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The Scholarship of Teaching and Learning in Canadian Post-Secondary Mathematics: 2000-2010

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Abstract

Published accounts of pedagogical experience and pedagogical research are critical resources to post-secondary mathematics instructors, and yet the quantity and scope of this literature is rarely summarized or reviewed. In this contribution, we analyze recent peer-reviewed journal publications regarding post-secondary mathematics, published by Canadian scholars. We classified this scholarship by institution, publication year, type of pedagogical scholarship, and by topic. We highlight topics of continual interest, changing trends in time and newly emerging themes. This review therefore provides a benchmark of current scholarship in this important area, as well as a point of comparison for similar data from other countries, and other disciplines.

Les comptes rendus publiés sur les expériences pédagogiques et la recherche sur la pédagogie sont des ressources essentielles pour les enseignants de mathématiques au niveau postsecondaire. Pourtant, la quantité et la portée de cette documentation font rarement l'objet de résumés ou d'analyses. Dans cet article, nous analysons les publications récentes de chercheurs canadiens sur les mathématiques au niveau postsecondaire, qui ont paru dans des revues révisées par les pairs. Nous avons classé ces publications par établissement, année de publication, type de recherche et sujet. Nous mettons en lumière les sujets d'intérêt constant, les tendances en évolution au fil du temps et les thèmes émergents. Cette recension constitue donc une référence sur les recherches universitaires actuelles dans ce domaine important ainsi qu'un point de comparaison pour des données similaires provenant d'autres pays et d'autres disciplines.

Keywords

mathematics; post-secondary education; pedagogical research; research literature; Canada

Cover Page Footnote

We thank Tom Haffie for his leadership in the overall project of reviewing the Canadian post-secondary scholarship in teaching and learning of science. We are very grateful to the librarians of The University of Western Ontario for the their help in locating the literature. This project is partially supported by the Dean of Science of The University of Western Ontario through a Learning Development Fellowship to BSC.

Many mathematics professors, worldwide, are expected to maintain a balance of research, teaching, and administrative duties. While faculty members with a research profile in mathematics may sustain a record of publication within their field of expertise, scholarly contributions to the pedagogical literature are comparatively rare. For those whose focus is largely teaching, the demands of instructional practice often preclude a deeper engagement with the pedagogical literature (Corless et al., 2011), or the contribution of experience, opinion or teaching research to this literature.

How often do mathematicians working in post-secondary institutions publish about teaching and learning? In what venues is their work disseminated? What are the major themes or trends discussed? Is this scholarship changing over time, and if so, in what ways? These questions suggest the need for a broad review of scholarly publications regarding undergraduate mathematics teaching. Since the teaching demands and expectations of many university professors can differ dramatically on the international scale, we restricted our focus to Canadian educators. Our review provides a snapshot of the published scholarship of mathematics teaching and learning in Canada, over the years 2000-2010.

With guidance from the Science Learning Development Coordinator and the professional science librarians at our institution, as well as assistance from the Canadian Mathematical Society (CMS), we conducted a broad literature search for peer-reviewed journal articles regarding undergraduate mathematics education. We classified this scholarship by publication date, institutional affiliation, type of scholarship (opinion piece, research on teaching, etc.), and by topic. We noted topics of continual interest, changing trends in time, and newly emerging themes. Our aim is to provide a benchmark of current scholarship in this critical area, as well as a point comparison for future studies from other countries, and other disciplines.

This paper is structured as follows. In the next section, we describe our methodology and the rationale for the inclusion or exclusion of different types scholarship of teaching and learning. Then, we present the classification of scholarship that met our inclusion criteria (i.e., by year and topic, institutional affiliation, and type of scholarship). Next, we highlight and discuss the following emergent themes: (a) student thinking, (b) the role of proof, (c) the use of technology in teaching mathematics education, (d) transitions from secondary to post-secondary education and to the workplace, (e) the recruitment and retention of mathematics undergraduates, and (f) topic-specific classroom content. Finally, we offer recommendations and possibilities for future directions for the scholarship of teaching and learning in post-secondary mathematics.

