College Teaching

ISSN: 8756-7555 (Print) 1930-8299 (Online) Journal homepage: http://www.tandfonline.com/loi/vcol20

Mathematics Teaching Assistant Preparation And Development

Natasha Speer , Timothy Gutmann & Teri J. Murphy

To cite this article: Natasha Speer , Timothy Gutmann & Teri J. Murphy (2005) Mathematics Teaching Assistant Preparation And Development, College Teaching, 53:2, 75-80, DOI: 10.3200/CTCH.53.2.75-80

To link to this article: http://dx.doi.org/10.3200/CTCH.53.2.75-80

Published online: 07 Aug 2010.

MATHEMATICS TEACHING ASSISTANT PREPARATION AND DEVELOPMENT

Natasha Speer, Timothy Gutmann, and Teri J. Murphy

Abstract. Teaching assistants (TAs) play vital roles in the mathematics education of undergraduates and may become mathematics professors. From the K–12 literature, it is clear that patterns of teaching practice, as well as beliefs about teaching and learning, form early in teachers' careers. Yet, although there is a large body of research about K–12 teachers, researchers are only beginning to consider the development of TAs. This article is an effort to foster collaboration between K–12 and undergraduate mathematics educators in framing and carrying out research on the nature of TA professional development. This article contains reviews of TA professional development, descriptions of practice- and research-oriented work, analysis of similarities and differences with K–12 mathematics education, descriptions of researchable questions, and potential agendas for future work.

At present, little is known about the characteristics (including teaching practices, beliefs, challenges, needs, and understandings of mathematics and teaching) of graduate students who are mathematics teaching assistants (TAs). Equally underexamined are the factors that shape and facilitate development and change in those characteristics. TAs, however, play significant roles in the instruction of undergraduate mathematics students. In addition, those who are TAs may go on to become faculty members. Hence, the importance of TAs to undergraduate mathematics education is substantial, both now and in the future. When one considers the importance of education in mathematics as a component of the national trend toward an increasing need for postsecondary studies, one is evermore aware of the need for inquiry into and professional development related to undergraduate mathematics teaching.

Over the past five years, mathematics educators have begun to address the issue of TAs in two ways: by designing preparation and development programs that target mathematics graduate students who are or will be teaching undergraduates and by beginning research programs focusing on the TA experience. Although the focus of this article is on mathematics TAs, the features of work in this area, as well as the challenges and opportunities it presents, can be found in other disciplines as well.

This article contains discussions of each of the following related areas: recent history of undergraduate mathematics education, TA preparation and development programs, analysis of connections to K–12 mathematics education research, some of the research already in progress, and future directions for research.

Undergraduate Mathematics Education and the Importance of TAs

Fueled by research and national reports about the state of the teaching and learning of college mathematics (National Science Foundation 1986; Seymour and Hewitt 1997), the amount of attention

Natasha Speer is an assistant professor in the teacher education and mathematics departments at Michigan State University. Timothy Gutmann is an assistant professor in the Department of Mathematical Sciences at the University of New England. Teri J. Murphy is an associate professor in the Department of Mathematics at the University of Oklahoma.

paid to undergraduate mathematics education has increased substantially over the past two decades. Efforts to improve teaching and learning have taken the form of instructional design projects (for example, new textbooks, computer-based curricula), research on student learning, and (to much lesser extents) research on teaching at the undergraduate level and professional development projects. Although more attention recently has been directed at undergraduate education than in the past, the focus of this attention has not been on instructional practices but on other aspects of education (such as curriculum development, uses of technology, and assessment).

Although no recent comprehensive surveys have been done, the general sense of the profession is that TAs play a critical role in the education of undergraduates at many universities. TAs often have significant responsibility for teaching lower-division courses, including courses for mathematics majors, client department service courses (such as engineering calculus), content courses for prospective K–12 teachers, and courses intended to meet the general mathematics needs of an educated citizenry (such as finite mathematics and quantitative reasoning). This responsibility comes in many forms: Some TAs have sole responsibility for teaching a course, some teach recitation or discussion sections that accompany large lectures given by faculty members, some work as homework graders, and some provide tutoring services to students. Whatever the form, contact with TAs may constitute a significant portion of undergraduates' instructional time in lower-division courses. Thus, the potential influence that TAs have on undergraduate students' experiences with mathematics is tremendous.

