College Mathematics Instructors' Use of Recommended Pedagogical Practices in a Two-Year and a Four-Year College

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Abstract

Poor mathematics preparation severely restricts students' future educational and occupational choices. This paper explores the extent to which differences were observed in the pedagogical practices of those teaching college introductory college math at a community college and at a four-year college. Although college math instructors generally may be poorly prepared to teach their assigned course content, this lack of preparation may be less characteristic of community college instructors for various reasons including their educational training and occupational priorities. Findings indicated that recommended practices such as metacognitive strategies and references to prior knowledge were more likely to be used by math instructors at a two-year than a four-year college. The implications of these findings for professional development and hiring requirements are discussed and emphasized for college math department chairs and administrators generally.

Plain Language Summary.

The current investigation was part of a larger US Department of Education project. A key goal of the project was to increase the number of Hispanic and low-income students graduating with STEM Baccalaureate degrees. The project was a collaboration between a two-year and a four-year institution, both public, in New York City that serve significant numbers of students from non-traditional groups. URMs make up 57% of the two-year and 39% of the four-year institution's enrollments; Hispanics make up 31% and 29% respectively of the enrollments (https://nces.ed.gov/ipeds/datacenter).

Educational research documents the relatively poor performance of American students on comparative international mathematics exams (Desilver 2017; U.S. Department of Education 2017). A report by Desilver (2017) indicated that US high school students ranked 38 out of 70 countries using the PISA international tests. This relatively poor performance has been found for decades in the educational literature (Digest of Education Statistics, 2017; U.S. Department of Education, 2019).

Within the United States, related research highlights subgroup math performance differences particularly pronounced among underrepresented minorities (URMs), especially Hispanic and African American students. More specifically, a U.S. Department of Education reported (2017) indicated that "From 1990 through 2017, the average mathematics scores for White 4th- and 8th-graders were higher than those of their Black and Hispanic peers…"

While such findings suggest skill and knowledge deficits, such deficit theories are not new (Comacho & Lord, 2013) and have been sharply criticized and countered by more in-depth theories regarding the immediate contextual causes of these academic performance differences (Ladson-Billings, 1995; Crisp, Taggart & Nora, 2015). Unfortunately, deficit approaches ultimately blame victims, fail to identify the ultimate sources of academic difficulties, and ignore their contextual sources.

One such obvious contextual source focuses on the inferior educational environments URM children experience including the quality of those teaching in these environments. Research has suggested for some time that schools in poorer socioeconomic settings have considerable difficulty attracting and retaining well-qualified teachers. As emphasized by Allensworth, Posnisciak and Mazzeo (2009), teachers reportedly leave underperforming schools while Guarino, Brown and Wyse (2011) argue that retention is a particular problem for poorer schools. Then, too, Holmes, Parker and Gibson (2019) emphasized that "schools serving at-risk children struggle to attract and retain teachers." Accordingly, the poor math performance of URM students may actually represent the culmination of the deficient teaching skills of math instructors generally, especially those assigned to teach math to students already poorly prepared and exacerbated by the accretion of such poor preparation over years.

A possible exception to such inadequate teaching skills may be found in those teaching in community colleges compared with those teaching the same content area in four-year colleges and universities. While the literature tends to ignore differences in pedagogical practices at different types of higher education institutions (Condon, Iverson, Manduca, Willett, Huber & Haswell, 2016) there are good reasons to expect differences in the teaching practices of these two groups and to assume teachers at two-year schools are more attuned to recommended pedagogical practices than teachers at four-year schools. One possible reason for this is that the occupational focus of community college teachers is more directly linked to instruction than to research-related activities.

Support for this expectation comes from research (Rifkin, 2000; National Study of Postsecondary Faculty, 1997) with two-year college instructors revealing a strong emphasis on instruction and professional development as factors in their hiring and tenure processes. Studies of those teaching at universities (Green, 2013; Tuchman, Gapinski & Hageman, 1977; Tuchman & Hageman, 1976) and four-year colleges (Rossman, 1976) revealed an emphasis on research and scholarship for tenure and merit pay rather than pedagogy.

