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MEMORANDUM

ATTENTION	Senate	**DATE**	October 8, 2014
FROM	Jon Driver, Vice-President, Academic and Provost, and Chair, SCUP	**PAGES**	1/1
RE:	Faculty of Science: External Review of the Department of Mathematics (SCUP 14-25)		

At its September 24, 2014 meeting, SCUP reviewed and approved the Action Plan for the Department of Mathematics that resulted from its External Review.

The Educational Goals Assessment Plan was reviewed and is attached for the information of Senate.

Motion:

That Senate approve the Action Plan for the Department of Mathematics that resulted from its External Review.

c: M. Trummer
C. Cupples

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MEMORANDUM

ATTENTION	Jon Driver, Chair, SCUP	**DATE**	September 16, 2014
FROM	Gord Myers, Associate Vice President, Academic	**PAGES**	1/1
RE:	Faculty of Science: External Review of the Department of Mathematics		

Attached are the External Review Report, the Action Plan, and the Educational Goals Assessment Plan for the Department of Mathematics.

Excerpt from the External Review Report:
"The SFU Mathematics Department is performing its research and education activities at a high level and would be widely regarded as (easily) one of the top 10 research departments in mathematics in Canada."

Motion:

> **That SCUP approve and recommend to Senate the Action Plan for the Department of Mathematics that resulted from its external review.**

Following the site visit, the Report of the External Review Team* for the Department of Mathematics was submitted in March 2014. The Reviewers made a number of recommendations based on the Terms of Reference that were provided to them. Subsequently, a meeting was held with the Dean, Faculty of Science, the Chair of the Department of Mathematics and the Director, Academic Planning and Budgeting (VPA) to consider the recommendations. An Action Plan was prepared taking into consideration the discussion at the meeting and the External Review Report. The Action Plan has been endorsed by the Department and the Dean.

SCUP recommends to Senate that the Department of Mathematics be advised to pursue the Action Plan.

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*External Review Team:
- Pamela Cook, University of Delaware (Chair of Review Team)
- Nathan Kutz, University of Washington
- Bruce Shepherd, McGill University
- Richard Lockhart (Internal), Simon Fraser University

Attachments:
1. External Review Report (March 2014)
2. Department of Mathematics Action Plan
3. Department of Mathematics Educational Goals Assessment Plan

cc Claire Cupples, Dean, Faculty of Science
Manfred Trummer, Chair, Department of Mathematics

External Review of the Mathematics Department at Simon Fraser University:

Pam Cook (University of Delaware),

Nathan Kutz (University of Washington),

Bruce Shepherd (McGill University)

3/14

The review committee conducted an on-site review of the Mathematics Department at Simon Fraser University (SFU) February 19-21, 2014. The committee appreciated the fact that the visit was well organized and that all parties were forthcoming and welcoming. The report, below, is presented in two parts: the first portion addresses overarching (University) or immediate issues; the second part addresses departmental issues and those questions, not already addressed, posed by the department and the university.

The SFU Mathematics Department is performing its research and education activities at a high level and would be widely regarded as (easily) one of the top 10 research departments in mathematics in Canada. This is despite a much lower headcount than competitors such as UBC or Toronto. Sensibly, the department has evolved to focus on only a few (strong) research groups: Applied Math, Discrete Math, Computational Number theory and Algebra, each of which would be (again easily) in the top 5 in Canada. In addition there is a strong and highly motivated group of teaching faculty with a bent towards carrying out research in the learning of mathematics. The departmental staff have taken a leadership role in working creatively to broaden their responsibilities overall in support of the department's mission. Individual staff portfolios have been re-organized to put back-ups in place for each task, while still allowing for an efficient work flow. Faculty/staff relations appear excellent.

University Issues

Performance-based Budgeting

There is real concern that the new budgeting approach (dollars follow students) could lead to a practice of poaching as other units see an advantage to taking over courses typically offered by the mathematics department. This approach has the potential for negative side-effects (for everyone) if not managed. Ultimately, it is critical that SFU as a whole be incentivized in such a way that departments are not discouraged from working with each other. Already, there is talk of engineering and physical sciences offering very similar courses to those being offered in mathematics and/or statistics. This cross college competition for student credit hours, if left unchecked, will promote an unhealthy and un-collegial atmosphere at SFU that will ultimately reflect poorly on both departments and the administration. A strategy set up by the Deans and Provost to incentivize cross-college and cross-departmental efforts could go a long way to maintaing a healthy balance.

On the flip-side, given that Mathematics provides teaching of many large service courses, it is worth their keeping an ear (and door and mind) open to ensure their courses are up to date for students in other faculties. For some courses, it is worth reaching out to a few key people in other departments for discussions.

The Surrey Campus and Operations Research (OR)

Faculty at Surrey, especially the two instructors, are generally positive about the vision of SFU-Surrey to play a central role in delivering higher-level education to the growing number of students south of the Fraser. The OR group presented encouraging numbers about how far they have come since the inception of their presence on the Surrey campus. Perhaps most significantly the data showed both a growing number of undergrad students in Math service courses, as well as improving performance metrics indicating that Surrey students are basically at par with Burnaby counterparts (in mathematics).

The separation of the OR group from the home department nevertheless is problematic and likely punitive to the faculty whose research is most mathematically inclined. It is also a disservice to the graduate students who are isolated from their peers, and to the courses and interactions which involve the Burnaby campus. Until SFU is ready to invest more resources to bolster the program, it seems ill-advised to allow a sense of exile to creep in. Having a small group of faculty, a small program, at a remote site is not a positive situation for the program or for the department. Drawing all members back to Burnaby would however make the SFU Math presence on the Surrey campus less viable and more vulnerable. Based on our short visit, but after many hours of conversations, we propose:

- Allow faculty to make an application to be re-based at Burnaby and to be approved or denied within the current academic year (to take place the following year).
- Returning faculty may still be held accountable for teaching responsibilities in the OR program. (Please see the three bullets below on how this might effectively be done).
- To assist cross-campus courses we propose the introduction of a wifi-enabled telecommuter bus. The idea should be to allow people to walk 5 minutes from their office and sit down and work uninterrupted until arrival at Surrey Campus. Such infrastructure is common at many universities and research facilities (e.g. Harvard, Cornell, Microsoft) where distance plays a role on the campus and people's time is of premium importance. This is the only reasonable way to encourage faculty to make the commute between campuses, especially as the commute back and forth takes a minimum of 1.5 hours of the day. Provided such a work environment can be established, then the connection and integration between the Surrey/Burnaby campus is tenable.
- Further expand/improve/incorporate online AV-setups for the delivery of courses from and to the Burnaby Campus. Such a solution is low cost and could be implemented almost immediately. The equipment is readily available and at reasonable prices. This would allow students and faculty to more naturally integrate the "shared classroom" (part of which is the physical teaching space in either campus, and the other is where the lectures are broadcast live). Students, although online at the other campus, could interact with the professor almost

as easily as if they were sitting live in class. Seminars and lectures can similarly be broadcast in this fashion, extending the technology far beyond its initial teaching infrastructure solution.

- Consider establishing a Professor in Residence position such that a faculty member from the Burnaby campus would spend a semester, or more, on the Surrey campus teaching. The Position would come with some perk (e.g., a reduced teaching load for one year on return to the Burnaby campus) but would allow for better integration of the two campuses and a committed faculty presence on the Surrey campus.

We noted the uneven distribution of graduate student supervision within the OR program. The program would be healthier if this could be evened out. This uneveness is due to the lack of critical mass in OR research faculty and the isolation of its faculty. If these numbers are not expanded other solutions should be considered.

<u>Space</u>

We note that Burnaby is, primarily, a commuting campus. Additionally, with the three semester system, there is no "cohort" of undergraduate students. Such a campus presents unique problems for student engagement and loyalty. In particular, we noticed a recent issue of *Maclean's* which reported on surveys of student "loyalty" to their undergraduate institution. Disappointingly, among those schools listed, SFU ranked close to last. On this type of campus, a commuter campus with students opting in and out in various semesters, it is even more critical to have a welcoming and usable undergraduate student lounge where students can meet, can work together, and can form a community. This space might include several computers, brochures on jobs, on summer undergraduate research opportunities, on the co-op program, as well as work space.