In addition to their importance as TAs, the current pool of graduate students is the source of mathematics faculty of the future. Several authors (Brown 1985; Eisenhart 1995; Lacey 1977; Lortie 1975; Zeichner and Tabachnick 1985) have discussed the significance of early experiences in solidifying beliefs, developing practices, and setting patterns of social learning for new teachers. Thus, the time spent as a TA is the time during which young mathematicians will develop teaching practices they likely will carry with them into their careers as faculty members. A TA's first teaching experience provides rich opportunities to support and shape emerging instructional practices. Yet, traditionally, support structures and guided enculturation experiences have not been available, let alone an expected part of graduate student professional development.

TA Preparation and Development Programs

TAs often have a great deal of responsibility for instruction but little opportunity to learn how to teach in ways other than those they have experienced themselves or those modeled by their faculty mentors. Even for college and university faculty, early and ongoing instructional development opportunities are limited (National Science Foundation 1992). Most students arrive in graduate school with little or no prior teaching experience. Before they start to teach, they may attend a department- or campus-wide orientation session lasting a few hours or a few days. These sessions address a broad range of topics. In a typical program, new TAs learn about campus and department course policies and procedures. They may receive information about the specific course they are teaching and a list of tasks they are expected to perform (such as grading homework, administering quizzes, holding exam review sessions, and so on). They might also receive information about teaching, learning, and interacting with students. In some cases, new TAs have the opportunity to practice teaching (often briefly) and receive feedback (often superficial) from their peers or instructors running the orientation sessions. In this article, we consider TA professional development programs and related research, beginning with a summary sketch of TA orientations, continuing with a discussion of recent publications related to preparing or assisting TAs in the classroom, and, finally, referencing recent and current research efforts to understand TAs' experiences, teaching practices, and needs.

In efforts to provide ongoing development opportunities, some institutions run semester- or year-long seminars to introduce graduate students to their roles as teachers as they are beginning to function as TAs. In 1999 and 2000, the American Mathematical Society–Mathematical Association of America Joint Committee on Teaching Assistants and Part-Time Instructors sponsored sessions about the preparation and development of mathematics graduate TAs. At both of these sessions, presenters described programs ranging from quick orientations to semester-long courses on teaching. Activities included reading about teaching and learning, microteaching, keeping journals, observing others teach, and participating in discussions (Murphy et al. 2000). Only a few presenters at these sessions referred to the literature on teacher preparation or professional development.

Additional ideas for curricula and reports of efforts were gathered in Case (1994) and ideas for professional development were presented by DeLong and Winter (2002). Rishel (2000) proposes mathematics-specific basic strategies for new (and experienced) TAs to be successful. Although these resources provide potentially useful information, in each of these publications there are few (if any) references to what the mathematics education community knows about teaching, learning, and the processes of learning to teach. To fuel conversations about deeper issues related to undergraduate teaching, Friedberg et al. (2001a, 2001b) offer crafted vignettes of common situations that challenge instructors' perspectives and behaviors. With support from the Fund for the Improvement of Postsecondary Education, these case studies were pilot-tested with groups of TAs over a period of years at a variety of institutions. Furthermore, recognizing that the mathematicians typically in charge of TA development programs lack experience with case study discussion as an instructional strategy, Friedberg and his colleagues held training workshops in the Boston area in 2000 and 2001. (See http://www.bc.edu/casestudies for more details.) Despite the wealth of valuable ideas collected here, none of these resources were specifically based on research about teaching assistants or related issues.

Meel (2000) describes a project using journaling and the reading of journals to help new TAs become reflective about their classroom experiences, as the beginnings of a project relating research and practice. The TAs who participated in

Speer's project (2001) were teaching reform-oriented calculus discussion sections for the first time and were simultaneously participating in a professional development program for which Speer was partially responsible (Heitsch and Speer 2000). These two efforts to connect research and practice are unusual because, for the most part, researchers and TA educators have worked separately.

TA educators have developed courses for beginning TAs to help address their first semester needs: They have published course materials, and many have participated in orientation sessions at the start of the semester for incoming TAs. These projects most frequently are limited in scope and in publication to the department where the TA educator works. Rarely do TA development course projects lead to collaboration with members of the larger mathematics and mathematics education communities (Friedberg et al.'s contributions [2001a, 2001b] are notable exceptions). Similarly, mathematics educators studying the experiences, beliefs, and contributions of TAs are distinctive in the field because of the relative isolation in which they have worked. Although many are tangentially aware of the work of others, collaboration in the field has been rare. Communication has so far been limited, and there is a clear need for TA educators and researchers to communicate, discuss, plan, and organize ideas, both within the groups and, perhaps more important, between the groups.