We hypothesized, therefore, that community college math instructors would be more attuned to these practices because their occupational focus is primarily instructional rather than scholarship. More specifically, we hypothesized that clear differences in pedagogical practices would be present between introductory college math classes taught at a four-year college for "traditional" students and the same classes taught at community colleges for less traditional, and often less well-prepared students. More specifically, the study compared the pedagogical practices of two-year and four-year college mathematics instructors predicting that the former would more frequently engage in recommended STEM pedagogical practices.

Method

Respondents

To compare the two-year and the four-year introductory college courses participating in this project, it was necessary to select courses covering similar content, but also courses possessing similar student enrollments. As such, comparisons of introductory biology and chemistry at the two- and four-year colleges would have been problematic as relatively small introductory courses were offered at the two-year college while relatively large lecture courses were offered at the four-year college. In contrast, introductory college math course enrollments were similar at both institutions, normally between 20 to 25 students per section.

In discussions with faculty and school administrators regarding classroom observations, both groups expressed concerns regarding the possible negative impacts on faculty from such observations. Of particular concern was the possibility that the information could be used to evaluate faculty. To allay this concern, no detailed demographic information about faculty or classrooms was collected.

Students enrolled in ten introductory college math sections, taught by eight different instructors, at a four-year college or in six equivalent sections, taught by five different instructors, at a community college participated in this investigation. Instructors at both colleges included males and females and faculty representing multiple racial/ethnic backgrounds. We observed approximately 400 total students; approximately 250 from the four-year and 150 from the two-year college. Exact student counts were not collected. At both institutions the math course covered basic algebra topics including: linear equations, inequalities, exponential and logarithmic functions. A recent articulation agreement between the two institutions verified course equivalences.

An important reason for focusing on introductory college mathematics was that content mastery was considered essential for success in subsequent STEM courses and disciplines such as chemistry and computer science (McCormick & Lucas, 2011). As such, it was important to determine how this content was being delivered to students generally and to URM students specifically.

