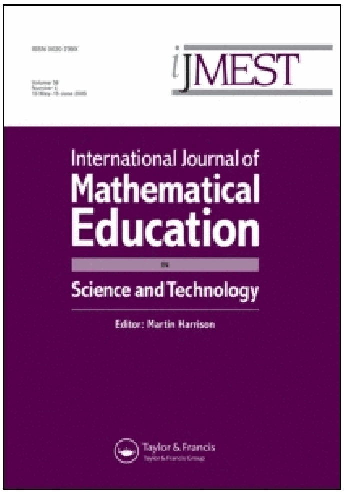

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Recruitment and retention of mathematics students in Canadian universities

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Data from Statistics Canada shows that while the number of mathematics degrees at the undergraduate and graduate levels remained relatively constant between 1992 and 2005, the total number of mathematics degrees as a percentage of all degrees awarded has slightly decreased over the same time period. To understand this situation better, we investigate present trends at Canadian universities – in particular, as they relate to the recruitment and retention of students into/within mathematics programs. Using data available from Statistics Canada, results of our own survey, as well as written and electronic references, we produce a snapshot of the situation at Canadian universities, and attempt to identify good practices that might be able to reverse the downward trend. Our survey shows that recruitment and retention are not at the top of the agenda in many mathematics departments across the country. However, we identified activities organized at every university that was represented in our survey that could be interpreted as efforts aimed at increasing numbers of mathematics students. In order to understand variables that affect recruitment and retention we take a look beyond a typical mathematics department, and discuss issues such as: careers in mathematics and the ways information about it is presented to students, promotion of mathematics and science as important areas of human endeavour, students' and parents' beliefs about mathematics and its role in one's life, self-selection out of mathematics, and emergence of new fields of applications in mathematics, such as biological sciences.

Keywords: mathematics; recruitment; retention; mathematics majors; mathematics degrees

1. Introduction

We have all heard (and perhaps uttered ourselves) statements to the effect that mathematics students are no longer what they used to be, followed by comments on how they know less and less mathematics; how they do not sign up for abstract courses (such as analysis, algebra or topology) in large enough numbers, and how, in general, their interest in pursuing a degree in mathematics has been on a decline for some time now. Is this really true? If so, what are the major factors that steer students away from studying mathematics, and consequently, from careers that involve mathematics?

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In 1957, the Soviet Union launched the Sputnik satellite, taking the lead in the space race. The US government's response that called for the creation of its own space program produced a demand for a large spectrum of experts, and caused a sizeable increase in student interest, enrolment in, and graduation from university mathematics, science and engineering programs. With the discovery of the Black–Scholes model for options pricing,[1] mathematics entered deeply into financial research (and has remained there). Applying mathematics to solve problems in financial, business and economics research was quite possibly the driving force behind the renewed increase in number of students majoring in mathematics in late 1970s to mid-1980s in North America.

What are the driving forces today – computer science, biological sciences or medicine? Are any of them (or some other discipline, or perhaps an event, or some discovery) capable of exerting an influence on mathematics of Sputnik's magnitude? Or, do we live in a world that is governed by fundamentally different forces that we do not understand well?

Data from Statistics Canada, Canada's national statistical agency, shows that while the number of mathematics degrees at the undergraduate and graduate levels remained relatively constant between 1992 and 2005, the total number of mathematics degrees as a percentage of all degrees awarded has slightly decreased over the same time period (see Figure 2 in Section 'Data Analysis'). Is this bad news? If so, how bad is it?

This article is our attempt at answering some of the questions we raised. We investigate present trends in mathematics at Canadian universities – in particular, as they relate to the recruitment and retention of students into/within mathematics programs. Using data available from Statistics Canada, results of our own survey, as well as written and electronic references, we aim to produce a snapshot of the situation at Canadian universities and attempt to identify good practices that might be able to reverse the downward trend.

Our research is part of the project 'Recruitment, Entrance and Retention of Students to University Mathematics Studies in Different Countries', started by a team of international researchers. An initial report has been discussed at the 11th International Conference on Mathematical Education (http://icme11.org/). We are grateful to Dr Derek Holton, who introduced this project to us, and to Dr Eric Muller, who gave us data from Statistics Canada, and whose knowledge, discussions and insights helped us a great deal.

2. Retention and recruitment in publications

The following is a summary of some publications related to recruitment and retention of students into mathematics programs. Since we had difficulties locating references that focus specifically on mathematics majors at Canadian universities, we extended our search to include American universities, as well as recruitment into science programs. Some references (mainly electronic) are mentioned in the 'Discussion' Section of this article.