The fact that graduate students are dispersed across campus was generally understood to have a negative impact. The students themselves were most emphatic about this point.

Space is a premium on any campus. Typically departments are subject to space allocation issues that span across decades of growth and/or decline of units, thus often imposing awkward historical constraints on the optimal use of space. However, the space as currently assigned is having a significant deleterious effect on both students and faculty alike. We strongly recommend that the Dean and Provost investigate a more constructive way of assigning space, perhaps trading spaces with other units. This could allow not only mathematics, but other units as well, to build a strong community of scholars. This issue has seemingly been neglected despite the known negative effects on the program.

Department: Groups and Centers

The department has divided itself into three groupings: the applied math group, the operations research group (on the Surrey campus) and the "rest of math". The latter nomenclature refers to pure mathematics, which includes the group in graph theory. The department has three Canada Research Chairs, two in applied math and one in graph theory; this is a solid number for the department's size. In addition, the department has done well on winning NSERC Accelerator awards. This is indicative of a strong research department.

For a department of this size, keeping three disparate research/graduate programs healthy is a sizable task. Stronger interaction within groups, between groups, and with the rest of the university should be continually encouraged for a healthy climate. Students would be well-served if they are exposed to a broader palette of courses throughout the department and the university. We urge the department to consider its strengths, the university's strengths, and where other mathematics departments are headed, and use this information to create a 5-10 year strategic plan for hiring which is proactive and which builds on their strengths. The current departmental hiring priorities span the gamut and do not focus on SFU and opportunities for growth for the SFU geographic location.

Applied Math

This group has had a long-standing reputation for excellence in the department for several decades. They have hired a strong group of young faculty who have done very well in upholding the reputation of the group. Indeed, the applied mathematics group continues to enjoy a strong national and international reputation. In comparison with Canadian universities, it is perhaps one of the top three applied math groups in the country. Much of the focus of this group is on numerical analysis and scientific computing methods for ordinary differential and partial differential equations. Around this theme, the group has developed a highly collegial and harmonious effort. Of the three main groups in the department, applied math is by far the most cohesive in their thinking, having developed a core set of courses for their students which reflects the overall mathematical philosophy of the group.

Given their success, the committee recommends that the applied mathematics group begin a process of thinking about their future and how to capitalize on their strength and strategic initiatives in the mathematical sciences. It was our impression that the group did not have much of a strategic plan aside from replacing retirements with people who looked very much like them. Given that the numerical analysis and scientific computing of PDEs is quite well established, it could be that this is an ideal time to delve into new areas to balance and broaden their portfolio of applied mathematics. Said another way, their viewpoint of applied mathematics was quite narrow in many regards, especially given all the fantastic developments happening in applied mathematics more broadly defined.

External interactions are typically a hallmark feature of strong applied mathematics departments. We learned of interesting research collaborations between the group and industry. This activity has also supported the training of some of their graduate students. The committee was expecting to hear more, however, about applied mathematics having a deeper integration, impact and collaboration with members of the scientific community at SFU. Given SFU's strength in the engineering, physical, and biological sciences, we think the applied mathematics group could take further advantage of the opportunities afforded by their scientific colleagues. Such engagements would ultimately be highly beneficial to the department and to SFU more broadly.

Pure Math

This group has a strong emphasis in discrete math with a core strength in graph theory. The discrete math group could possibly rank 3^{rd} in Canada. This is confirmed not only by the quality of the journals in which faculty publishes, but also the quality of the graduate program and their associated NSERC funding levels. Apart from their strength in graph theory, a second strong research theme is the group working under the umbrella of CECM (discussed later).

We found it ironic that our draft itinerary used the term ``Rest of Math" for meeting the overall ``Pure Math" group. While this suggested a jovial perspective, most members of the group expressed a desire for a more unified vision for the pure math graduate program, more in line with the applied mathematics program.

An ideal state would ensure that each member of the group gives a graduate course in an area of their expertise at least once every second year. Such a palette of ``flagship courses" could potentially attract the interest of graduate students in the department and university more broadly if course outlines are balanced accordingly. This would also allow student to sample a broader array of courses at the graduate level, and keep overall enrolments and enthusiasm high. This approach may require students to back off occasionally from delving into their own research programs, but would give them broader perspective. In addition, the quality and diversity of the researchers involved, means graduate students would be exposed to a wider spectrum of techniques which could actually be brought to bear on their research program. Supervisors hopefully would encourage this approach of sampling courses (perhaps even more than the requirements) realizing this ultimately makes students more marketable at graduation.

Teaching Faculty

We were greatly impressed with the systematic approach of the group and the strong research presence on the learning of mathematics. The fact that such a group is housed within a Department of Mathematics is a huge asset for the department and SFU. It should continue to be fostered. Apart from individuals handling their responsible courses, and their research output, the group's activities have other benefits.

- Their course workshops provide a support framework to lighten the load for other faculty involved by centralizing work. This also provides a defacto prep-course for new grad student sessional lecturers (at least for courses with an associated workshop).
- Their two online courses also act as a (unique) foray (peek) into the world of MOOCs. Such delivery mechanisms are under evaluation at most top universities. The Surrey-Burnaby split actually represents another opportunity to experiment with the technology of online delivery – also see our comments under IRMACS.
- The group is obviously invaluable in terms of outreach generally, but we were especially impressed by their one week teacher summer camps. We believe there is a significant opportunity for a more substantial professional degree or accreditation here. Anyone who has a child doing elementary or high school math would likely agree. How to turn a summer camp

into a short course where teachers (or government) are willing to bear the tuition cost is obviously a challenge. We believe the added value is there however, so it is worth thinking of ways for it to be monetized.

Centers

As the last external evaluation report, we strongly recommend the continuation of the investment and support of SFU for Pacific Institute of Mathematical Sciences (PIMS). In addition to local activities such as distinguished lectures and schools, PIMS also provides competitive funding for graduate students, post-doctoral fellows and collaborative research groups. It also gives a critical mass for mathematical research in the West (including Alberta, Saskatchewan and Washington State) to act as a counter-balance to traditional strength in Eastern Canada and the US.

Since the last site visit, MITACS has moved head offices to UBC and seems to continue to expand its role in taking mathematical (and beyond) pursuits downstream into Canadian companies. The connections between SFU and MITACS are obviously very strong and should be maintained if not only because together with co-operative education it is an organization which provides a clear path to non-academic pursuits of highly trained mathematicians.

IRMACS

IRMACS is a university resource in which the department holds a membership. It appeared to us that the burden of the center falls on mathematics and that the university has not supported the center in strongly investing in its success. We were not specifically asked to evaluate IRMACS, but we learned enough to believe that it has potential for even greater things given the right leadership and support. The university should work with the center in creating a viable budget model for the center.

The physical space provided by the center is excellent; we certainly enjoyed carrying out our meetings there. With the CFI funds being exhausted, it remains a question of how to sustain the center for the long-term without diluting its mission and promise. As discussed in the section on the Surrey campus, IRMACS could also be a key unit in providing a more seamless delivery of courses offered at Burnaby but attended by students in Surrey (or vice versa). Indeed, the IRMACS space had almost all the high-tech video and connectivity software required of an on-line teaching space. Scaling up such a system seems almost mandatory for the success of the new campus.

Two comments regarding IRMACS:

- We feel that it is imperative that a leader, capable of advocating for IRMACS and of reaching out to partners, be sought to carry forward this important work for SFU.
- On the Department's list of concerns and questions a question was asked regarding whether the department should more actively explore Industrial Chairs. IRMACS could be useful in terms of attracting such a chair, and a recipient should in turn be useful for defining the vision for the center.

Center for Experimental and Constructive Mathematics (CECM)

CECM's mandate is to explore and promote the interplay of conventional mathematics with modern computation and communication in the mathematical sciences.