Methods

In collaboration with the professional science librarians at Western University, we used a number of commercial database resources (e.g., CBCA Education, Google Scholar, Inspec, MathSciNet, ProQuest, Scopus, and Web of Science) to gather a large database of pedagogical scholarship relating to post-secondary mathematics. We used variations of key search terms (e.g., Canada, college, education, mathematics, post-secondary, teaching, and university) to locate relevant scholarship. Aside from indexed databases of the published literature, a request was sent through the Canadian Mathematical Society newsletter to solicit further literature for this review.

Inclusion and Exclusion Criteria

The initial list of publications gathered was refined according to pre-defined inclusion criteria. To review current scholarship in the field, works published from 2000 through 2010 were considered.

We only included studies relating to post-secondary education or those that addressed both secondary and post-secondary components. Many publications could be applied to mathematics education at any educational/program level and these were judged on a case-by-case basis according to their relevance to post-secondary education. Although we did not exclude publications by those in education departments, our primary interest was in the scholarship of teaching and learning in mathematics departments, which typically involves the teaching of mathematics to students majoring in science, engineering, mathematics, statistics and related disciplines. We thus also excluded research on educating preservice and inservice mathematics teachers, differentiating teacher education from post-secondary mathematics education more generally. We searched author affiliations and included publications for which at least one author is affiliated with a Canadian post-secondary institution. Our search found only publications in English, whereas English and French are both official languages of Canada and mathematics teaching and research are performed in both languages. We note that several peer-reviewed journals in mathematics education do publish in both languages, for example the journal *"For the Learning of Mathematics. An International Journal of Mathematics Education"*. Although no French-language publications were submitted in response to our solicitation through the CMS, we believe that a review of French-language pedagogical scholarship in Canada is a clear avenue for future work.

Applying these inclusion criteria allowed us to refine our database of publications to several hundred books, book chapters, conference proceedings, and journal articles. In many cases it was difficult to assess the extent to which book chapters and conference proceedings, in particular, had been subject to peer-review. Conference proceedings were also problematic because many are not indexed in publication databases and are thus only partially represented in our sample. To further focus our review, we therefore limited our consideration to journal articles in peer-reviewed publications. These articles represent the highest quality of scholarship due to rigourous peer-review processes and we were able to gather what we believe to be a representative number of articles. In total, 51 peer-reviewed journal articles authored by at least one person affiliated with a Canadian university served as the data for this study.

Classification

To explore trends in this pedagogical scholarship, we classified those publications meeting the inclusion criteria in various ways. First, we classified each paper by type of scholarship, based on a scheme proposed by Weimer (2006). Weimer catalogues the pedagogical literature in two main categories: (a) wisdom of practice and (b) research scholarship. As the name suggests, the wisdom of practice literature describes best-practice advice, written by experienced post-secondary educators. Such articles generally do not include research results but describe personal accounts of change (documenting changes and their results within courses or departments), recommended practice (how to teach), recommended content (what to teach), and personal narratives (reflections on teaching). In contrast, publications classified as research scholarship are based on the results of pedagogical research. This research need not be a traditional, quantitative study (controlled experiment); qualitative studies (for example interviews), and descriptive research (collecting and analyzing survey data) are also included as research scholarship.

In addition to classifying papers by type of scholarship, we grouped papers by topic, such that issues of sustained interest, or novel, emerging issues could be identified. Although this classification scheme was somewhat subjective, this analysis of the literature distilled a number of important themes.

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Results

Pedagogical Scholarship Categories

Table 1 presents the results of our categorization according to type of pedagogical scholarship. We note that the distribution among categories is far from uniform. In particular, recommended content accounted for 27% of the publications in our sample. This was consistent with our expectations, given the strong history in post-secondary mathematics of publishing and sharing subject-specific instructional ideas. Interestingly, descriptive research (e.g., the analysis of survey data) accounted for over 27% of the papers and was the next largest category. In contrast, recommended practice (e.g., how to teach) accounted for only 6% of this literature and only 8% of the literature described quantitative studies (e.g., controlled experiments). This last observation is in contrast with Weimer's observation that education researchers have recently been producing more quantitative scholarship (Weimer, 2006).