In 'Talking about leaving: Why undergraduates leave the sciences' [1], authors Seymour and Hewitt provide an extensive study of recruitment and retention of science, mathematics, and engineering (SME) majors at seven American universities. The goal of the study was to determine the difference between students who persist in SME programs and students who switch out. The most significant finding of the study is that switchers and non-switchers do not have fundamentally different personality traits or experiences; switching decisions are made as a result of issues that affect both switchers and non-switchers alike [1]. The most commonly cited reasons for switching out of SME majors were, in order of importance, 'lack or loss of science interest,' 'belief that a non-SME major holds more interest, or offers better education,' 'poor teaching by SME faculty,' and 'feeling overwhelmed by the pace and load of curriculum demands' [1, p. 32]. Constructively addressing these issues (and a few others) combined with systematic integration of new technologies has been the recipe for success at recruitment and retention efforts at Brock University [2].

A particularly interesting finding of the study was that, while poor teaching factored into 36.1% of switching decisions, it was also mentioned as concern by 90.2% of switchers and 73.7% of non-switchers [1]. The most commonly used words to describe SME professors were 'unapproachable,' 'cold,' 'unavailable,' 'aloof,' 'indifferent,' and 'intimidating' [1, p. 141]. Students defined good teachers as those who are concerned about their students' learning and are enthusiastic for the subject as well as the topics being covered each day. Our survey (see Section 'Data Analysis') shows that faculty, in general, believe that the quality of teaching at their institutions is reasonable or good. It might be of interest to survey students on the same question.

Specifically relating to mathematics majors, the study shows that 'the greatest proportionate loss of women by switching occurs in mathematics/statistics' [1, p. 20]. Furthermore, mathematics majors are the most uncertain about what careers are available to them after graduation. Of the students who switch out of mathematics, 45.2% of female switchers and 8.5% of male switchers transfer into education programs [1]. The most popular transfer programs for male switchers from mathematics are humanities and fine arts.

In 1990, the report entitled 'A challenge of numbers: People in the mathematical sciences' was compiled for the US National Research Council's Committee on the Mathematical Sciences in the Year 2000 [3]. This report presents comprehensive data about the state of mathematical sciences (mathematics, statistics and computer science) in post-secondary institutions in the US. It states that although interest in mathematics (measured by number of mathematical science degrees awarded) was high in the late 1960s, interest decreased in the 1970s and was on a slight increase by the mid-1980s [4] (and see Holton et al., this issue). Of the mathematical sciences, however, mathematics was struggling to attract students. The report raises several issues linked to recruitment and retention into mathematical sciences, such as shifting interests of students, difficulties in the transition from secondary to post-secondary mathematics, mathematics teacher education and renewal and revitalization of mathematical sciences faculty [4].

Recruitment into science is the topic of Tobias' research study 'They're not dumb, they're different: Stalking the second tier' [5]. Tobias suggests that in order to recruit to science, we should be not be looking at 'who does science and why, but who doesn't do science, and why not' [5, p. 13]. She defines two 'tiers' of students: the first tier contains students who are motivated and fit easily into the competitive environment of scientific disciplines; second tier students are students who are capable of studying science (i.e. are academically strong), but for a variety of reasons, choose not to. As a solution, Tobias suggests that we 'stalk' the second tier, by researching why these students leave or choose not to study science in order to change our science programs to attract them. She presents a research study in which she gets several very bright non-science graduate students to seriously audit a physics or chemistry course. These students were in programs such as literature, creative writing, and philosophy. Results were that all of the participants but one (there were seven) scored easily in the top 10% of the course, one even trying for top grade. Tobias' findings suggest that there is a pool of potential mathematics students that could be tapped into.

3. Methodology

We started working on this project in March 2008, when we met with Dr Eric Muller, Professor Emeritus at Brock University, and a member of the international team that initiated this project on recruitment and retention. From Dr Muller, we obtained two sets of data: graduation numbers from Canadian Universities collected and presented by Statistics Canada, as well as the responses to the Canadian Mathematics Society (CMS) survey that was distributed via email to a number of university faculty across Canada. Data on graduation rates is available for free, but not to the level of detail that we needed – Statistics Canada required a payment to separate graduation numbers for mathematics from those for statistics.

The response rate to the CMS survey was low – a total of eight replies were received. It is not known to how many people the survey was emailed, but the number was certainly close to 100. Because of the low response rate, and because we identified a number of additional issues that were not part of the survey, we decided to create our own instrument and administer it to the same constituency. To the original list of five questions we added 11 new ones, in order to collect qualitative data that would allow us to understand the issues better, as well as to create a more comprehensive image of activities within mathematics departments at Canadian universities. This expanded survey, entitled 'Recruitment and Retention of Math Majors in Canadian Universities' (hereafter referred to as 'the survey'), is appended to this article.

Discouraged by the low-response rate to the original survey, we decided (initially) not to email our survey to potential respondents. Instead, we felt that a more personal approach might be more effective. Using data available on Internet pages of mathematics departments at Canadian universities, we compiled a list of people whom we would have liked to participate in the survey. This list was based on the person's university affiliation (we wanted participation from all provinces in Canada) and their overall reputation and (possible) activity in the area of mathematics education. In other words, we wanted to approach people who would be likely to have access to the data we were looking for, and/or whose personal experience could provide us with useful information.