Procedure

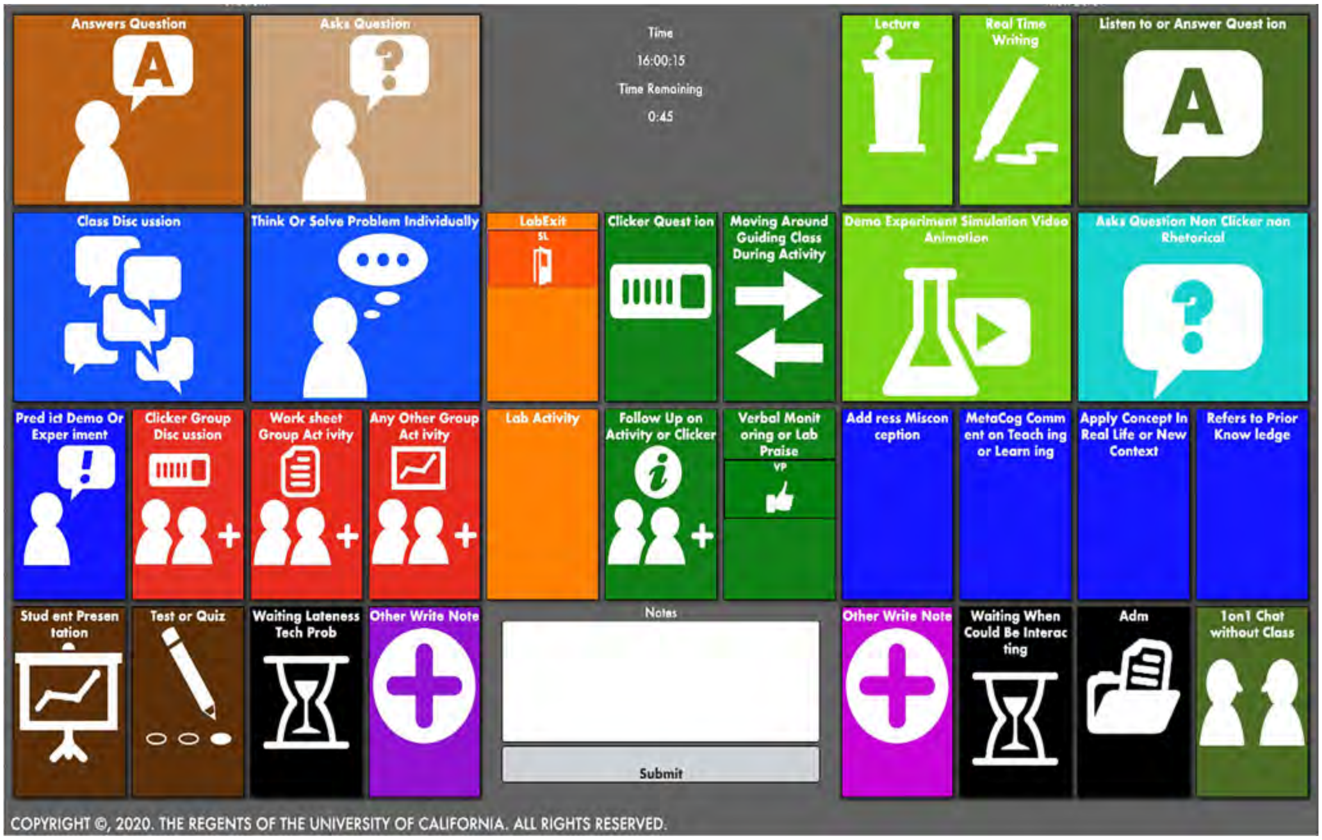
<u>Observation Tool.</u>

The data collected focused on faculty and student classroom behaviors in introductory college math, small (25-30 students) classes using the Classroom Observation Protocol in Undergraduate STEM or COPUS. It is a discipline-independent tool requiring little training to achieve inter-rater reliability scores above 0.9 (Lund, Pilarz, Velasco, Chakraverty, Rosploch, Undersander, et al. 2015; Smith, Jones, Gilbert & Wieman, 2013). Faculty with little or no experience with the protocol are able to use it reliably. In initial COPUS work, Smith and her colleagues found average kappa scores from 0.79 to 0.87, good interrater reliability (Landis & Koch 1977). Subsequently, the COPUS was integrated into the Generalized Observation and Reflection Protocol (GORP) at the University of California at Davis.

Using the original COPUS observational system and its instructor and student behavioral categories adapted to the GORP platform, researcher are able to design their own observational protocol, or modify an existing protocol, to provide a customized mobile-friendly interface to make observations. Our observations were based, therefore, on the GORP platform described in the following section. **Figure 1** illustrates the platform interface used in this research to record both instructor and student behaviors.

Initially, with the assistance of science educators involved in this research project, we modified the GORP by adding a few instructor behaviors shown in research to be of particular relevance to STEM education. These included instructor "refers to prior knowledge," "makes a metacognitive comment," "addresses misconception" and "applies concept to real-life." Again, it is important to emphasize that these new categories were added at the suggestion of science educators who maintained that these and similar instructor behaviors were indicative of exemplary STEM pedagogical techniques generally. Final observational categories may be found in **Figure 1**. Because of the flexible GORP platform, such modifications were easily added to the observational

Figure 1



coding system. This flexibility is often highlighted as one of the more attractive features of the system. To summarize, our observational system was a modified version of the COPUS made available to us for observational recording through the GORP platform.

Observers make observations in two-minute segments denoting specific instructor or student behaviors by pressing a laptop computer interface. In any segment, an observer may select numerous categories such as "instructor asks question," "student answers question," and "instructor applies concept to real-life situation," depending on observed instructor' and/or student' behaviors. This enables comparisons of the relative frequencies of selected behavioral categories in a standard unit of time (two minutes) over extended periods of time.