The center works nicely to tie together faculty (most or all of whom have some bent towards computation) working in discrete mathematics, number theory and algebra. The center makes good use of its space by offering facilities to grad students (7 of which are associated with CECM), summer research projects, and visiting faculty. The CECM offices are where most of the action occurs for summer students on these research topics. It boosts their productivity to be working together in close quarters. This culminates in the (CECM-founded) summer research poster session in August, which has now expanded to become the "Symposium for the Mathematics of Computation".

- We felt the facilities of CECM could be used to further advantage in future outreach events sponsored by the Dept. Much of the research performed here can be visualized and made accessible to a broad audience.
- The CECM keeps an open door policy to faculty throughout the school, and has been supported by its consulting efforts in the past (perhaps most notably to MAPLE). Given the expertise of members, pursuing further such links is an avenue to consider. For instance, it is not hard to imagine fruitful collaboration between members of the group and anyone on campus with large integer programming problems

Teaching

Graduate Program

Overall the graduate program of the department has done well, especially considering the lower emphasis placed on graduate studies by the British Columbia Government relative to say Ontario or Quebec. This means that the program size is primarily capped by the departmental NSERC funding levels (although some faculty may be at capacity in terms of supervision).

Two key issues were problematic for the graduate students: space and, for one group, the qualifying exams. The space issue has been alluded to earlier. The students are simply spread out across the campus and there is no community around mathematics for them. An important part of graduate school is to have a community whereby students can learn more broadly what others are doing. This also enables students to use their peers as key resources in their professional and intellectual development.

The qualifying exams of the "pure" group need restructuring as the students (and the faculty) uniformly thought the current setup is not good. Faculty may wish to discuss alternatives with the students in order to improve the overall experience.

Undergraduate Programs

We applaud the fact that the department now has a student advisor who is working to better understand and link to the students. We think it is critical to track the students – in particular to have clear data on where the students go after graduation. This may suggest better or new programming for the department. The department report mentions the "borrowed" space that the current advisor uses; a more permanent (accessible and visible) space solution must be found for the advisor.

Modern employers of math graduates are often interested in quantitative skills, particularly computing. With this in mind it is worth exploring whether more students should be in a Math/CS major. Other joint majors that have been successfully instituted at other universities are Math/Economics, Quantitative Biology (math and biology), and Math and Statistics. Creation of joint majors might not only increase the number of majors, but also increase the interactions between mathematics and other departments.

The university and the department should bolster their efforts to attract students to the co-op stream of mathematics. This is an ideal program for connecting students with mathematical skills to employers with problems which require them.

We are encouraged by the information that SFU has changed the requirement for an Honors degree from being punitive (extra credits) to requiring an equal number of credits to that of a normal degree. This should allow for an increase in the number of honors students. We encourage the university to think of an honors degree as a university honors degree so that students can take "honors" courses in other departments. It would be beneficial to the department, and SFU more broadly, to build an honors cohort of students, some of the most stellar students at SFU and worthy of some investment. Ideally, such a cohort might have a dedicated space in the mathematics department and would be targeted at an early stage for research opportunities across the department.

In some cases faculty should consider slight modifications to courses that would make them more accessible to students from other departments (and vice versa math students be encouraged to take extra-departmental courses, most notable in CS). Obviously such an exercise can be a delicate balance between designing a course with broader appeal versus dilution of core mathematical content. Changes might be as simple as changing the title, or updating content to occasionally highlight applications of mathematical techniques within the lectures. We note that the department report refers to: calculus courses as "dull service courses" that should be looked at. We are encouraged that the department, in order to boost the number of minors, has introduced new courses (302,3,4) with titles such as "Computing with Mathematics: The Mathematics of (mostly Olympic) Sport" which have attracted 50-75 students (and one, 303 has a wait list.) As pointed out, this not only increases the number of students enrolled in math, increases the math awareness of a number of students, but also has "given faculty an opportunity to do something different." We applaud this effort.

Educational Objectives and Learning Outcomes

The department is on the beginning of assessment. Learning objectives for service courses and overall educational objectives for the majors have been mapped out. The latter appear in the self-study report and are sensible. In addition each program provides more detailed objectives. The plans to evaluate the overall objectives are being developed and are ambitious but hopefully realistic and not too onerous; administration should keep an eye open that this review process is streamlined and does not end up taking more time than it is worth. Other departments have developed assessment plans and the department would benefit by investigating those for best practices in order to avoid "recreating the wheel".

Other

Salaries

There is no denying that Vancouver is a wonderful city, but the SFU salary levels are low (and the pay raise structure complicated). Some of these salaries may have looked competitive even 10 years ago, but given the housing market there is a completely different reality on the ground. UBC salaries are evidently higher, and UBC has introduced a more competitive housing assistance program.

We cannot comment on the reasons for recent departures, but we can say that those departures do represent a significant loss of talent. Although the reasons for anybody leaving are complicated and involve a variety of professional and personal reasons, the low pay at SFU will ultimately make it very easy for faculty to weigh their options given any incentive to do so. If salaries can't be upgraded, at the minimum, better faculty assistance programs (housing assistance, or university owned housing options, for example) should be instituted.

Appendix A - Summary of Recommendations

Appendix A

SFU Summary of Recommendations
(addendum to the 3/14 report of the external evaluation of the Mathematics Department).

1. The Surrey Campus and Operations Research (OR)
   - Allow faculty to make an application to be re-based at Burnaby and to be approved or denied within the current academic year (to take place the following year).
   - To assist cross-campus courses we recommend the introduction of a wifi-enabled telecommuter bus.
   - We recommend the university expand/improve/incorporate online AV-setups for the delivery of courses from and to the Burnaby Campus.
   - We recommend the university consider establishing a Professor in Residence position such that a faculty member from the Burnaby campus would spend a semester, or more, on the Surrey campus teaching.

2. Space
   - We recommend creation of an undergraduate student lounge. Ideally, contiguous to this space, "permanent" housing for the student advisor.
   - We recommend the geographic unification of the graduate students' offices.
   - We recommend that the Dean and Provost investigate a constructive way of assigning space, perhaps trading spaces with other units.

3. Department:
   - We recommend the department (with an eye to considering its strengths, the university's strengths, and where mathematics opportunities are today) create a 5-10 year *proactive* strategic hiring plan.
   - We recommend the "pure" math group re-consider its graduate course offerings and requirements in order to offer a wider spectrum to the students, and to better use the expertise of the faculty.
   - We recommend consideration of creation of joint majors to attract and better prepare students (math/cis for example).
   - We recommend financial support for honors students for summer undergraduate research.

Centers

- We recommend the continuation of SFU's financial support for the Pacific Institute of Mathematical Sciences (PIMS) and for MITACS.
- We recommend that a permanent leader, capable of advocating for IRMACS and of reaching out to partners, be sought to carry forward this important work for SFU.

Salaries/Retention

Faculty salaries and any raises available should be clarified and if possible upgraded. If this is not possible, then at the minimum, we recommend better faculty assistance programs (housing assistance, or university owned housing options, for example) be instituted.

EXTERNAL REVIEW – ACTION PLAN

Section 1 – To be completed by the Responsible Unit Person e.g. Chair or Director			
Unit under review MATHEMATICS	**Date of Review Site visit** Feb 19-21, 2014	**Responsible Unit person** Manfred Trummer	**Faculty Dean** **Dr Claire Cupples** ....