The yearly meeting of Canadian Mathematics Education Study Group (CMESG) in May 2008 was the best opportunity for us to approach the faculty from our list in person, explain the purpose of our survey and ask them to answer some (or all) of the questions. We were able to approach about 40% of the faculty from our list. Not having other means of contacting the remaining 60%, we decided to send them the survey over email.

In total, we administered between 65 and 70 surveys, and received 14 completed surveys [by 'completed' we mean that some (not necessarily all) questions were answered]. We should mention that even though we were a little more successful in our data collection than the original CMS survey, we had hoped for a greater number of responses.[2] Furthermore, some surveys were not filled out completely. Although useful data was obtained, there was disappointment with the lack of, as well as the quality of responses. For instance, stating that the enrolment trend of mathematics majors and co-majors in a department has been generally increasing, without further elaboration on where the increase could have come from (e.g. general increase in student population, actual increase in students signing up for a math program, etc.) was not particularly useful to us.

4. Data analysis

In this section we analyse quantitative data from Statistics Canada, as well as qualitative data obtained through the two surveys (original CMS survey and our own survey).

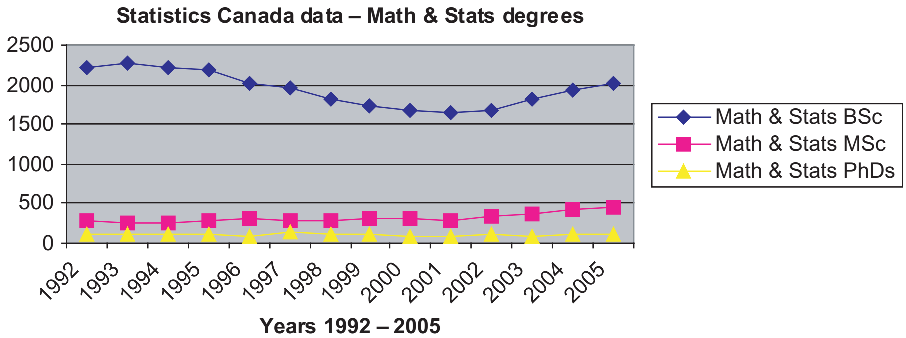

Figure 1. Number of degrees in mathematics and statistics, 1992–2005.

Data from Statistics Canada that was available to us describes the number of mathematics and statistics degrees awarded at the undergraduate, Masters and Doctoral levels from 1992 to 2005. The degrees awarded through Bachelor of Arts programs are not included. The data also gives the number of degrees awarded as a percentage of all science degrees awarded each year.

At the undergraduate level, the number of mathematics and statistics degrees awarded has fluctuated over the given time period. In 1993, the maximum number of degrees was awarded (2286). Since then, the number of degrees fell to a minimum of 1656 in 2001, and is currently slightly increasing, as Figure 1 shows.

Statistics Canada was able to separate the number of mathematics degrees from the number of statistics degrees for the years 2001–2005. In that interval, we witness increases in both numbers (undergraduate mathematics degrees from 1611 in 2001 to 2028 in 2005, and undergraduate statistics degrees from 45 in 2001 to 96 in 2005). This information (i.e. mathematics and statistics degrees decoupled) is not shown in Figure 1.

The number of Masters degrees in mathematics and statistics has been steadily increasing since 2001, whereas the number of Doctoral degrees in mathematics and statistics has remained relatively constant in the interval 1992–2005 (Figure 1). If we separate the data, and look at the years 2001–2005, we see a steady increase in the number of Masters degrees in mathematics, from 246 in 2001 to 402 in 2005. In the same time interval, the number of Doctorates in mathematics remained more or less stable, fluctuating between 90 and 99.

Relatively, when compared to all disciplines, the total number of mathematics and statistics degrees (undergraduate, Masters, and Doctoral combined) has been slightly declining (Figure 2).

The percentage of undergraduate degrees in mathematics and statistics has been mostly decreasing from 1992 until 2002, from about 1.8% in 1992 and 1993 to 1.25% in 2002. Since then it has been slowly increasing, reaching 1.33% in 2005. The percentage of degrees in mathematics (only) has been stable in the interval 2001–2005 (at about 1.25%).

Likewise, the percentage of Masters degrees in mathematics and statistics has remained relatively stable over the time period 1992–2005. The number of Masters degrees in mathematics only (again, we have data for years 2001–2005) has been fluctuating between 1% and 1.2% of all degrees rewarded. The percentage of Doctoral degrees in mathematics and statistics decreased from about 3.5% in the early 1990s to about 2.5% in 2005. Doctorates in mathematics (without statistics) decreased as well, from about 2.6% in 2001 to 2.3% in 2005.