Connections to K–12 Research

Literature addressing teaching and learning at the K–12 level includes a rich base of information about how preservice teachers think about mathematics and about the teaching and learning of mathematics. This base is extended to document how established teachers practice in and reflect on their own classrooms. In particular, there is a developing base of information about how teachers' knowledge, beliefs, and practices shape the implementation of new instructional practices. There is no comparable base of information about TAs, neither about their knowledge or beliefs related to mathematics, nor about the teaching or learning of mathematics, nor about how they understand and think about their own classroom practices. Indeed, although the research on general undergraduate mathematics teaching and learning is increasing, the body of literature that exists is still very small relative to that for the K–12 level.

Undergraduate mathematics education research is related to research into mathematics teaching and learning at the precollege level, but there are at least three important distinctions: the relatively short history of research at the undergraduate level, the content focus in undergraduate mathematics, and the individuals involved in conducting research in this area (Schoenfeld 1994; Selden and Selden 1993).

Brief History of Undergraduate Mathematics Education Research

Research in the teaching and learning of mathematics at precollege levels (as well as some research on college teaching in general) has been ongoing since early in the twentieth century. Research specifically in undergraduate mathematics education, however, has only been active since the mid-1980s. At that time, sparked by concerns about enrollment and retention rates, as well as the depth of student understanding, attention to undergraduate mathematics increased substantially. Mathematics educators and mathematicians began a variety of projects related to the teaching and learning of calculus. These efforts in the name of calculus "reform," now referred to as the Calculus Reform Movement (Douglas 1986), took a variety of shapes, but most common were curriculum development, revision to assessment practices, and the introduction of technology into instruction. Concurrent with these developments came increased activity in research in collegiate mathematics education. Again, the efforts varied, but the vast majority of work focused on documenting and understanding the nature of student learning of particular mathematical concepts. Although major reform projects (Project Calc at Duke University and the Calculus Consortium at Harvard) offered summer professional development workshops for individuals who would use their materials to teach (that is, some professional development work was done), more general inquiry into the larger picture of how college mathematics instructors (both TAs and professors) conceptualize teaching remains noticeably absent from the literature. Instead, projects have described the implementation of curricula (Ferrini-Mundy and Schram 1997) and multiple authors have examined such topics as students' understanding of limit (Williams 1991), use of cooperative group projects in teaching (Dees 1991), and students' transitions from high school to college calculus (Star and Smith, forthcoming). Thus, the mathematics educator's lens has been focused more recently on undergraduate *learning*, but it has not yet turned to investigating undergraduate *teaching*.

College Content Focus

An important consequence of the centrality of the Calculus Reform Movement in the development of undergraduate mathematics education research has been a focus on student learning of mathematical topics included in specific courses (especially calculus, differential equations, linear algebra, and abstract algebra) or on the role of understanding of precollege topics (such as functions) in student learning in college courses. Issues of learning often are particular to the specific content area. Combine that fact with characteristics that are unique to college students, and it is clear that research at the college level is inherently different from work at the K–12 level. The focus on college-level topics is also related to the demographics of the research community, now increased by the inclusion of mathematicians whose interest is naturally in student learning of college-level concepts.

Researcher Characteristics

The third distinction is the different demographics of the researcher populations in each area. Precollege mathematics education research typically is carried out by mathematics education faculty, the majority of whom hold doctoral degrees in education. Work in this area often involves some level of collaboration with teachers in schools. In some cases, these researchers have expanded their agendas to include an examination of issues at the undergraduate level, but this is rare.

Undergraduate mathematics education has attracted the interest of many mathematicians, most of whom were prepared to

conduct research in the discipline of mathematics. These mathematicians have developed questions about student learning during their own teaching careers. Unlike their colleagues in mathematics education who have professional interests in a wide range of issues in precollege education, these mathematicians are most directly concerned with the success of undergraduate students in mathematics courses. This is especially true in courses perceived to serve large groups of students (where enrollment and failure rate concerns have been raised by administrators), many of whom are challenged by the material. Because of these factors, much of the research at the undergraduate level focuses on documenting whether or not students understand particular ideas or possess certain skills. Although similar work occurs at K–12 levels, it is not nearly so dominant.

Another way in which K–12 education researchers and mathematicians with an interest in education differ is that the latter group often begins with little formal exposure to the existing body of mathematics education research and learning theory. They succeed through a kind of on-the-job training and, thus, their experiences, competencies, backgrounds, and perspectives are different from those of mathematics educators and are important factors influencing the nature of the projects they pursue.

