this study, we felt these were worth reporting.

One constraint on student teachers was the cooperating teacher. Some student teachers mentioned they felt stifled to try a variety of teaching strategies either because the students in the school were used to and more comfortable with a more traditional teaching style, the cooperating teacher was not perceived as supportive of change, and/or cooperating teachers expected the student teacher to employ the same structure that they did. As one student teacher said, "I kind of felt limited because of the structure that was already set up and the expectations that the students already had of the instructor…I didn't feel I had a lot of freedom."

Another influence on student teachers' actual instruction was management issues. Student behavior (or misbehavior) led several student teachers to change their teaching plans during a lesson and to rethink using certain methodologies in future lessons.

Curriculum restrictions came up several times as an influential factor. One student teacher felt confined in mathematics by the textbook. This middle school student teacher felt that the book, coupled with time constraints to complete it, limited his ability to come up with content that was relevant to middle schoolers. An elementary student teacher also felt bound by the mathematics curriculum. In contrast, this same student felt the science curriculum at that level was less-defined. This perceived lack of structure in science led the student teacher to be more creative in science, even though she felt science was not her strength.

All of these factors (sense of autonomy in designing lessons, curricula and management) impact the types and amount of reform teaching that can occur in a classroom. Even seasoned teachers are impacted by these variables, and some are not under the immediate control of the instructor.

Conclusions

What can be learned from this study is that reform-oriented teaching strategies are being used by student teachers in their science and mathematics classes. Some student teachers were doing more reform teaching than others, but all student teachers—regardless of grade level or content area—planned and taught lessons typified by collaboration, checking for pre/ misconceptions, evidence of pedagogical content knowledge, and using multiple representations. We find these to be positive findings. There were several areas in which students teachers' observed lessons were lacking. Student teachers' classes did not show much evidence of encouraging students to problem-solve, challenge ideas, or engage in divergent thinking. Observed lessons were low in promoting conceptual understanding and establishing interdisciplinary connections. Weaknesses are expected given that they are novices and have other concerns to handle besides instruction (e.g. management issues, time management, problems of being in another teacher's domain). These profiles of reform teaching behavior, highlighting strengths and weaknesses, will provide concrete guidance for mathematics and science teacher educators for evaluating science, math, and educational experiences, courses, and programs.

Student teachers seemed very cognizant of their teaching strengths and weaknesses. Oregon requires student teachers to prepare unit plans that include reflections on the delivery of the lessons, and most, if not all, of the student preparation institutions require student teachers to develop a teaching portfolio. The student teachers in our sample, then, have been trained to examine their own teaching. They seemed to have developed the skills necessary to reflect on their teaching for the purpose of improving future instruction. At the same time, there are areas where student teachers are likely to over-generalize and overstate their capabilities. These areas, such as interdisciplinary teaching at the elementary level, may reflect overly broad assumptions about what constitutes these teaching skills. Our data should help focus appropriate reflection on teacher education practices that need critical examination.

Finally, there is evidence that modeling reform-type strategies in science and mathematics content courses do influence student teacher reports of how they prepare and deliver instruction in their own classes. Student teachers felt there were often limits placed on what and how they could teach based on restrictions in their practica settings; however, most referred to specific techniques used in their college science and mathematics preparation and education courses when discussing influences on their instructional planning process.

Implications for Future Research

The study we have done has provided a profile of teaching of a small set of student teachers who had been taught by OCEPT Faculty Fellows. It has highlighted the strengths and weaknesses in the use of reform-oriented teaching ideas in these student teachers' classroom instruction. It has indicated where teacher preparation programs, interpreted here to include the science and mathematics content courses as well as education courses, are being successful with the training of preservice teachers, and where they need to do more examination and remediation.

Among the many questions generated by this study are: What can we do to help our student teachers develop better tools in their teaching repertoire? In what areas are college science and mathematics courses most effective in demonstrating reformed teaching practices for prospective teachers? What are reasonable expectations for demonstrated performance of reformed practices at the student teaching level? What should be the role of an induction program for new science and mathematics teachers in developing instruction that supports reform learning goals? What evidence is needed to support that reform strategies are being implemented? Is just seeing grouping really evidence of encouraging collaboration among students? Is reviewing last night's homework assignment sufficient for evidence of preassessment? These are both programmatic and research design questions.

It should be noted that these findings are the initial results of a longitudinal study, which will continue for an additional three years. Besides examining reform teaching strategies used by student teachers, we will also be following the student teachers into their years as beginning teachers to see what changes, if any, result as one develops from a student teacher to a novice professional.

Because the student teachers commented on specific strategies used by the OCEPT Faculty Fellows that they found influential in their own teaching, the notion that modeling in college courses can impact K-12 teaching appears to be true. Our data suggest the kinds of elements recalled by student teachers but not the way in which these instructional concepts are developed.

The chain of experiences in teacher education starts with college science and mathematics courses, continues through education courses, student teaching and other field experiences, and extends to the induction years of teaching. This is a complex process in which college content courses are playing a part. Increasing college faculty interest in new teaching approaches for upgrading the content knowledge of future and practicing teachers holds promise. This may result in promoting collaborative research efforts between science, mathematics, and education faculty. It can also serve as a starting point for research in designing data-based feedback to professors and graduate teaching assistants for the improvement of teaching.

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Table 1. List of OTOP items with brief descriptors

Item Number	Descriptor
1	habits of mind/problem solving
2	metacognition
3	student discourse and collaboration
4	challenging of ideas
5	attending to pre/misconceptions
6	conceptual understanding
7	divergent thinking

8

interdisciplinary connections/relevance

9

pedagogical content knowledge

10

use of multiple representations

Table 2. Percent frequency of OTOP items seen during 26 elementary classroom observations.

OTOP item12345678910not seen4481944152300infrequent5458355427585042428frequent4238582769383535892

Table 3. Percent frequency of OTOP items seen during 24 middle/high school classroom observations.

OTOP item12345678910not seen1308131317133340infrequent4650176725507538850frequent4250752163331329850

Figure 1. Graph showing percentages of frequencies of OTOP items in Elementary classes

Figure 2. Graph showing percentages of frequencies of OTOP items in Middle/high school classes

Figure 3. Comparisons of percentages of frequently seen items on OTOP between the elementary and middle/high school observations

Figure 4. Comparisons of percentages of frequently seen items on OTOP between the elementary level science and mathematics observations

Figure 5. Comparisons of percentages of frequently seen items on OTOP between the middle/high school level science and mathematics observations

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