Notes

1. *It is **not** expected that every recommendation made by the Review Team be covered by this Action Plan. The major thrusts of the Report should be identified and some consolidation of the recommendations may be possible while other recommendations of lesser importance may be excluded.*
2. *Attach the required plan to assess the success of the **Educational Goals** as an addendum (Senate 2013).*
3. *Should any additional response be warranted, it should be attached as a separate document.*
4. *[Recommendation Am.n, and page x]: refers to External Review report, Appendix section "m", bullet point "n", "page x" to the appropriate page in the main part of the report.*
5. *Italic underline blue font: Quotes from the external review report.*

1. PROGRAMMING

1.1 Action/s (description what is going to be done):

1.1.1 Undergraduate:

- **Industrial Math Program (i.e., Operations Research, OR) in Surrey.** *["Allow faculty to make an application to be re-based at Burnaby and to be approved or denied within the current academic year (to take place the following year)." Recommendation A1.1, and page 2]* The department will investigate the advantages and drawbacks of bringing this program to the Burnaby Campus. If the department recommends moving the program to the Burnaby Campus, we will bring forward a proposal. Proposal by April 2015.
- **Joint Major programs.** *["We recommend consideration of creation of joint majors to attract and better prepare students (math/cs for example)." Recommendation A3.3, and page 8]* Discussions have started with Economics on a joint ECON/MATH major. We intend to collaborate with the Department of Statistics and Actuarial Sciences on creating a joint MATH/STAT major. If successful, programs should go into calendar by December 2015.
- **Honours program.** *["We recommend financial support for honors students for summer undergraduate research." Recommendation A3.4, and page 8]* The department is redesigning its honours program. The new requirements will include a project component. Summer term research opportunities that already exist for our top students would naturally provide content for such projects. April 2015, First cohort to start under the new program in Fall of 2015.
- **Review and tweaking of undergraduate course content.** *["In some cases faculty should consider slight modifications to courses*

that would make them more accessible to students from other departments" - ***page 8, last paragraph of "Undergraduate Programs]*** **In addition to a general review suggested by the committee we have proposed an initiative where we consult home departments of our service course students to integrate examples from courses in their program into our service courses. Spring 2016 (and ongoing).**

1.1.2 Graduate:

- **Pure Math Graduate Program.** *["We recommend the "pure" math group re-consider its graduate course offerings and requirements in order to offer a wider spectrum to the students, and to better use the expertise of the faculty." Recommendation A3.2, and page 5]* **A faculty committee will review and update course offerings and degree requirements for the pure math graduate degrees. March 2015.**
- **Pure Math Grad Qualifying Exam.** *["The qualifying exams of the "pure" group need restructuring as the students (and the faculty) uniformly thought the current setup is not good. Faculty may wish to discuss alternatives with the students in order to improve the overall experience." Recommendation A3.2, and page 7]* **A committee of two including the pure math graduate program chair will propose modifications to the current exam format, or a new exam format. March 2015.**
- **M.Sc. for High School Teachers.** *["...we were especially impressed by their one-week teacher summer camps. We believe there is a significant opportunity for a more substantial professional degree or accreditation here." page 5]* **Teaching faculty are looking into redeveloping a previously submitted proposal for an M.Sc. directed at Math teachers, and will bring a proposal to the department. Likely a hybrid on-line and class based course, with class meetings on Saturday. Proposal by September 2015.**

1.2 Resource implications (if any): **Bringing the OR program to the Burnaby Campus would likely go hand-in-hand with all or most of the Surrey based research faculty members moving to Burnaby. This requires office space for faculty members and graduate students. Without space commitments, such a move is not feasible. A consequence might be the need for another lecturer position in Surrey. The external review mentioned a "Faculty in Residence" program for Surrey, which would also carry some cost. For the review of course content in our service courses we feel that this could best be handled as part of a Limited Term Lecturer Position. The M.Sc. program for High School Teachers is expected to recover cost.**

1.3 Expected completion date/s: listed above

2. RESEARCH

2.1 Action/s (what is going to be done):

- **The Department will work on a strategic research and hiring plan with a five to ten year horizon.** *["We recommend the department (with an eye to considering its strengths, the university's strengths, and where mathematics opportunities are today) create a 5--10 year proactive strategic hiring plan." Recommendation A3.1, and pages 4- 5]* First draft by December 2014, plan by March 2015. The department feels that our current hiring plan is a good basis. It remains a departmental priority to hire candidates who show excellence in their field, who have a high level of interest in teaching, and who will make good colleagues.

2.2 Resource implications ((if any):

No resource implications for the plan, but there will be for the implementation.

2.3 Expected completion date/s: First draft by December 2014.

3. ADMINISTRATION

3.1 Action/s (what is going to be done):

- **"Faculty exchanges" between Surrey and Burnaby.** *["We recommend the university consider establishing a Professor in Residence position such that a faculty member from the Burnaby campus would spend a semester, or more, on the Surrey campus teaching." Recommendation A1.4, and page 3]* This is an excellent suggestion in the external review report. The department will propose such a program. It touches on workload issues, so the plan will need the Dean's approval. December 2014.
- **Academic Advising.** *["We applaud the fact that the department now has a student advisor who is working to better understand and link to the students. We think it is critical to track the students – in particular to have clear data on where the students go after graduation. This may suggest better or new programming for the department. The department report mentions the "borrowed" space that the current advisor uses; a more permanent (accessible and visible) space solution must be found for the advisor." page 8]* The review report commended the department for creating this position. The scope of this position has expanded considerably. The incumbent is involved in a host of teaching related and outreach activities. Our department serves thousands of

students (about 10000 course enrollments per year), and we have a host of initiatives aimed at improving learning outcomes for struggling students, while trying to offer more challenging options to our top students. The department wants to review our current set-up, change the job description of the Advisor position to more accurately reflect the scope of the role in our department, which goes beyond traditional advising. Detailed proposal by December 2014.

3.2 Resource implications (if any):

- **"Faculty exchanges":** Workload implication of one course per year per exchange, a total of two courses. Implication for the sessional budget roughly $16,000 per year.
- **Academic Advising.** Our proposal may ask for extra staff resources, or result in a new type of instructional coordinator position at possibly a higher classification. Cost of APSA position reclassification.

3.3 Expected completion date/s:

WORKING ENVIRONMENT

4 N/A

4. SPACE *(OTHER)*

5.1 Action/s:

"We recommend creation of an undergraduate student lounge. Ideally, contiguous to this space, "permanent" housing for the student advisor. We recommend the geographic unification of the graduate students' offices. We recommend that the Dean and Provost investigate a constructive way of assigning space, perhaps trading spaces with other units." Recommendations A2.1 (as well as A2.2 and A2.3).

Individual office space: *[--related to Recommendation A1.1, A2.1, and page 3]* Split AQ 4100 (current Q-Workshop) into 5 individual offices. This will allow us to create office space contiguous to our K10500 hallway. If a temporary home for the Q-workshop can be found, completion by December 2014 or April 2015 is possible.

- **Math Student Support Centre in WMC.** *[page 8]* Proposal to create a student learning hub in WMC, featuring two workshops, one computer lab, and an open collaborative space. April 2015, ready for use for summer 2015 term.
- **Student Lounge ("Math Hangout").** *[Recommendation A2.1, and page 3 and 8]* We are proposing to designate the open study space west of our Algebra Workshop (AQ4135) as a "Math Hangout", open to all students, encouraging students to engage with each other, and as a meeting point for working together on math homework assignments. There is a precedent for this sort of arrangement at the Beedie School of Business. December 2014.
- **Math Student Union Lounge.** *[Recommendation A2.1]* The current space is shared between Math (MSU), Statistics and OR students. It would be nice to open up this space more and make it more inviting, for example by replacing some of the west wall with a glass wall. Proposal for a minor "face-lift". December 2014.
- **Geographic unification of graduate student space.** *[Recommendation A2.2, and page 11]* It is difficult to imagine a solution to this problem within existing buildings at SFU. One idea is to add another level to the Math/Stats wing of SCK; clearly this would be a major capital project requiring significant financial resources. No specific date, something to keep in mind for a longer time horizon.

5.2 **<u>Resource implications (if any):</u>** For the "Math Hangout" minor cost for furniture and possibly some screens for collaboration. The WMC space renovation will likely cost around $1,000,000. Conversion of the Q-space: $120,000. MSU Lounge: $15,000. Major building project would be in the 8-10 Mio Dollar range (IRMACS was about 6 Mio$).

5.3 **<u>Expected completion date/s:</u>**

The above action plan has been considered by the Unit under review and has been discussed and agreed to by the Dean.