Although mathematics educators have primary responsibility for the preparation of school mathematics teachers, professionally they may be housed in departments of education or mathematics. In the latter case, their different professional responsibilities and interests still serve to identify them as a separate group within the department. Thus, it is often mathematicians, or mathematicians with interest in mathematics education with backgrounds as described above, who take responsibility for the design and implementation of TA preparation programs.

TA and K–12 Teacher Comparisons

K–12 teachers and TAs are different from and similar to one another in some interesting ways. Unlike most elementary and secondary schoolteachers, college instructors do not typically participate in compulsory, extensive teacher preparation programs. Like elementary and secondary schoolteachers, TAs (and other college instructors) can become isolated from colleagues, with little or no opportunity to grow from interactions with other instructors (Lortie 1975; Murphy and Wahl 2003). For many, their first jobs as TAs will be the only time in their careers when they (may) participate in (essentially minimal) professional development about teaching. K–12 teachers, on the other hand, may encounter a variety of opportunities for professional development throughout their careers. Because faculty members are unlikely to receive any further guidance regarding their teaching, the practices they develop as TAs may shape their teaching for the rest of their careers. Support and professional development associated with their initial teaching may be the only formal opportunity to help college instructors develop their teaching practices in effective ways.

The similarities may point to ways in which the existing research base on K–12 teacher development can be applied to TAs. Differences may help identify areas where additional research is especially needed. In both situations, making use of and building on what is known from research in K–12 teacher development could be an important component of the design and implementation of professional development for TAs.

Research in Progress

Thus far, most of the attention to TAs has been on professional development activities and programs. Now, however, the community is poised to engage in research in substantial ways and will be able to build on the momentum gained by research in undergraduate mathematics education and by the increasing investment in TAs as current and future key players in undergraduate education. Ideally, research directions will be based on the needs of TAs and TA educators, and findings will inform the design of increasingly effective preparation and development programs.

Some groundwork research is already in progress. For example, DeFranco and McGivney-Burelle (2001) reported on TAs' beliefs about the nature of teaching and learning mathematics. Speer (2001) also conducted a study about TAs' perspectives, focusing on the instructional practices of TAs teaching calculus and the relationship between collections of beliefs and moment-to-moment teaching decisions in class. A broader approach is to consider the entire graduate experience. For example, Herzig (2001) investigated reasons for attrition among mathematics graduate students, finding a mismatch between the preferred work styles of students who left (for example, collaborative) and the perceived culture of the discipline. Related work includes research that addresses the cultural climate in which mathematicians work. Examples of this approach are Gutmann's ethnographic case study (2000) of a small, teaching-focused mathematics department; Enzensberger's essay (1999) that addressed the attitude toward mathematics common in the general population; and Damarin's sociological observation (2000) that mathematicians represent a marked category and, like other minority groups, operate in a world partially defined by their otherness.

The issue of enculturation is especially important. Graduate students must learn to function in their departments. To succeed, they need, or at least believe they need (Lacey 1977), to adopt the habits and attitudes of their faculty mentors. Pressures to become part of the existing culture are strong. Even TAs who arrive in graduate school with substantial concern for undergraduate education and strong motivation to teach may find that holding on to those ideals is incompatible with success as defined by their department, their faculty mentors, and the discipline as a whole. With proper support and enculturation, it may be possible to build on and nurture good intentions and practices.

Directions for Future Research

As the mathematics education community becomes more aware of the importance of TA issues, there is a growing need to organize what has been done, to facilitate cooperative efforts at understanding these issues, and to discuss and determine needs for future work. In particular, so that research and practice are not disjointed, it is critical that participants from multiple perspectives have opportunities to share their ideas, articulate challenges, report on progress, and

establish further agendas for moving the field forward. To that end, this article is meant to fuel a discussion.

The community needs large-scale investigations to identify critical, widespread issues. Small case studies will provide in-depth understanding of TAs' perspectives and the challenges they face. Research with longitudinal designs will inform the design of exemplary programs that have a lasting influence on instructional practices. Given that TAs are critical agents in college instruction, such research is especially vital at this time of increased attention to the quality of education at the undergraduate level.