For training purposes and to standardize observational procedures, we initially paired adjacent observers, thus enabling them to confer when they disagreed on selected categories. Meetings between observers involved with training sessions-where all observers observed the same videotaped lecture - allowed us to clarify some of the more abstract observational categories such as 'instructor refers to prior knowledge.' Six observers, 2 males and 4 females conducted the classroom observations that are the focus of this study.

Following these procedures, project staff developed a manual that observers consulted regarding the concrete meaning of some of the more ambiguous categories thus standardizing the observational process. Specific examples of such categories in the manual included:

<u>Think or Solve Problem Individually:</u> The instructor explicitly poses an open-ended question that must be "solved," in the sense that the question does not call for a straightforward out-of-the-book response. Instead, students work through some puzzle on their own, applying concepts previously learned. Importantly, they are not simply reciting facts.

<u>Address Misconception Instructor Statements Include:</u> The instructor must explicitly draw attention to some error that individual or group makes, tends to make, or is in danger of making.
e.g. "You may think X but actually Y"
"You might be tempted or you might guess that X but actually Y"
"Don't make the mistake to think that X."

<u>Metacognitive Instructor Statements Include:</u> The instructor explicitly talks about the difficulty of learning a particular idea.The instructor discusses attempts to teach an idea to or use a technique with students.

Refers to Prior Knowledge Instructor Statements Include:
Needs to be explicit reference to prior knowledge from previous course or part of class.
"You should remember this from Bio 105."
"We spoke last week about X."
"You've probably learned from your own visits to the doctor that…"

Using our modified GORP platform, responses were collected and made available to us through the University of California at Davis website (https://cee.ucdavis.edu/GORP).

In the present study, over 500 minutes of observation occurred at the two-year institution and over 1000 minutes at the four-year institution. In almost all instances, observations occurred during standard 50-minute course sections of introductory college math at the two schools.

Results

It is not surprising that the most frequently observed instructor behavior at both colleges was writing on the board (observed in 46% and 44% of segments respectively). This is likely because math instructors illustrate mathematical proofs concretely for students on the board and, as a result, spend considerable class time writing on the board.

Other comparative percentages of observed behaviors at the two-year and the four-year colleges may be found in **Table 1.**

Table 1: Comparison of Two-Year and Four-Year College Math Classroom Behaviors[1]

Category	QC 115	QCC 119		
I Lectures	44%	46%		Ns
I asks question	**24%**	**66%**	**146.6**	**<.001**
S answers question	23%	60%	115.4	"
S asks question	**12%**	**25%**	**25.86**	**<.01**
I answers question	11%	26%	39.33	<.01
I writes on board	53%	67%	19.74	"
Class discussion	2%	6%		ns
S thinks/prob solves	19%	21%		ns
I moves around class/guides	8%	4%	4.63	<.05
I uses verbal monitor/praise	**0%**	**15%**	**80.85**	**<.001**
Worksheet activity	**7%**	**0%**	**18.54**	**<.01**
Address Misconception	1%	3%		ns
Reference to prior knowledge	**1%**	**21%**	**96.47**	**<.001**
Metacognitive comment	**4%**	**23%**	**70.53**	**"**
Applies info to real/new	0%	0%		ns
Demonstration	0%	0%		ns

[1] **I=Instructor; S=Student**

Of special importance in this table are the striking differences observed between two-year and four-year college math instructors regarding references to prior knowledge and the use of metacognitive strategies, two teaching practices emphasized by the science educators associated with this research. Specifically, college math instructors at the two-year college were more likely to refer to their students' prior knowledge in class and also more likely to employ metacognitive strategies such as indicating the importance of a particular concept. It should be emphasized that these categories were included in the GORP data collection platform because of their considered importance as STEM preferred pedagogical practices for enhancing student learning.