Unit Leader (signed)	Date
Name ...Manfred TRUMMER... Title......Dept Chair.....	**......June 16, 2014.........**

Section 2 - Dean's comments and endorsement of the Action Plan:

In general, the Review Team has done an excellent job of identifying the main challenges facing the Department of Mathematics, and the department has developed a thoughtful response. I support the direction that the department is taking, and look forward to helping it continue on its successful trajectory.

Two of the biggest issues facing the department are the lack of space on the Burnaby campus and the future of math service teaching and math programs on the Surrey campus. The two problems overlap. I am committed to working with Math on the design and financing of additional teaching and workshop space at Burnaby, and on the expansion of desperately needed office capacity. Additional office space will facilitate the move of Surrey-based faculty to Burnaby if the department chooses that option. It is unfortunate that the department is spread out in so many buildings at Burnaby, but there does not seem to be any alternative at this point.

I believe that the department itself is best placed to decide whether or not to relocate the Operations Research program to Burnaby from Surrey. Math service teaching at Surrey could be done by non-research faculty, as is the case with other Science departments, recognizing that there are plusses and minuses to such a solution. Of course, the final decisions may hinge on the University's choices regarding the future of the Surrey campus in general. In the meantime, I will continue to cooperate with the department to work through these issues.

Devising effective processes for student academic advising continues to be an issue not only in Math but, I would argue, throughout the university. Student and advisor time is often wasted as students shuttle among Student Services, the department where they are doing their major and the departments where they are taking their courses. I and my staff will work with our departments and with Student Services towards solutions.

The Math Department has shown a commendable willingness to partner with other Science departments, particularly the three life science departments where the majority of our program students reside, in better integrating math into the curriculum. The Faculty of Science will help to fund initiatives of this sort through INSPIRE.

Faculty Dean	Date
....	30 July 2014

PROGRAM ASSESSMENT PLAN FOR THE MATHEMATICS DEPARTMENT

This document was prepared part of our self-study document for the 2014 departmental review. The layout of this document is as follows:

- Our interpretation of the SFU program assessment process.
- A brief description of our process.
- Preliminary findings.
- A plan for assessing and improving our programs over the next 7 years.

Part 1. **Our program assessment philosophy.**

Many universities and professional programs have very detailed requirements for program assessment, course level learning outcomes and data collection. SFU currently has none. Because we are early in this process individual departments are encouraged to develop their own ideas about what to do and how to do it.

We have endeavoured to develop a process which is:

(1) Sensible. (i.e. in line with our goals and not overly time consuming to implement and manage.)

(2) Defensible to our external peers.

(3) Useful for us to measure and improve the areas of our programs we care about.

(4) Open to input from all interested department members.

We have chosen to develop the same educational objectives for all our programs but allow each to have different performance expectations. We will gather only grade-determined data in our large classes but individualized data for our small math major classes. Lastly, we have developed course level learning objectives only for service classes, classes taught by many different people and core mathematics classes. This corresponds to about 15 classes.

Part 2. Educational Objectives

We focus only on the mathematics programs we coordinate: Math major, Math Honors, Applied Math major and Applied Math Honors. Later, we will work with other departments on our joint programs Some aspects of our performance indicators will be able to be measured in the service classes.

We have chosen objectives which are in line with the broad University goals, the Faculty of Science Degree Learning Expectations and our own strengths.

Educational Objectives for the mathematics department

(1) Students are able to solve mathematical problems with mathematical techniques.

(2) Students are able to state and prove mathematical theorems.

(3) Students are able to formulate mathematical descriptions of real-world problems.

(4) Students are able to use mathematical software to formulate and solve mathematical problems.

(5) Students are able to communicate effectively in oral, written and graphical forms.

(6) Students are able to collaborate and work in teams.

The first three are not particularly contentious and are essentially identical to the common goals of all EU mathematics departments as set out in the EU Tuning document.

The fourth is a recognition of the importance of computing in modern mathematics, something our department values more strongly than many.

The last two are soft skills that are important for all students to develop over their time with us. It is not clear that the format of most of our classes clearly support these yet.

At the moment I would speculate that we succeed on 1 with all students, 2 with most, 3 and 4 with some and we do not have a systematic approach to 5 and 6.

1. Performance indicator rubrics

The level of detail here is a balance between workload and utility. Typically we would do "small" classes on a per student basis and large classes by simply totaling grade columns.

In all cases we will grade success on a four point scale. For small classes we will include a brief descriptor.

We want to use the same rubrics at all levels so that we can track progress through the program so some indicators supersede others. For instance, any student who can model complex systems systematically can translate word problems into mathematical language.

These rubrics will be used to generate spreadsheets or webforms by front office staff. Large classes could be done automagically from submitted grade data and some input from professor. Small classes could be done through canvas. With some foresight and planning this could be made consistent and as low impact as possible.

Indicator	0	1	2	3
Proceed in a systematic manner	unable	With guidance	Without guidance	Ready for Grad school
Solve problems in Analyis or DEs	unable	With guidance	Without guidance	Ready for Grad school
Solve problems in discrete math or Graph Theory	unable	With guidance	Without guidance	Ready for Grad school
Solve problems in an application area	unable	With guidance	Without guidance	Ready for Grad school

Indicator	F/D	C	B	A
Proceed in a systematic manner	-	-	-	-
Solve problems in Analyis or DEs	-	-	-	-
Solve problems in discrete math or Graph Theory	-	-	-	-
Solve problems in an application area	-	-	-	-

TABLE 1. Rubrics for: Students can solve mathematical problems with mathematical techniques.

Indicator	0	1	2	3
Know definitions	None	Basic	Intermediate	Ready for Grad School
State theorems	None	Basic	Intermediate	Ready for Grad School
Conceive of a proof	No	With guidance	Without Guidance	Ready for Grad School
Use known theorems to prove results	Never	Simple	Advanced	Ready for Grad School

Indicator	F/D	C	B	A
Know definitions	-	-	-	-
State theorems	-	-	-	-
Conceive of a proof	-	-	-	-
Use known theorems to prove results	-	-	-	-

TABLE 2. Rubrics for: Students can solve mathematical problems with mathematical techniques

Indicator	0	1	2	3
Translate word problems into mathematics	unable	With guidance	Without guidance	Ready for Grad school
Identify relevant math technique	unable	With guidance	Without guidance	Ready for Grad school
Simplify a given model systematically	unable	With guidance	Without guidance	Ready for Grad school
Model a complex situation systematically	unable	With guidance	Without guidance	Ready for Grad school

Indicator	F/D	C	B	A
Translate word problems into mathematics	-	-	-	-
Identify relevant math technique	-	-	-	-
Simplify a given model systematically	-	-	-	-
Model a complex situation systematically	-	-	-	-

TABLE 3. Rubrics for: Students are able to formulate mathematical descriptions of real-world problems.

Indicator	0	1	2	3
Use Maple	No	Basic	Intermediate	Ready for Grad School
Use Matlab	No	Basic	Intermediate	Ready for Grad School
Use other	Never	Simple	Advanced	Ready for Grad School
Debug and validate output	No	Basic	Intermediate	Ready for Grad School

Indicator	F/D	C	B	A
Use Maple	-	-	-	-
Use Matlab	-	-	-	-
Use other	-	-	-	-
Debug and validate output	-	-	-	-

TABLE 4. Rubrics for: Students are able to use mathematical software to formulate and solve mathematical problems.

Indicator	0	1	2	3
Communication of information and ideas verbally	incoherent	some clarity	considerable clarity	clarity and confidence
Communication of information and ideas in writing	incoherent	some clarity	considerable clarity	clarity and confidence
Communication of information and ideas graphically	incoherent	some clarity	considerable clarity	clarity and confidence
Spelling and grammar	Many errors	Some errors	Few errors	No errors

Indicator	F/D	C	B	A
Communication of information and ideas verbally	-	-	-	-
Communication of information and ideas in writing	-	-	-	-
Communication of information and ideas graphically	-	-	-	-
Spelling and grammar	-	-	-	-

TABLE 5. Students are able to communicate effectively in oral, written and graphical forms.