Overall, although the wisdom of practice literature outnumbered the research scholarship literature in our sample, research scholarship still accounted for nearly half of the papers we examined (47%).

Table 1
Classifying the Pedagogical Scholarship Based on Weimer's Scheme

Type	Total	Subtype	Total
Wisdom of Practice	27	Personal Accounts	4
		Recommended Practices	3
		Recommended Content	14
		Personal Narratives	6
Research Scholarship	24	Quantitative	4
		Qualitative Studies	6
		Descriptive Research	14
Total	51		51

Theme Categories

After reviewing the papers in detail then classifying them, several consistent topics of concern emerged. We created the following seven categories for classification:

1. Student Thinking: Papers exploring students' opinions, experiences and mental constructs.
2. Proof: The role of proof in undergraduate mathematics education.
3. Technology: The use of technology in teaching mathematics.
4. Transitions: Transitions from secondary to post-secondary education, or transitions from post-secondary education to the workplace.
5. Retention: Recruitment and retention of mathematics undergraduates.
6. Subject Specific: Specific topics from the undergraduate curriculum.
7. Miscellaneous: Papers that do not belong to any of the other categories.

Approximately 80% of the papers we reviewed addressed one or more of the first six themes. The remaining papers were classified as miscellaneous. The results of categorizing the literature jointly by topic and by publication year are shown in Table 2. From this analysis, a number of patterns emerge. We note that the content of specific courses was the most popular topic addressed, accounting for 31% of our sample. In addition, this topic remained relevant throughout the study period with some publications nearly every year. Given that most educational researchers at the post-secondary level are also practicing post-secondary teachers, this result was not surprising.

A further 16% of the papers in our study addressed the use of technology in teaching mathematics. Despite the ubiquitous availability of computers, the internet, and portable communication technologies throughout the study period, publications in this area are clustered in more recent years (2009 and 2010).

A surprising finding was that 12% of our sample addressed the transition from secondary to post-secondary education, making this the third ranked topic of concern. Again, interest in this topic was maintained throughout the years studied. We discuss the concerns addressed in these papers in some detail in a later section. Until further data become available, it is unknown whether this issue is of equal importance internationally, or is of particular concern in the Canadian educational context.

Trends in Time

The rightmost column of Table 2 also shows the total number of publications in our sample for each publication year. By inspection, it is unclear whether these data indicate a trend towards increasing publication rates over time (with 2010 as an outlier), or a constant publication rate over time (with 2008 and 2009 as outliers). To investigate further, we increased our sample size by including, for this analysis only, both book chapters and peer-reviewed conference proceedings. This increased our sample size to 85 publications. In this larger sample there was a clear and statistically significant increase in publication rates over time (a simple linear regression yields $r^2 = 0.73$, $P < .05$, two-tailed t-test, 9 degrees of freedom; data not shown).

Table 2
Classifying the Pedagogical Scholarship by Topic.

Year	Student Thinking	Proof	Technology	Transitions	Student Retention	Content	Miscellaneous	Yearly Total
2000		1		1		1	1	4
2001						1	1	2
2002						1		1
2003			1		1			2
2004						1		1
2005	1	1		1		1	1	5
2006			1	1		1	2	5
2007	1					2		3
2008	1	2		1		5	1	10
2009			3	2	3	1	4	13
2010			3			2		5
Total	3	4	8	6	4	16	10	51

Note. If a publication addressed more than one topic, a primary topic was chosen such that each publication is counted only once in this table.

Institutional Affiliations

Aside from categorizing the papers by type and topic, we also organized them by institution to examine the geographical distribution of this scholarship; results are shown in Table 3. The Canadian population is concentrated in British Columbia, Ontario, and Quebec and many post-secondary institutions are located in these provinces. It is therefore not surprising that the majority of scholarship in teaching and learning appears to be produced in these provinces. This trend is driven by high publication rates from McMaster University, Simon Fraser University, the University of Toronto, and the Royal Military College of Canada. Quebec's strong showing is particularly impressive given that there were no French-language papers in our review.