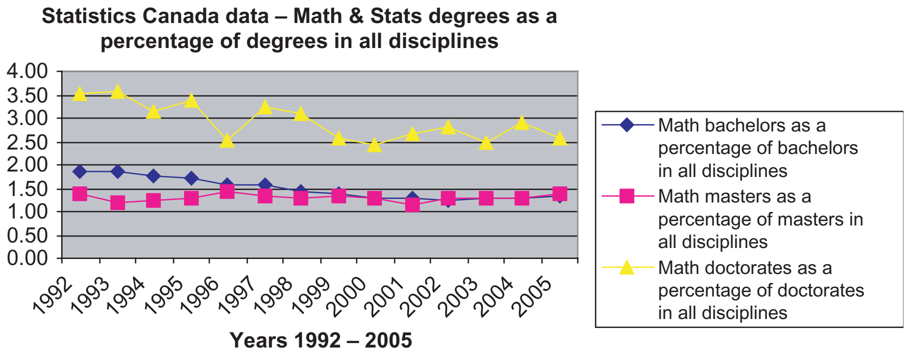

Figure 2. Number of degrees in mathematics and statistics as percentage of degrees in all disciplines, 1992–2005.

Next, we discuss the results of the two surveys.

In Ontario and Eastern Canada (without Quebec), survey results (questions 1 and 2) show that the numbers of undergraduate mathematics majors are either stable or decreasing, both absolutely and relatively (to the total enrolment at each institution). The only university that reported an increase in absolute (but not in relative) numbers was the University of Waterloo. Of the four faculty from Quebec, two indicated an increase or slight increase in enrolment (both absolute and relative) at their institutions, whereas two indicated a decrease in both absolute and relative numbers. The single sample from Western Canada indicated that enrolment for mathematics students is remaining stable, even though the total enrolment at the institution is decreasing.

Questions 3 and 4 inquire about substantial changes that mathematics departments may have introduced in their core courses for math majors, as well as about implementation (if any) of new service courses in mathematics. Reading the answers, we identified certain new directions mathematics departments are taking in order to appeal to a broader range of undergraduate students. Four universities mention introducing mathematics courses for life sciences and/or for psychology students. At McMaster University, the new 'Calculus for Life Sciences' course introduces the concept of time-discrete dynamical systems very early, so that meaningful applications (such as allometry, various population models, or models of dissolution of drugs) can be studied right away. At Brock University, a new core undergraduate mathematics program, called Mathematics Integrated with Computers and Application, has been introduced. Other changes include increased emphasis on using mathematical software Maple, or introduction of dynamic geometry software. On the list of new courses introduced at various universities we find Mathematical Reasoning, Introduction to Numerical and Computational Methods, as well as courses that cover fundamental concepts in mathematics (that seem to be present in almost every mathematics course, but are rarely given the attention they deserve, such as: careful study of the integers, real and complex numbers, and infinity). As well, we witness attempts at breaking large size calculus courses in first year into streamed versions, adjusted to the needs of a particular program (science, life science, engineering, business, etc.).

Some service courses introduced recently provide a non-standard introduction to mathematics, such as Recreational Mathematics or Mathematics of Art and Architecture. The rationale is that they might attract students from all corners of a university campus, and perhaps persuade a few to consider switching into some mathematics-rich program.

Unfortunately, it is not clear from the survey responses whether or not these courses are actually successful in bringing in new mathematics majors. Evidence and experience from McMaster University (discussed in more detail in the following section) suggest that students who are really good at mathematics, but do not major in it, take extra courses in mathematics (beyond those required by their program) because they like mathematics. However, as a rule, they do not switch; a smaller number might complete a minor in mathematics.

Questions 5–8 focus on efforts aimed at recruiting good mathematics students from high schools and from faculties/programs within each university, as well as efforts aimed at retaining the students that are enrolled in mathematics programs. A large number of mathematics departments surveyed offer outreach activities for high school students. Those include special seminars and lectures, invitations to high school students to attend university lectures, math and science camps (throughout the summer), math contests, online group problem solving competitions, and university faculty giving lectures at local high schools. Reading through surveys, we did not find any indication of, or possible evidence for, the success of such efforts.

Survey respondents offered a variety of incentives aimed at retaining students within mathematics programs, such as: improvement of interaction between students and faculty, creation of space that math majors could consider their 'home,' offering drop-in help centres where tutors are available for one-on-one help, or increasing co-op opportunities. The mathematics department at St. Francis Xavier University published a brochure named 'Mathbook', which contains a directory of all faculty and their research interests, describes the programs and various options available for completion, as well as information about past graduates and their career paths. Further incentives include: increase in the number (or creation) of teaching and tutoring positions for good undergraduate maths students, in-course scholarships, or introduction of 'interesting upper year math courses,' such as mathematical cryptography, mathematical finance or ancient and classical mathematics. As well, three institutions cited increasing interaction with first-year students as an important factor in retention. Several respondents mentioned that social and academic activities organized by maths (or maths and stats) could positively affect retention numbers.