Indicator	0	1	2	3
?	?	?	?	?
?	?	?	?	?
?	?	?	?	?
?	?	?	?	?

Indicator	F/D	C	B	A
Use Maple	-	-	-	-
Use Matlab	-	-	-	-
Use other	-	-	-	-
Debug and validate output	-	-	-	-

TABLE 6. Rubrics for: Students are able to collaborate and work in teams.

2. Program Goals

Each of our programs has different targets for the performance indicators.

Targets for Math Major			
Learning Objective	Target	Goal	Reality
(1)	2 3's and 2 2's	75%	
(2)	2 3's and 2 2's	75%	
(3)	2 3's and 2 2's	75%	
(4)	3 2's	75%	
(5)	3 2's	75%	
(6)	3 2's	75%	

Targets for Math Honors			
Learning Objective	Target	Goal	Reality
(1)	3 3s	100%	
(2)	4 3's	100 %	
(3)	2 3's and 2 2's	100%	
(4)	2 3's	75%	
(5)	3 3's	75%	
(6)	2 3's	75%	

Targets for Applied Math Major			
Learning Objective	Target	Goal	Reality
(1)	2 3's and 2 2's	75%	
(2)	2 3's and 2 2's	75%	
(3)	3 3's and a 2	75%	
(4)	3 2's	75%	
(5)	3 2's	75%	
(6)	2 3's	75%	

Targets for Math Honors			
Learning Objective	Target	Goal	Reality
(1)	3 3s	100%	
(2)	4 3's	100 %	
(3)	2 3's and 2 2's	100%	
(4)	2 3's	100%	
(5)	2 3's and 2 2's	75%	
(6)	2 3's	100%	

Part 3. Course level learning objectives

We have chosen to specify formal learning outcomes for:

(1) **Service Classes.** To share with the departments whose students we are teaching.

(2) **Courses taught frequently and by many different instructors.** To ensure uniformity across offerings.

(3) **Core classes taken by all our majors.** For consistency and clarity as these classes are linch pin requirements for many other classes.

These categories lead to about 16 classes, fewer than half our classes but most of our teaching seats.

See the Appendix for sample Learning Outcome lists.

Once these have all been collected, we will ask the following questions:

(1) What, if any, educational objectives does this class impact? (*Curriculum Mapping.*)

(2) Does this class appropriately cover the material assumed by later classes? (*Learning outputs.*)

(3) Are the pre-requisites sensible? (*Learning inputs.*)

We also want to ensure that pre-requisites make sense given that courses slowly shift over time.

To do this, we start by simply constructing a flowchart of what classes are currently required and flow these chains black to 1xx classes. On the next page there is a chart for a portion of the math program. From this we can determine wether the pre-requisite material assumed covered actually is and is done in appropriate detail. This can be done as part of determining learning outcomes at a course level, part of the curriculum mapping for educational objectives or independently. A sample of this is on the following page.

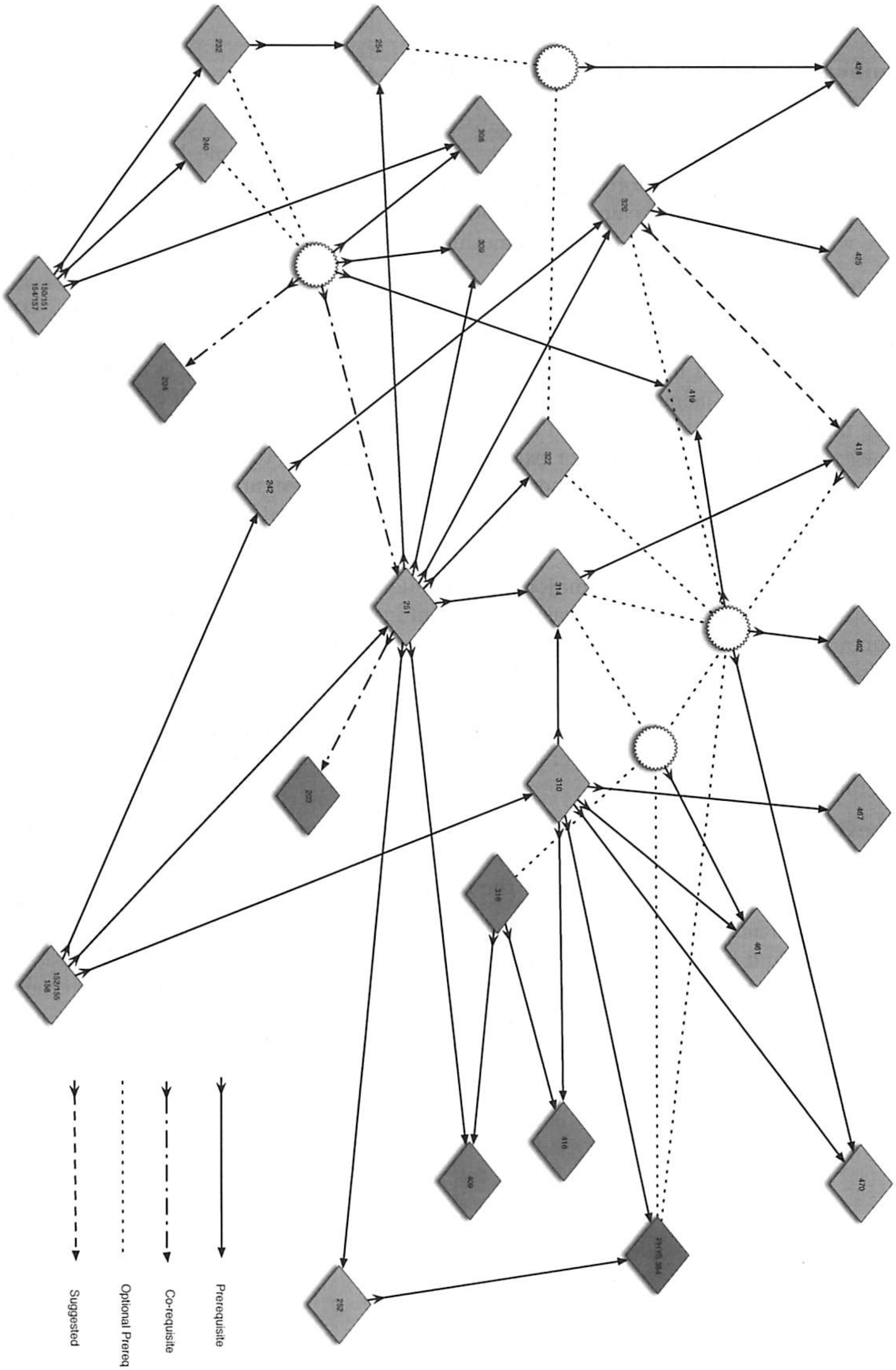

FIGURE 1. Flowchart leading to most 4xx classes taken by Applied Math students.

Lastly, it is important to consider what grades mean at different levels. We consider both typical habits and levels of mastery.

Significance of Grade Levels for 1xx and 2xx classes

A level: An A level grade indicates that the student has achieved the course aims with only minor gaps, and is completely ready to proceed to higher-level courses using this material without additional preparation. A students are as a rule highly consistent in meeting deadlines and performing well on midterms, and generally strive to keep up with the material. A students can typically do all assigned work with no assistance and are aware when they do not understand something.

B level: A B level grade indicates that the student has grasped the main ideas of the course, with some noticeable gaps, and is not clear on some of the harder concepts. Basic errors will be present, though not pervasive. A B student will typically find it difficult to apply the material in the course to new situations. The B student is ready to take on subsequent courses using this material but can expect to have to review certain portions of the material to be able to attain a similar grade. B students are usually exhibit minor inconsistencies on assignments, for example not finding time to get assistance in a timely way, and usually reveal some weaknesses in background in assignments, tests and exams. B students recognize that they do not completely understand but not always precisely where their problem lies.