From our review of research and resources, we offer the following sample of questions that mathematics education researchers might consider pursuing:

1. In what ways and to what extent does research about pre- and in-service K–12 teachers apply to TAs? In particular, what are the similarities and differences in knowledge and beliefs about teaching and about mathematics held by these different populations?
2. What are TAs' expectations about teaching? What are their self-images in terms of thinking of themselves as teachers? How do these expectations/images evolve as TAs gain experience?
3. What are TAs' conceptions of mathematics? Conceptions of teaching? Conceptions of how students learn mathematics?
4. What adaptations need to be made for K–12 professional development models and programs to work in the TA setting?
5. What effects do students' perceptions of TAs have on their teaching practices? What effects do faculty members' perceptions have?
6. What challenges and opportunities does cultural context present? How do TAs learn how to value teaching?

Question 1 deserves pride of placement. As we consider a research agenda, we should build on existing work, yet be mindful of its limitations in this area. Consider the work of Van Dooren, Verschaffel, and Onghena (2002), who correlated preservice primary teachers' problem-solving strategies and skills with their subsequent assessments of student work. It would not be unreasonable to ask how mathematics TAs' approaches to solving problems might correlate with their assessments of their own students' work. In asking this, we must consider the important question of how TAs value teaching and how this valuation couples with their sense of their own mathematics work as similar to or different from undergraduate mathematics. (The two areas are qualitatively different, with beginning college mathematics liberally weighted toward skill in algebraic computing and graduate mathematics focused on the development of theory.) To further complicate the puzzle, while the preservice teacher sees teaching as her primary job responsibility, the TA must fulfill important responsibilities of personal study (and later, as a faculty member, responsibilities of scholarship and service as well). Thus, although research on the teaching of school mathematics undoubtedly contains significant findings applicable to the work done by TAs, the TA relationships to mathematics and to the work environment are sufficiently different from those of the school teachers to require careful thought and, in fact, careful research into how such findings apply. Answers to questions 2–6 are needed to provide the background that will allow proper processing of question 1.

Conclusion

As research on school mathematics teaching and learning attempts to guide teachers and curriculum developers in their work with schoolchildren and informs us about the professional lives and work of school teachers, research on TAs will provide insight into an important component of the undergraduate mathematics learning experience and should guide program heads as they consider the needs of these future faculty members. TAs are not unlike preservice teachers, who will need a rich and reflective understanding of their teaching practices if they are to make informed decisions and respond professionally to changes in mathematics education. As a group, they present a new challenge for mathematics educators: understanding how knowledge of mathematics and pedagogical content knowledge affect teaching when significant other activities (personal scholarship, university service) have legitimate claim on an individual's time and interests. These features of context provide great challenges as well as interesting opportunities for research that has the potential to improve both current and future undergraduate mathematics education.

Key words: teaching assistants, mathematics, professional development

NOTE

Literature review suggests the most recent numbers related to classroom contact hours provided by TAs are reported in *Response to the Challenge: Keys to Improved Instruction by Teaching Assistants and Part Time Instructors* (Case 1989).

REFERENCES

Brown, C. A. 1985. A study of the socialization to teaching of a beginning secondary mathematics teacher. PhD diss., University of Georgia.

Case, B. A., ed. 1989. *Response to the challenge: Keys to improved instruction by teaching assistants and part-time instructors.* Vol. 11. Washington, DC: Mathematical Association of America.

———, ed. 1994. *You're the professor, what next? Ideas and resources for preparing college teachers*. Vol. 35. Washington, DC: Mathematical Association of America.

Damarin, S. K. 2000. The mathematically able as a marked category. *Gender & Education* 12 (1): 69–85.

Dees, R. L. 1991. The role of cooperative learning in increasing problem-solving ability in a college remedial course. *Journal for Research in Mathematics Education* 22 (5): 409–21.

DeFranco, T. C., and J. McGivney-Burelle. 2001. The beliefs and instructional practices of mathematics teaching assistants participating in a mathematics pedagogy course. Paper presented at the 23rd annual conference of Psychology of Mathematics Education–North America, Snowbird, Utah.

DeLong, M., and D. Winter. 2002. *Learning to teach and teaching to learn mathematics: Resources for professional development.* Vol. 57. Washington, DC: Mathematical Association of America.

Douglas, R. G., ed. 1986. *Toward a lean and lively calculus.* Vol. 6. Washington, DC: Mathematical Association of America.

Eisenhart, M. 1995. The fax, the jazz player, and the self-story teller: How do people organize culture? *Anthropology & Education Quarterly* 26 (1): 3–26.

Enzensberger, H. M. 1999. Why no one knows we're living in a golden age of mathematics. *Chronicle of Higher Education*, April 30.