Table 3
Classifying the Pedagogical Scholarship by Institution and Province.

Institution	Publications by Institution	Publications by Province
Alberta		
Athabasca University	1	2
University of Alberta	1	
British Columbia		
Simon Fraser University	6	10
University of British Columbia	2	
University of Northern British Columbia	1	
University of Victoria	1	
Manitoba		
University of Winnipeg	1	1
Nova Scotia		
Acadia University	2	3
Dalhousie University	1	
Ontario		
Brock University	3	31
Lakehead University	3	
McMaster University	7	
Queen's University	1	
Royal Military College of Canada	5	
Trent University	1	
University of Ottawa	1	
University of Toronto	6	
Western University	1	
University of Windsor	2	
University of Waterloo	1	

Table 3 (continued)

Quebec			
	Cégep de Rimouski	2	10
	Concordia University	2	
	Dawson College	1	
	McGill University	2	
	Université de Montreal	2	
	Université de Sherbrooke	1	

Note. If a publication has multiple authors from the same institution, that publication is counted only once for that institution. If a publication has multiple authors and some are from different institutions, that publication is counted once for each institution.

Thematic Analysis

In this section, we discuss the themes and concerns that emerged in our analysis of the literature. For the sake of brevity we do not address here every paper which met the inclusion criteria; nonetheless, for the interested reader, we provide a list of all the papers classified as addressing each theme at the end of each subsection below.

Student Thinking

As mentioned previously, a trend that emerged from our analysis was a focus on student thinking. Several papers in our review involved surveys or reflections on students' attitudes, including beliefs, experiences or insights, towards mathematics. This included a survey of nearly 1200 undergraduate students in five countries, examining their views on mathematics (Petocz et al., 2007), and two other studies focusing on Canadian students' frustrations (Sierpinska, Bobos, & Knipping, 2008), and their moments of insight (Liljedahl, 2005). These papers are exemplars of a larger trend, on Canadian campuses and elsewhere, to focus on the "learning" in teaching and learning (e.g., Huba & Freed, 2000). Understanding the minds of our students – their attitudes, prior experiences, frustrations and successes – seems critical to improving their learning not only in mathematics, but across the undergraduate curriculum. Overall three papers were classified as having a primary focus on student thinking: Liljedahl (2005), Petocz et al. (2007), and Sierpinska et al. (2008).

The Role of Proof

Another recurring topic in the papers we examined was mathematical proof, which has been called a difficult and contentious issue in mathematics education (Hanna, 1995). The role of proof in understanding mathematics is the primary focus of five papers in our dataset, spread across the decade, indicating a continued interest in teaching not only the requisite techniques, but also the foundational mathematical thinking required for proof. Of particular interest was a recent contribution addressing the role of digital tools in the teaching of mathematical proof (Borwein, 2005). This paper suggests that technology be introduced at the heart of the mathematical curriculum. The four papers addressing proof were: Borwein (2005), Hanna and Barbeau (2008), Hanna and de Villiers (2008), and Hanna (2000).

Technology

In addition to its role in proof, the use of technology (in a broad sense) in mathematics education was an important theme in the papers we reviewed. Several papers focused on the use of computer algebra systems (CAS), particularly in linear algebra courses. While CAS were, in general, favourably reviewed as important tools for student learning, student frustration with gaining competency in these tools was also reported (Jeffrey, 2010). Online learning, in its various forms, was another focus of attention in the papers in our sample, including papers addressing the potential benefits of online distance education (Peschke, 2009), and online office hours (Hooper, Pollanen, & Teismann, 2006). A more surprising result was reported in a series of two papers by Joordens, Le, Grinnell, and Chrysostomou (2009) and Le, Joordens, Chrysostomou, and Grinnell (2010). Here researchers investigated the effects of having lectures videotaped and made available online after the traditional classroom lectures. Counter intuitively, they found that students who attended classes *and* utilized the online lectures were often those who performed most poorly. In general, these publications suggest that technological advances offer many possibilities for improved communication and mathematical exploration, but reliance on technology may also have unintended effects. Technology was the primary theme in 16% of the papers reviewed in our sample: Hooper et al. (2006), Hazzan and Zazkis (2003), Jeffrey (2010), Joordens et al. (2009), Klasa (2010), Le et al. (2010), Muller, Buteau, Klincsik, Perjesi-Hamori, and Sarvari (2009), and Peschke (2009).