C level: A C level grade shows major gaps in understanding some important material, and consistent weakness in applying basic ideas even in known situations. Basic errors will be common. C students will typically find subsequent courses extremely difficult, and are at risk in those courses unless they do substantial additional work. C students often struggle to meet deadlines and often submit work that is incomplete or even miss assignments altogether. Weaknesses in background are common and often extensive. C students are often confused on what they understand and what they do not and tend to imagine they "can make it up later".

D Level: A D level grade shows major gaps and weaknesses across the board, and is indicative of not being ready to proceed to further material related to the course content. Student success typically decreases as the term progresses.

F level: Students receiving an F for the course will have failed to grasp large portions of the material and have mastered virtually nothing, will consistently make basic errors even in prerequisite material, and in general will not be able to give any coherent account of any significant topic studied. F students typically will have failed to do assignments in a timely way or will have been consistently poor on regular work. They also generally show weak performance in tests.

Part 4. Implementation details

Given that SFU departmental reviews happen at most once every seven years a simple schedule for this process would be:

Year	Fall	Spring	Summer
2013-14	Develop draft objectives & indicators	Consult with department	Curriculum Map
2014-15	Collect: Goals 1 & 2	Collect: Goals 1 & 2	Analyze Goals 1 & 2
2015-16	Collect: Goals 3 & 4 Evaluate success for 1 & 2	Collect: Goals 3 & 4 Report to dept. on 1 & 2	Analyze Goals 3 & 4 Modify
2016-17	Collect: Goals 5 & 6 Evaluate success for 3 & 4	Collect: Goals 5 & 6 Report to dept. on 3 & 4	Analyze Goals 5 & 6 Modify
2017-18	Collect: Goals 1 & 2 Evaluate success for 5 & 6	Collect: Goals 1 & 2 Report to dept. on 5 & 6	Rate progress Modify
2018-19	Collect: Goals 3 & 4 Evaluate success for 1 & 2	Collect: Goals 3 & 4 Report to dept. on 1 & 2	Rate progress Modify
2019-20	Collect: Goals 5 & 6 Evaluate success for 3 & 4	Collect: Goals 5 & 6 Report to dept. on 3 & 4	Rate progress Modify

Modify here could mean tweak course or some aspect, change objectives or performance indicators. There might be nothing to do.

Once the learning outcomes are in place they do not need to be re-examined on a regular basis. Only when new courses are added, or some taken away, if problems are identified when looking at program objectives and when preparing a self-study report for external review.

Assessment of the performance objectives will be performed by the curriculum committee with assistance of the departmental advisor and undergraduate secretary. The learning outcomes for individual classes will be distributed to all instructors teaching that class as well as those teaching pre- and co-requisite and follow-on classes. The workshop coordinators will ensure that the learning outcomes for their classes are closely followed and that grades are set in accordance with the accepted departmental guidelines.

3. Appendix: Sample Course Level Outcomes Documents

In this section we include examples of the kind of outcomes that are generated for individual courses. These include two major service courses (Math 150 and Math 190) and two core courses (Math 240 and 242). These may be taught be a wide variety of instructors and the outlines are already standardized. These outcome lists aim to ensure that both instructors and students are aware of the objectives in light of the outlines. For Math 150 an outline is included.

Math 150

Description: Designed for students specializing in mathematics, physics, chemistry, computing science and engineering. Recommended for students with no previous knowledge of Calculus. An extensive review of polynomial, rational, logarithmic, exponential, and trigonometric functions and their properties and graphs. Limits, continuity, and derivatives. Techniques of differentiation, including logarithmic and implicit differentiation. The Mean Value Theorem. Applications of Differentiation including extrema, curve sketching, related rates, Newton's method. Antiderivatives and applications. Conic sections, polar coordinates, parametric curves. Prerequisite: REQ-Pre-Calculus 12 (or equivalent) with a grade of at least A, or MATH 100 with a grade of at least B, or achieving a satisfactory grade on the Simon Fraser University Calculus Readiness Test. Students with credit for either MATH 150, 154 or 157 may not take MATH 151 for further credit. Quantitative

Textbook and detailed list of topics:

Calculus - Early Transcendentals 7th ed., Stewart:

Chapter 1 - Functions and Models 1.1 Four ways to represent a function
1.2 Mathematical Models: A Catalogue of Essential functions
1.3 New Functions from Old Functions
1.5 Exponential Functions
1.6 Inverse Functions and Logarithms

Chapter 2 - Limits and Derivatives
2.1 Tangent and Velocity Problems
2.2 Limit of a Function
2.3 Calculating Limits Using the Limit Laws
2.4 Precise Definition of a Limit
2.5 Continuity
2.6 Limits at Infinity; Horizontal Asymptotes
2.7 Derivatives and Rates of Change
2.8 The Derivative as a Function

Chapter 3 - Differentiation Rules
3.1 Derivatives of Polynomials and Exponential Functions
3.2 Product and Quotient Rules
3.3 Derivatives of Trigonometric Functions
3.4 The Chain Rule
3.5 Implicit Differentiation

3.6 Derivatives of Logarithmic Functions
3.7 Rates of Change in the Natural and Social Sciences
3.8 Exponential Growth and Decay
3.9 Related Rates
3.10 Linear Approximations and Differentials
3.11 Hyperbolic Functions

Chapter 4 - Applications of Differentiation
4.1 Maximum and Minimum Values
4.2 The Mean Value Theorem
4.3 How Derivatives Affect the Shape of a Graph
4.4 Indeterminate Forms and L'Hospital's Rule
4.5 Summary of Curve Sketching
4.7 Optimization Problems
4.9 Newton's Method
4.10 Antiderivatives

Chapter 10 - Parametric Equations and Polar Coordinates
10.1 Curves Defined by Parametric Equations
10.2 Calculus with Parametric Curves
10.3 Polar Coordinates
10.5 Conic Sections
10.6 Conic Sections in Polar Coordinates

Learning outcomes: Upon successful completion of the course, the student will have knowledge and develop intuitive approaches to the following mathematical concepts: infinitesimals, continuity, rates of change and the smoothness of curves. Specifically, the student will be able to:

- Classify functions by their analytical representation (polynomials, rational functions, etc.) and their properties (monotone, continuous, differentiable, etc.)
- State the definition of the limit of a function and calculate limits by using techniques and properties introduced in the course
- Apply limits to find and classify eventual asymptotes
- State the definition of the continuity of a function at a point and on an interval and apply it to decide if a function is continuous or not and to classify eventual points of discontinuity
- State and apply the Intermediate Value Theorem
- State the definition of the derivative of a function at a point and on an interval and apply it to calculate derivatives of functions
- Relate the derivative with the instantaneous rate of change and the slope of the tangent line

- Distinguish the concepts of continuity and differentiability
- Calculate derivatives by using rules of differentiation
- Use linear approximation to estimate a given number
- Solve related rates problems
- Solve one-variable optimization problems
- State and apply the Mean Value Theorem
- Use various calculus techniques and facts to draw a graph of a function
- Use Newton's method to estimate the roots of a function
- State the definition of the antiderivative of a function and find antiderivatives in some simple cases
- Find the derivative of a function given parametrically and draw its graph
- Find the derivative of a function given in polar coordinates and draw its graph
- Distinguish the types of conic sections

MATH 190 LEARNING OUTCOMES
DRAFT

Calendar Description:
MATH 190-4 Principles of Mathematics for Teachers
Mathematical ideas involved in number systems and geometry in the elementary and middle school curriculum. Overview of the historical development of these ideas, and their place in contemporary mathematics. Language and notation of mathematics; problem solving; whole number, fractional number, and rational number systems. Plane geometry, solid geometry, metric geometry, and the geometry of the motion. Introduction to probability and statistics.