Ferrini-Mundy, J., and T. Schram, eds. 1997. *The recognizing and recording reform in mathematics education project: Insights, issues, and implications*. Vol. 8. Reston, VA: National Council of Teachers of Mathematics.

Friedberg, S., A. Ash, E. Brown, D. Hughes Hallett, R. Kasman, M. Kenney, L. A. Mantini, W. McCallum, J. Teitelbaum, and L. Zia. 2001a. *Teaching mathematics in colleges and universities: Case studies for today's classroom: Faculty edition.* Providence, RI: American Mathematical Society.

———. 2001b. *Teaching mathematics in colleges and universities: Case studies for today's classroom: Graduate student edition.* Providence, RI: American Mathematical Society.

Gutmann, T. 2000. Mathematics and sociocultural behavior: A case study of the enculturation of a new mathematician. PhD diss., University of New Hampshire.

Heitsch, C., and N. M. Speer. 2000. Math 300 instructor's guide. Berkeley, CA: Department of Mathematics, U.C. Berkeley.

Herzig, A. H. 2001. The role of the intellectual culture of mathematics in doctoral student attrition. Paper presented at the 23rd annual conference of Psychology of Mathematics Education–North America, Snowbird, Utah.

Lacey, C. 1977. *The socialization of teachers.* London: Methuen.

Lortie, D. C. 1975. *Schoolteacher: A sociological study.* Chicago: University of Chicago Press.

Meel, D. 2000. Case study of adjustment: A graduate teaching assistant's struggles. Paper presented at the 22nd annual conference of Psychology of Mathematics Education–North America, Tucson, Arizona.

Murphy, T. J., W. Branson, S. Friedberg, L. C. Kappe, J. Madden, D. Manderscheid, L. Mantini, E. Marchisotto, P. McCreary, A. Nestler, J. Novak, S. Plisch, N. Speer, J. Wilson, and L. Zia. 2000. Innovative programs address professional development of teaching assistants and adjuncts. *FOCUS: The Newsletter of the Mathematical Association of America* 20, no. 5 (May/June): 9.

Murphy, T. J., and K. Wahl. 2003. Adapting a workshop calculus model to college algebra: Instructional challenges. *American Mathematical Association of Two-Year Colleges Review* 24 (2): 33–44.

National Science Foundation. 1986. Undergraduate science, mathematics and engineering education: Role for the National Science Foundation and recommendations for action by other sectors to strengthen collegiate education and pursue excellence in the next generation of U.S. leadership in science and technology. Washington, DC: National Science Board, NSB Task Committee on Undergraduate Science and Engineering Education.

———. 1992. America's academic future: A report of the Presidential Young Investigator Colloquium on U.S. Engineering, Mathematics, and Science Education for the Year 2010 and Beyond. Washington, DC: Directorate for Education and Human Resources, National Science Foundation.

Rishel, T. 2000. *Teaching first: A guide for new mathematicians.* Vol. 54. Washington, DC: Mathematical Association of America.

Schoenfeld, A. H. 1994. Some notes on the enterprise (research in collegiate mathematics education, that is). In *Research in collegiate mathematics education I*, ed. E. Dubinsky, A. H. Schoenfeld, and J. Kaput, vol. 4, 1–20. Providence, RI: American Mathematical Society.

Selden, A., and J. Selden. 1993. Collegiate mathematics education research: What would that be like? *College Mathematics Journal* 24 (5): 431–45.

Seymour, E., and N. Hewitt. 1997. *Talking about leaving: Why undergraduates leave the sciences.* Boulder, CO: Westview Press.

Speer, N. M. 2001. Connecting beliefs and teaching practices: A study of teaching assistants in collegiate reform calculus courses. PhD diss., University of California, Berkeley.

Star, J., and J. Smith. In press. An image of calculus reform: Students' experiences of Harvard calculus. *Research in Collegiate Mathematics Education.*

Van Dooren, W., L. Verschaffel, and P. Onghena. 2002. The impact of preservice teachers' content knowledge on their evaluation of students' strategies for solving arithmetic and algebra word problems. *Journal for Research in Mathematics Education* 33 (5): 319–51.

Williams, S. R. 1991. Models of limit held by college calculus students. *Journal for Research in Mathematics Education* 22 (3): 219–36.

Zeichner, K. M., and B. R. Tabachnick. 1985. The development of teacher perspectives: Social strategies and institutional control in the socialization of beginning teachers. *Journal of Education for Teaching* 11 (1): 1–25.