Most respondents were unable to determine exactly what effect recruitment and retention efforts had on the number of students in their faculties, but there is general belief that all efforts have had positive outcomes. At a few institutions, however, we find projects that were initially very well received, but were later abandoned, as their creators and leaders retired or lost interest.

The Faculty of Mathematics at the University of Waterloo provides a good example of a strong commitment to recruitment and retention of mathematics majors. Along with providing career counselling and a large number of co-op opportunities, the faculty offers mathematics contests for high school students (contest participation and/or success are used in decisions about admissions and scholarships). Furthermore, the faculty has an active recruitment program, including an international recruiter, responsible for attracting students from abroad and for assisting with transition issues these students might experience when they arrive in Canada. The website for the Faculty provides detailed information on careers available to mathematics graduates, including a video presentation on career paths of recent alumni.

Questions 9 and 10 provide information on the level of interest in recruitment and retention within mathematics departments. Out of 10 completed surveys representing eight institutions, three respondents reported low interest in recruitment, four reported medium interest, and three reported high interest. Interest in retention is lower, with five respondents reporting low interest and five respondents reporting medium interest. Only one respondent ranked retention as more important than recruitment, whereas five respondents indicated that retention is less important to their departments than recruitment.

In response to question 12, four faculty did not know what type of data is available on recruitment and retention, nor were able to identify the person at their institution who could provide such data. Two respondents suggested contacting the registrar but were not able to give a contact name. Only four respondents were able to give the contact information of someone who would have access to recruitment and retention data. Furthermore, three respondents mentioned knowing of departmental activities aimed at discussing issues of recruitment and retention. These results suggest that recruitment and retention is not a priority in many university mathematics departments.

Question 11 explores the reasons why students do not sign up for maths programs, or why they decide to switch out and pursue study in another subject. Of nine respondents who answered the question, five mentioned lack of job opportunities for mathematics graduates as the main reason why high school students do not chose to enter math programs. Two respondents elaborated, mentioning that students believe that teaching is the only career available to them upon graduation. Another commonly cited reason why students do not enter maths programs is the perceived difficulty of some courses, which was mentioned by four respondents. 'Myths' about high levels of difficulty of some courses should not be taken lightly. The first casualty is students' expectations – even good students, signing up for (what they sometimes call) 'impossible courses' downgrade expectations about their performance in such courses. Other reasons for switching cited in the surveys include: math courses being too theoretical, heavy course loads, underestimates of the amount of studying required, and course scheduling which makes it difficult for students to take the courses they are really interested in.

Some issues mentioned here have been addressed by recruitment and retention efforts. For example, many departmental websites list job opportunities for mathematics majors. One reason for the perceived lack of job opportunities may be because it is uncertain how much maths is actually involved in many of the careers listed. For example, 'accountant' is often listed as a potential career, but most people do not know exactly what or how much math is required of an accountant (we will elaborate on this issue in the 'Discussion' Section). As one survey respondent suggested, perhaps we need a national program to emphasize the advantages of an undergraduate math degree.

In response to question 13, all respondents wrote positively about the quality of teaching in their department. Answers ranged from 'fair' to 'good' to 'excellent.' Several respondents mentioned that quality of teaching is not a factor that contributes to attrition rates. All survey respondents seem to be satisfied with the quality of graduating students from their institution (question 14). Many mentioned that there are usually a few exceptional students, and many good or mediocre students.

Lack of funding (especially for foreign students, also for scholarships) seems to be the major factor affecting the recruitment of students into MS and PhD programs (question 15). Frustration was expressed over the fact that some departments have faculty available and willing to engage, but lack of money makes offers to potential graduate students financially unattractive. Competition between universities was mentioned as a force that negatively impacts recruitment into graduate schools at smaller-size universities.

5. Discussion

In this part we elaborate on some issues that explicitly, or implicitly, came up in our surveys and data analysis. We comment on ways of promoting mathematics as a career, students' and parents' beliefs about mathematics and science, and discuss issues such as new applications of mathematics and students' self-selection out of mathematics.

5.1. *Promoting mathematics*

Many mathematics departments use some variation of the phrase 'mathematics is everywhere' (given with or without further elaboration) in their attempts to promote mathematics and recruit students. Beautifully designed posters suggest particular ways in which a certain piece of mathematics is used in solving problems coming from real-life situations. For instance, in the student-friendly area (within the Department of Mathematics and Statistics) at McMaster University, we find such posters, published by Isaac Newton Institute for Mathematical sciences for the World Mathematical Year 2000, and displayed initially in the trains of the London Underground [6].