Learning outcomes:

At the end of the course, successful students should be able to:

- Understand and use mathematics language and terminology correctly;
- Correctly present and explain solutions to mathematical problems;
- Appreciate the need for precision and rigour in mathematics definitions and reasoning that is appropriate for the level of a learner;
- Understand and evaluate mathematical materials related to the elementary school curriculum
- Understand concepts of quantity and value;
- Use quantitative analysis and other strategies to solve mathematical problems;
- Understand properties of base ten and other numeration systems;
- Understand the concept of place value in base ten and other numeration systems;
- Understand the meaning and properties of whole number operations, various models for these operations and be able to describe situations where various models can be used;
- Understand the meanings and models for fractions;
- Relate fractions, decimals and percents;
- Perform operations on fractions, illustrate these operations using diagrams and deeply understand the meaning of these operations;
- Understand the difference between additive and multiplicative comparisons of quantities;
- Analyze and solve problems that require multiplicative comparisons;
- Understand the concept of divisibility and of a factor and a multiple;
- Understand the concept of prime and composite numbers and their properties;
- Understand and use the Fundamental Theorem of Arithmetic;
- Determine whether the number is prime or composite and represent composite numbers as products of primes;
- Determine GCF and LCM of two or more whole numbers;
- Understand the concept of a geometric dimension;

- Recognize, define and classify a variety of 2D and 3D shapes: lines, planes, angles, circles, spheres, polygons, polyhedra, etc.;
- Understand, describe and classify symmetries of 2D and 3D objects;
- Understand, classify and find images of geometric transformations: isometries and similarities;
- Understand the concept of measure and unit;
- Derive formulas for and calculate areas, surface areas and volumes of basic geometric objects and use appropriate units in these calculations;
- Understand relations between areas and volumes of similar shapes;
- Understand and use Pythagorean Theorem

MATH240: Algebra I: Linear Algebra

Course Level Learning Outcomes

Course Description: Numerous problems of interest in science, engineering, computing science and commerce can be represented by systems of linear equations. This course explores the celebrated Gaussian Elimination algorithm: a general method for computing all solutions to any such linear system, or for detecting that no solutions can exist.

The idea of a matrix is fundamental to this exploration and basic matrix operations are explored: addition, multiplication, transpose, inverse and determinant. Our main focus is on the vector spaces $\mathbb{R}^2$, $\mathbb{R}^3$, and more generally on $\mathbb{R}^n$, in which we discuss elementary operations on vectors, linear independence, spanning sets, bases, the rank of a matrix, orthogonal bases, and the Gram-Schmidt process.

We also study vector spaces in an abstract setting, which brings together in a unified way many of the ideas studied across science. We examine the concepts of linear independence, span, bases, subspaces, and dimension within an abstract vector space. The connection between linear transformations and matrices, as well as the kernel and range of a linear transformation are explored. Eigenvalues, eigenvectors, and eigenspaces are discussed, as well as similar matrices and diagonalizable matrices.

This course emphasizes mathematical proof: students will be presented proofs of the main theorems in linear algebra, as well as construct their own proofs to statements made about the objects studied in this course.

Objectives:

- **Linear Systems:** Student will be able to
  - represent a system of linear equations by a matrix;
  - use the Gaussian Elimination algorithm to compute the general solution to a given system of linear equations or show that no solution exist;
  - prove elementary statements concerning the theory of systems of linear equations;
  - understand some applications of systems of linear equations.
- **Matrix Algebra:** Students will be able to
  - perform the operations of addition, scalar multiplication, and multiplication, and find the transpose and inverse of a matrix;
  - calculate determinants using various methods: row operations, column operations, and expansion down any column and across any row;
  - prove elementary statements concerning the theory of matrices and determinants;
- **Vector Spaces and Linear Transformations:** Students will be able to
  - prove algebraic statements about vector addition, scalar multiplication, inner products, projections, norms, orthogonal vectors, linear independence, spanning sets, subspaces, bases, and dimension for $\mathbb{R}^n$ and abstract vector spaces;
  - understand the relationships between A being invertible, $\det A$, $Ax = 0$ having a solution, the rank of A, and the rows of A being linearly independent.
  - apply the Gram-Schmidt process to orthogonalize a basis;
  - compute the kernel, range, rank, and nullity of a linear transformation;
  - determine the matrix associated with a linear transformation with respect to given bases, and understand the relationship between the operations on linear transformations and their corresponding matrices;

- determine the change-of-basis matrix;
- prove statements of an algebraic nature concerning linear transformations.
- compute eigenvalues and their corresponding eigenspaces.
- prove elementary facts concerning eigenvalues and eigenvectors.
- determine if a matrix is diagonalizable, and if it is, diagonalize it.
- prove certain specified theorems given in the course.

MATH 242 LEARNING OUTCOMES
DRAFT

TA

Calendar Description
MATH 242-3 Introduction to Analysis I
Mathematical induction. Limits of real sequences and real functions. Continuity and its consequences. The mean value theorem. The fundamental theorem of calculus. Series. Prerequisite: MATH 152; or MATH 155 or 158 with a grade of B. Quantitative.

Learning Outcomes - Short Version
The student will know the $\epsilon - \delta$ definition of limit together with necessary background about the real numbers, and understands how to apply this appropriately in the context of sequences, functions of a single real variable, and series. The student will learn the definitions and proofs for basic concepts and results that allow a clear understanding of the roots of the differential and integral calculus in the limit definition, and will be familiar with how the main results of first year calculus are proved. Students are also exposed to notions of uniform continuity and uniform convergence and their applications. Throughout the course students will apply the knowledge learned from studying these basic theorems to prove selected simple results from the definitions and theorems. The student will complete the course with a certain level of comfort in doing simple proofs in analysis, including an incipient understanding of how to criticize whether their own proofs are complete, correct, and efficient.

Learning Outcomes - Long Version

(1) Starting from an intuitive idea of what a real number is, the student will understand the ideas of countable and uncountable sets and the fact that the rationals are dense in the reals.
(2) The student will know the least upper bound property in the form that states that monotone bounded sequences of real numbers converge. They will understand the terminology of open and closed sets and of limit points, as they apply to subsets of the reals.
(3) The student will learn the $\epsilon - N$ and $\epsilon - \delta$ definitions of the limit of a sequence and of the limit of a function at a point, will be able to use this definition to prove that certain simple limits have the value that is known from introductory calculus, and to derive the basic properties of limits rigorously.

Date: June 11, 2012.

(4) Students will know the definitions of continuity of a function at a point, and on an interval.
(5) Students will be exposed to the idea of uniform continuity and be aware of the importance of uniformity in the proof of the extreme-value theorem.
(6) Students will know the definition of the derivative of a function, be able to give (with proof) an example of a function that is not differentiable but is continuous at a point, and prove basic theorems (for example the product rule) from introductory calculus.
(7) The statement and proof of the mean value theorem will be known, and students will appreciate the applications of this theorem to the proof of standard facts from first-year calculus.
(8) The definition of the Riemann integral will be known, and the student will be exposed to basic arguments about upper and lower sums, be able to state a criterion on these sums for Riemann integrability and use this criterion to show integrability for some simple functions.
(9) The relationship between differentiability and integrability will be explored, and students will be comfortable with the main ideas of the proof of the fundamental theorem of calculus.
(10) Students are to understand the definition of convergence of infinite series in terms of earlier definitions in the course, and to grasp how this definition and the Cauchy criterion are used to prove some simple convergence tests.
(11) The student will then apply these concepts to series of functions, notably power series, and is exposed to basic ideas about representation of functions as Taylor series.
(12) Students will know the definition of uniform convergence, and understand how to apply it to simple examples to show non-uniformity of convergence.
(13) Students will know that power series are uniformly convergent within their domains of convergence, and understand the relationship of the continuity of the terms of a power series to continuity of the sum.

Throughout the course students will apply the knowledge learned from studying these basic theorems to prove selected simple results from the definitions and theorems. In addition to such proofs involving a small number of steps, students will become familiar with longer arguments and gain practice in identifying key ideas in the proofs of major theorems. The examination will include a combination of repeating known definitions and theorems, proving results and solving problems already studied, and students will be invited to show that they can apply the definitions and theorems in situations that are not identical to those already seen.

A main aim of the course is for the student to understand the relationship between the concepts in the course and the methods of single-variable calculus. To achieve this, students will learn how to use precise definitions of mathematical concepts, how to read and understand theorems and their proofs using such definitions, how to make their own proofs in analysis, and how to criticize whether their own proofs are correct or not.