Similarly, while the importance of providing students positive feedback and praise is linked to enhanced student learning, comparative analyses revealed that two-year college instructors praised their students more often than their four-year college colleagues. Such encouragement, in conjunction with their use of recommended instructional approaches suggests that community college students, including Hispanic and URM students, are probably receiving superior math instruction than those enrolled at the four-year college.

Observational data also revealed that instructors at the four-year college were more likely to engage in worksheet activity with their students and to move around the classroom in a greater proportion of observed segments than their counterparts at the two-year college. The importance of these behaviors for student learning is not obvious.

Table 1 also highlights differences between the frequency with which faculty and students asked and answered questions. Again, community college students and faculty both asked and answered more questions than their respective four-year counterparts. These behaviors may be important indicators of more active instructional approaches and related to more intensive student engagement and learning. Again, both of these may be particularly beneficial for the large proportions of Hispanic and URMs attending the two-year college (Winterer1, Froyd, Martin & Foster; 2020).

Discussion

Previous research (Authors) revealed that college math teachers generally fail to employ effective instructor behaviors such as addressing student misconceptions (Caleon & Subramaniam, 2010), making references to prior knowledge (García-Carmona, Criado & Cruz-Guzmán, 2018; Hodara, 2011), using metacognitive strategies (Perry, Lundie & Golder, 2018; Zohar, 1999), and applying concrete examples to demonstrate difficult math concepts (Muschia & Muschia, 2011; Roth, 1992). The present study extends this work to a comparison of two-year and four-year college math instructors. The purpose of this comparison was to test the hypothesis that community college instructors will be more likely to incorporate recommended STEM teaching practices than four-year college math instructors. This hypothesis was based upon the assumption that teaching is a more central focus at community colleges than at four-year colleges and universities where research productivity is more directly linked to faculty tenure and promotion.

Despite the relatively infrequent faculty use of recommended pedagogical practices, math instructors teaching introductory college math at the community college, as predicted, were significantly more likely to engage in some of these practices than those teaching an equivalent course at a four-year college. More specifically, math teachers at the community college were more likely to ask questions, to make references to their students' prior knowledge and to make metacognitive comments than those teaching at the four-year school. They were also more likely to praise their students

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This finding also suggests that there may also be important pedagogical in addition to the obvious financial reasons for URMs generally and Hispanic students specifically to begin their college education at a two-year rather than four-year institution. Not only is tuition far lower, it also appears that the instructional approach in required courses such as introductory algebra may be superior as well. Of course, this will need validation in future studies employing multiple examples of both types of institutions. Such a validation study, however, would be welcome at the present time.

Community college math instructors made references to students' prior knowledge attempting to activate relevant math schemas while employing metacognitive strategies to assist students master difficult math concepts and support their transition to a more advanced level of mathematical knowledge. As such community college math instructors scaffolded their students' math knowledge and by asking questions simultaneously actively engaged them in the process of knowledge construction (Vygotsky, 1962). Taken together, these findings suggest that the classroom behaviors of community college math instructors align more closely with Vygotsky's social constructivist perspective (1968) than those teaching at the four-year college. In a very real sense, instructors teaching math at a two-year rather took on the role of the more knowledgeable other while working to guide their students more than instructors at the four-year college. They also were more likely to praise their students in the process.

Reinforcement in the form of instructor praise has been shown to enhance student learning in a variety of educational contexts (Boles 1975; Wiering & von Otterlo 2012). Once again, math instructors at the two-year college were significantly more likely to have interacted with their students in encouraging ways. In this regard, math faculty at the community college not only guided their students, they also reinforced their math learning as well.