However, what most of these posters promote is *research-level mathematics* that only a very small fraction of graduates in mathematics might engage with. A simple analysis of an average person's daily activities [7] shows that no mathematics beyond high school level is used in most peoples' lives. Furthermore, many activities and jobs requiring math at (or below) high school level (such as cashiers figuring out change by mental arithmetic, calculating taxes, home renovation planning, or nurses calculating the dosage of a medicine) have been 'outsourced' to machines (cash registers, Excel, tax software, CAD, and similar software), or to a specific individual ('expert,' such as a tax preparation professional or head nurse in a hospital). In many cases, the reason for this is to reduce the probability of making potentially costly errors.

It seems that a very few graduates (with an *undergraduate* degree in mathematics) engage, in their professional life, with the mathematics they learnt *in university*. To put it differently, people who use mathematics in a significant way in their jobs hold either MSc or PhD degree in mathematics, or in another field – and as such could be qualified as 'applied' – for instance, architecture, computer science, or mathematics and biology, mathematics and medicine, physics, etc. A quick look at one global math jobs website[3] that lists jobs available at the moment in a number of countries, confirms our claim (of course, this page is not the only source of job opportunities in maths).

We have to be clear when talking about situations that require engagement in mathematics. For instance, the design of a global positioning system (GPS) device requires a large amount of sophisticated mathematics, but its use does not. A person using GPS in her/his car should not considered to be using or doing mathematics. The production of a DVD, or encryption of information sent over the internet, again, involve extremely rich mathematics; however, watching a DVD, or using the internet (in a way that a very large majority of people do) does not require knowing any of that (or other) mathematics. Many of us do not use any calculus to figure out how to slow down as we drive towards a traffic light.

In conclusion – we need to be very careful about how we present mathematics (as future career, as something we engage with, or need, daily) to our students. Promoting transferable skills obtained by studying mathematics (in particular problem-solving, critical thinking, logical reasoning and communication of scientific ideas and results to a wide variety of audiences), together with careful statements about how, and to what extent, mathematics is truly used in various professions, seems like a good strategy.

5.2. *Students' and parents' views and beliefs on mathematics and science in general*

We could easily argue that, in our science-based society, mathematics indeed plays a very important role, and that it is not mathematics, nor its many applications and uses, that are on the decline. What seems to be on the decline is the interest in studying mathematics (and/or pursuing mathematics as a career option) among today's young people in the so-called Western world. Lack of motivation for (and, in some cases, negative experiences with) studying science and mathematics among elementary and high school students and their views of scientists and mathematicians, coupled with their parents' (sometimes quite unfavourable) opinions and beliefs about science and mathematics as a career, create a somewhat skewed image of mathematics and its role in society that might be quite difficult to modify.

As reported in the USA Today[4] 'only half of children in grades 6–12 say that understanding sciences and having strong maths skills are essential for them to succeed in life after high school' [8]. About 70% of parents polled stated that they believed their children are getting the right amount of science and mathematics. Although parents believe that, in principle, mathematics and science education are important (62% of parents said that it is crucial for most of today's students to learn high-level maths, like advanced algebra and calculus), when it comes to their own children, they view it quite differently – only 32% said that their child's school should teach more maths and science [8]. As well, students themselves do not rank mathematics and science education highly: 'Students put a lack of science and maths near the bottom of problems they see at school. They are much more worried about bad language, cheating or the pressure for good grades' [8].

In 2005, as part of the Einstein year, the Science Learning Centre in London, England, surveyed about 11,000 students aged 11–15 for their views on science and scientists [9]. According to the survey, around 70% of students polled said they did not picture scientists as 'normal young and attractive men and women.' And although they believe that science is important (around 80% agreed that scientists did 'very important work' and 70% thought they worked 'creatively and imaginatively'), very few students think that they will pursue science as a career [9]. The reasons that some students articulated as 'because you would constantly be depressed and tired and not have time for family' or 'because they all wear big glasses and white coats and I am female,' indicate that one of the serious issues that needs to be dealt with in the promotion of mathematics is the overall image of science and scientists.

Because messages seem to be the same, we do not discuss other relevant surveys, such as the global study Relevance of Science Education from Oslo University, Norway [10].

5.3. *Mathematics and biology*

The emergence of biology as a major 'user' of mathematics is perhaps the most recent of major factors that have shaped mathematics and its applications. Advances and discoveries in biology (such as the human genome project, stem cell research, or cloning), and the impact on all life due to global climate changes have contributed a great deal to a surge in interest in biological sciences. Advances in the area of bio-based fuels (and the general shift towards a bio-based economy in general) further contribute to the number of front-page news stories about biology and biological sciences, cementing, in public eyes, their present dominant position as *the* fields of scientific research. According to Statistics Canada, biology was the most popular field of study for doctoral students in 2004/2005. Of about 4000 students who earned their doctorates in that period, 21% were in biological sciences [11,12]. Engineering and humanities followed with more than 10%, while 9% graduated from both psychology and education and 8% from social sciences.