Transitions

The transition from high school to university, or from university to the workplace, was a topic which emerged repeatedly in our literature sample. Papers here ranged from the extremely practical, such as developing online or print resources to ease the secondary-tertiary transition (Habash, Suurtaam, Yagoub, Kara, & Ibrahim, 2006; Kajander & Lovric, 2005), to the highly theoretical, such as a comparison of this transition to the abstract notion of a rite of passage in anthropology (Clark & Lovric, 2008, 2009). Curriculum changes and uneven exposure to calculus at the secondary level (Fayowski, Hyndman, & MacMillan, 2009), as well as increasing access to technology in the home (Miller & Goyder, 2000) are implicated as creating a moving target for the design of first-year university courses. Since over 12% of the papers in this review addressed these transitions, this is clearly an extremely topical issue in contemporary mathematics education. Cultural factors and education systems at the primary and secondary level clearly influence the transition to university, yet it is unclear whether this concern is particular to the Canadian educational system, or is a topic of international interest. The papers in this survey for which these transitions were the primary focus were: Clark and Lovric (2008), Clark and Lovric (2009), Fayowski et al. (2009), Habash et al. (2006), Kajander and Lovric (2005), and Miller and Goyder (2000).

Recruitment and Retention

Related to these transitions, the recruitment and retention of mathematics students were also topics of current interest. Ezeife (2003) writes specifically about students from minority and indigenous cultural backgrounds worldwide, suggesting classroom strategies and approaches that might improve enrolment and retention of these students. Fenwick-Sehl, Fioroni, and Lovric (2009) give a detailed picture of recruitment and retention in mathematics at Canadian universities, using data from Statistics Canada and the results of their own survey. These authors discuss a wide range of issues which impact recruitment and retention, including the activities of university mathematics departments, but also broadening to such issues as students' and parents' beliefs about mathematics, and information about careers in math and science. Broadening further, Holton, Muller, Oikkonen, Sanchez Valenzuela, and Zizhao (2009) examine enrolments in undergraduate mathematics in a sample of countries worldwide: Mexico, The Netherlands, New Zealand, the People's Republic of China, Singapore and the USA. The data were collected by a survey team for the International Congress on Mathematical Education (ICME) in 2008. The study discusses detailed factors affecting individual countries, or affecting individual departments from which the data were collected. Related to these approaches, Muller (2009) characterizes "dynamic" or "vital" university mathematics departments and concludes with examples of revitalized undergraduate programs within such departments. In summary, serious concerns about recruitment and retention emerge in this literature for all Canadian mathematics students, with particular attention to women and to students from minority or indigenous backgrounds. As evidenced by the ICME study, this appears to mirror concerns shared internationally regarding declining enrolments in mathematics. The four papers primarily addressing this theme were: Ezeife (2003), Fenwick-Sehl et al. (2009), Holton et al. (2009), and Muller (2009).

Subject-Specific Content

Papers addressing specific classroom content were the most prevalent classification in the literature we chose to review. These papers are best typified in the "Classroom Notes" section of IJMEST, the *International Journal of Mathematical Education in Science and Technology*. Contributions by Gauthier (2004, 2005, 2006, 2008a, 2008b), Tian and Styan (2002), and Barabé and Dubeau (2007) address specific topics in the undergraduate mathematics curriculum, offering novel or simplified techniques for teaching, solving or proving various concepts. The concept of infinity (Biza, Nardia, & González-Martín, 2009; Mamolo & Zazkis, 2008), the Riemann integral (Thomson, 2007, 2010), and the completeness property of the set of real numbers (Bergé, 2008, 2010) were repeated topics. The remaining papers in this category addressed issues at the interface of mathematics, computer science and engineering (Terlaky, 2001; Tremblay, 2000; Farmer, 2008).