Surprisingly, there was not a single segment in which an instructor from either institution attempted to help students understand a basic mathematical concept with reference to a real-life example. One explanation for this may be that math faculty have difficulty envisioning such examples because it is not a central element of their own educational training or academic pursuits. Although, it would seem that for many students, especially those having difficulty with abstract mathematical concepts, real-life examples that concretize abstractions, would facilitate their learning. Additionally, the use of real-life, concrete examples could also create opportunities for class discussions thus engaging more students and leading to livelier student-to-student and student-to-instructor interactions and more active learning. Such discussions, in turn, could increase the likelihood that students would master the difficult conceptual content.

In addition to their more frequent deployment of recommended STEM pedagogical practices, community college math instructors also asked their students more questions. Such questioning is likely to increase student engagement and represents an example of the active teaching approach recommended in the literature (Hake, 1998; Prince, 2004). A critical problem with the passive, teacher-centered approach to teaching is that it often fails to engage students' involvement in the class and in the content being covered. Active instruction, in contrast, requires students to think more deeply about course content (Bonwell & Eison, 1991; Prince, 2004). According to Konopka, Adaime, and Mosele (2015), a key element in active instruction is to require students to assume a more active role in the instructional process by asking questions and requiring students to answer them. Studies (Freeman, Eddy, Mcdonough, Smith, Okoroafor, Jordt, & Wenderoth, 2014; Hake, 1998) reveal significant student improvement in comparisons of active versus passive instruction

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Such findings support the contention of Angelo and Cross (1993) that one of the best ways to enhance student learning is to enhance teachers' instructional approaches. In line with this, research reveals that Hispanic STEM students preferred classes with instructors who had a clear plan while sharing their goals and endeavoring to ensure students understood the material (Barbosa & Seton Hall University, 2011). These are teacher attributes that correspond with the use of the recommended pedagogical practices highlighted in the current study. With these practices, teachers work to relate current information to prior student experiences and highlight difficult course content (metacognition). They also praise their students at the same time. In the study, such behaviors were far more likely to occur in introductory algebra taught at the two-year college.

While these are preliminary findings, that certainly require replication, they suggest that, at least when it comes to introductory college mathematics courses, Hispanic students may be better served by enrolling in such courses at two-year rather than four-year colleges, Additionally, based on these findings, there is a pressing need for math department chairs to seriously consider organizing professional development workshops to highlight current pedagogical principles and the tools for integrating them into an instructor's toolbox. Because such workshops would be largely data driven, based on the presentation of research findings, they might attract senior, tenured STEM faculty as well as more junior faculty and adjuncts. Moreover, with new faculty hires more attention should be given to including teaching knowledge in the interviewing process with prospective hires as done routinely in community college faculty hiring. In this way we can improve college-level math instruction and thereby enhance the mathematics performance of URMs as well as all undergraduate students.

This research indicates that the GORP observational tool can be easily deployed to investigate instructor-student interactions and individual behaviors in math and other college-level STEM disciplines. The modifiability of this tool only enhances its utility. Moreover, as more researchers employ the GORP platform, opportunities for data sharing will emerge. At a recent national STEM conference session on classroom assessment tools, more audience members indicated working with the GORP platform than with any other observational tool.

Limitations.

The most obvious limitation of the current study is the limited number of comparison schools. One would have more confidence in the potential significance of the observed pedagogical differences if more schools had been available for comparisons. At the very least, the findings indicate that college administrators, including science deans and math department chairs should determine the extent to which state-of-the-art teaching practices are widely discussed and modeled in professional development training.

Another limitation of the research concerns the ambiguity or fuzziness of some the observational categories used to assess instructor behaviors. More work is required to clearly delineate concepts such as metacognition before they can be readily integrated in similar observational studies of STEM college-level classes. Another limitation concerned the voluntary nature of the faculty participants involved with these observations. To increase participation, we had to eliminate any potential instructor identifier information from the data collection. The requirement for strict instructor anonymity made it impossible for us to systematically collect such information. Future comparisons of two-year and four-year college instructors, should collect more detailed demographic information to allow for more sophisticated statistical analyses, including the investigation of interactions between instructor characteristics such as gender and racial/ethnic background and the use of particular pedagogical practices.

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