J.E. Cohen argues in 'Mathematics Is Biology's Next Microscope, Only Better; Biology Is Mathematics' Next Physics, Only Better' [13] that it is mathematics that researchers in all areas of biological sciences are turning towards. 'Mathematics broadly interpreted is a more general microscope. It can reveal otherwise invisible worlds in all kinds of data [. . .]. For example, computer tomography can reveal a cross-section of a human head from the density of X-ray beams without ever opening the head, by using the Radon transform to infer the densities of materials at each location within the head [. . .] Today's biologists increasingly recognize that appropriate mathematics can help interpret any kind of data. In this sense, mathematics is biology's next microscope, only better' [13]. It is not just biology that will profit from mathematics, the benefits are mutual: 'Coping with the hyper-diversity of life at every scale of spatial and temporal organization will require fundamental conceptual advances in mathematics' [13]. The interaction between mathematics and biology is not historically a new phenomenon (recall, for instance, 'traditional' applications such as logistic growth or dynamics of interacting populations). However, since the early 1990s we have been witnessing 'explosive synergy between biology and mathematics' [13] that will contribute to the advances in both disciplines.

Thus, what might work well in terms of attracting students into mathematics is a promotion (and thinking) of mathematics as a highly applied discipline. Although this idea (not at all new) seems to be fairly straightforward, it is not – as it requires university mathematics departments to redefine their use of the word 'applied.' A case in point: research in mathematics and biology, that uses mathematics in a significant way and contributes to new knowledge in biology (but not to – formally – new knowledge in mathematics) may not be recognized as a PhD thesis in mathematics. The highest levels of education are not the only ones requiring changes. Appropriate education will have to be delivered throughout the whole educational system: 'Educating the next generation of scientists will require early emphasis on quantitative skills in primary and secondary schools and more opportunities for training in both biology and mathematics at undergraduate, graduate and postdoctoral levels' [3].

5.4. *Self-selection out of mathematics*

From the 1990s until 2007, McMaster University students were taking the same calculus course (coded Math 1A3; in 2008, streamed (specialized) versions of calculus were introduced). Noticing that really good students in the course rarely take other courses in mathematics (first-year linear algebra, or upper level), the course instructor (co-author, Miroslav Lovric) decided to find out where these students end up. The fact that students from almost every faculty had to take Math 1A3 (with the exception of engineering students) allowed for a cohort analysis of success in the course. Analysis has been done on several occasions, and in all cases gave almost identical results. In particular, in fall term 2007, the average (mean) of class tests in Math 1A3 for all students was 69%. The highest achieving students were from the Bachelor of Health Sciences program,[5] whose average was 90% (in other words, an *average* student in this program, according to McMaster University grading policy, achieved the maximum course grade!). Science and business students followed, with averages of 70% and 69% respectively. Social sciences students' average was 59%, and, at the bottom, humanities students with average mark of 51%. Furthermore, evidence from maths competitions held at McMaster University in the last 15 years, as well as anecdotal evidence, suggest that a certain number of good mathematics students pursue studies in engineering. For instance, the winner of the 2007 McMaster University mathematics competition was a group of students majoring in electrical engineering. So, it seems that many students who are good at mathematics 'self-select' out in favour of fields such as medicine, computer science, or engineering. However, some do continue taking mathematics courses, even though they are not required courses in their programs of study. When asked for a reason, many of them imply, in one way or another, that it is because they like math.

The phenomenon of 'self-selection' out of mathematics could be identified among mathematically gifted female students as well. Recent research [14,15] shows that, on average, women who are good at mathematics also possess strong verbal abilities; the verbal skills of men who are good at maths are not nearly as strong. Consequently, the career options for mathematically gifted female students are wider than for male students, and it seems that female students do exercise their freedom, opting for areas such as medicine, biological sciences, humanities, and social sciences [14]. Further to this, mathematics has been traditionally seen as an overly competitive discipline, something that females tend to dislike and, consequently, stay away from [15].

6. Epilogue

Our survey shows that recruitment and retention are not at the top of the agenda in many mathematics departments across the country. However, we found that there are activities, organized at every university that was represented in our survey, that could be interpreted as efforts aimed at increasing numbers of mathematics students. The case of Brock University [2] shows that systematic, carefully designed, long-term efforts could be quite successful (our survey did not manage to capture responses from all universities in Canada, so there could be other success stories we are not aware of). On average, the number of students entering mathematics programs seems to be stabilizing at the moment, meaning that the graduation rates in the near future will be close to the 2005 numbers presented in Figure 1.

Can we do better? Say, if we double the efforts at recruitment? The answer is not at all straightforward, as it depends on many complexities outside mathematics that characterize the social and cultural landscape in Canada (and in the whole world) in the first decade of the 21st century. Some we touched upon in the 'Discussion' Section:

- Careers. Well-wishing, but unclear and misleading promotional campaigns could create serious misconceptions about jobs in mathematics.
- Promotion of mathematics and science. The image of mathematicians and scientists, and the message of importance of what they do need to be enhanced.
- Students and parents do not place learning mathematics and science subjects near the top of their concerns about education.
- Emergence of biology as a major source of applications in mathematics. We might be forced to redefine what 'applied' in 'applied mathematics' stands for.