Other Topics

The theme of women in mathematics was addressed explicitly by only two papers in this review, although we note that this topic appeared in several book chapters and conference proceedings that did not meet our inclusion criteria. Shapka (2009) describes a research study in which Grade 9 and 10 girls were taught in an all-girls' classroom or a co-ed classroom for math and/or science. Although mainly pertaining to secondary education, this study is relevant here because the success and perceived competence of the subjects were tracked during post-secondary education as well. The 26 girls in the all-girl classes did seem to benefit, during high school, from this intervention, but no long-term benefit at the post-secondary level was observed. In a second study of women in math, Gadalla (2001) characterized post-secondary enrolments of Canadian women in mathematics, engineering and computer science. The intriguing finding of this study is that these patterns varied substantially by discipline, suggesting that discipline-specific factors outweigh, or at least modify, more general factors affecting women's enrolment in all three disciplines.

A number of other topics were only addressed in one or two papers in our collection. Nonetheless the issues discussed in these papers are topical concerns for university mathematics departments across Canada: large class sizes (Jungic, Kent, & Menz, 2006; Kajander, 2006), grade inflation (Anglin & Meng, 2000), appropriate textbooks (Kajander & Lovric, 2009), and mathematics for engineers (Winkelman, 2009). Other papers address the possibility of service learning (Sherman & MacDonald, 2009), learning strategies (Muis, 2008), or discuss the historical context of, or historical approaches to the teaching of mathematics (Babb, 2005).

Future Directions

This review dovetails with a larger initiative at Western University. In 2011, Western hosted the Western Conference on Science Education, focused on post-secondary education in the sciences, including mathematics and statistics. As part of that conference, and as a benchmark of the Canadian Scholarship of Teaching and Learning (SoTL) landscape, a larger review of the pedagogical literature was undertaken, including an array of scientific disciplines such as actuarial sciences, biology, chemistry, earth sciences, physics, statistics and science information literacy (Haffie et al., 2011). Thus, this review of the literature pertaining to undergraduate mathematics should ultimately be joined by, and contrasted with, similar reviews emerging for other disciplines.

As mentioned in the introduction, our aim was to provide a snapshot of the recent published literature in mathematics teaching and learning, identifying emerging themes (such as online education) and issues of sustained interest (such as the secondary to post-secondary transition). We hope that this benchmark can be both a point of comparison for similar studies from other countries, and also for changes over the next decade in Canadian post-secondary education.

Topics which were *not* addressed in this sample of the literature were also informative. We focused on post-secondary mathematics, and actively excluded a large body of literature addressing primary and secondary education. However, there was no need to apply an exclusion criterion at the other end of this spectrum: not a single work in our database addressed the teaching and learning of graduate students in mathematics. Given the critical importance of graduate course work in mathematics, as compared to other scientific disciplines, this suggests a clear opportunity for future scholarly contributions to the pedagogical literature. Graduate students form a uniquely talented and motivated group, and teaching these students likewise has unique challenges and rewards. Published accounts of shared experience in this regard would form a valuable contribution to the field, and might be particularly useful to new instructors at the graduate level.

We restricted our data collection to aspects of each publication that could be assessed through inspection of the published record. Thus, a number of intriguing and important questions remain unanswered. For example, it would be fascinating to know more about the authors contributing to this literature: are those contributing to pedagogical scholarship more likely to be pre- or post-tenure? Do these authors teach more, on average, than colleagues in their respective departments? What factors influence faculty members with a research focus in mathematics to contribute to the teaching literature, and what credit is offered at an institutional level for these efforts? We hope that the work presented here will serve as a foundation for future research efforts addressing these deeper, and critical, questions.

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