- Self-selection out of mathematics. Some of the best and brightest maths students decide to pursue other interests, either as a field of study or as a future career.

It might well be that we are not even aware of the forces that will shape mathematics and its teaching and learning in the decades to come.

Notes

1. Black–Scholes model was created in 1973 by Fischer Black and Myron Scholes, and then further developed by Robert Merton. Scholes and Merton received the Nobel Prize in Economics for it in 1997 (Black died in 1995).
2. We will not analyse the reasons for this here. Perhaps the low response rate indicates that retention and recruitment are not at the top of agenda for some mathematics departments in Canada. Of course, a number of other factors could have influenced a person's decision not to fill in our survey.
3. www.math-jobs.com; based in Switzerland, the site covers maths job markets worldwide; contains database of maths jobs searchable by country, category (banking, statistics, computing, technology, teaching, academic), etc.
4. Due to the absence of similar surveys in Canada we decided to use this one, which was conducted in the US. The findings are based on phone interviews with a nationally random sample of 1342 public school students in grades 6 to 12, and of 1379 parents of children in public school. The survey was organized and analysed by Public Agenda, a public opinion research group that tracks education trends.
5. This program prepares students for a career in medicine, either as practitioner (e.g. physician – of course, medical school is required or nurse), or researcher (e.g., academia, pharmaceutical industry).

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Appendix: Copy of the survey that was used (note: original CMS survey contains the first 5 questions)

Recruitment and retention of math majors in Canadian universities

(1) For the last five years, the enrolment trend of mathematics majors and co-majors in your department has been generally [circle one] increasing, the same, decreasing.

(2) In your opinion, for the last five years, the enrolment trend of mathematics majors and co-majors in your department relative to the total enrolment at your university has been generally [circle one] increasing, the same, decreasing.

(3) In the last ten years, and in the first two years of undergraduate studies, has your department made any substantial changes to its core mathematics courses for majors and co-majors? [circle one] yes, no. *If yes, for each course, please provide year of implementation, and brief comments* (*course description* (*or course number with URL*) *admission requirements, teaching approach, etc.*)

(4) In the last ten years, and in the first two years of undergraduate studies, has your mathematics department implemented any new Service Courses in mathematics? [circle one] yes, no. *If yes, for each course, please provide a brief description* (*or a course number with URL*), *indicate for whom it was designed, and some comments on student enrolments.*

(5) In the last ten years, has your mathematics department implemented any new ways to boost its retention rates of mathematics majors? [circle one] Yes, no. *If yes, please provide a brief description of these initiatives and their impact on retention rates* (*ex. Grants, scholarships, introduction of a coop program, interesting courses, change in advertising, interdisciplinary programs, cross listed courses, other opportunities*)

(6) Have there been any efforts in your university to boost its recruitment rates from high school? If so, please briefly describe these efforts. (ex. High school outreach, high school visits, promotional events, science/math Olympics, advertising efforts, special purpose introductory courses)

(7) Have there been any efforts in your university to boost its recruitment of students from other departments in your university? *If so, please briefly describe these efforts.*

(8) Can you identify strategies your department has found effective in recruiting/retaining/attracting students to (in) mathematics?

(9) Can you identify any activities within your department which are specifically aimed at discussing issues of recruitment of mathematics students from high school or from other departments in the university? (i.e., departmental meetings) What is the level of interest within your department on issues of recruitment? [circle one] low, medium, high.

(10) Can you identify any activities within your department which are specifically aimed at discussing issues of retention of mathematics majors? (i.e., departmental meetings) What is

the level of interest within your department on issues of retention? [circle one] low, medium, high.

(11) Identify some reasons you think mathematics students at your university decide to leave the program and switch to another program. (Course offerings, courses perceived to be difficult, quality of teaching, length of the program, class size, flexibility in program). Identify some reasons you think students at your university choose not to enter the mathematics program. (perception of difficulty, entrance requirements, job opportunities)

(12) What kind of data is available in your university about recruitment and retention? What is a good way to get this information? Can you provide a contact for this information?

(13) What is your perception of the overall quality of teaching in your university's mathematics department? To what extent do you think this contributes to attrition rates?

(14) To what extent do you feel you are satisfied with the quality of your mathematics students? What, in your opinion, is the impression your mathematics graduates have about the program at your university? (difficulty level, feelings of reward, etc.)

(15) Please briefly comment on issues of recruitment and retention in the MSc and PhD mathematics programs at your university.

(16) Please feel free to comment on any issues/situations that you might want to mention, that have not been captured (or not captured adequately) in our questions.