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Simon Fraser University
Strand Hall 3100
8888 University Drive
Burnaby BC
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MEMORANDUM

ATTENTION: Senate	TEL
FROM: Peter Keller, Vice-President, Academic and Provost, and Chair, SCUP	
RE: External Review Mid-Cycle Report for the Department of Mathematics (SCUP 18-01)	
DATE: January 12, 2018	TIME

At its January 10, 2018 meeting, SCUP reviewed the Mid-Cycle Report for the Department of Mathematics which resulted from its 2014 external review. The report is attached for the information of Senate.

SCUP 18-01

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MEMORANDUM

ATTENTION: Peter Keller, Chair, SCUP	TEL
FROM: Wade Parkhouse, Vice-Provost and Associate Vice-President, Academic	
RE: External Review Mid-Cycle Report for the Department of Mathematics	WParkhouse
DATE: December 13, 2017	TIME

The External Review of the Department of Mathematics was undertaken in February 2014. As per the Senate guidelines, the Unit is required to submit a mid-cycle report describing its progress in implementing the External Review Action Plan. The mid-cycle report, together with a copy of the Action Plan approved by Senate, and the mid-cycle report on the Unit's assessment of its Educational Goals are attached for the information of SCUP.

c: Mary-Catherine Kropinski, Chair, Department of Mathematics
Claire Cupples, Dean, Faculty of Science

SFU

DEPARTMENT OF MATHEMATICS
FACULTY OF SCIENCE

DR MC KROPINSKI
PROFESSOR AND
DEPARTMENT CHAIR

MAILING ADDRESS

Dept Of Mathematics
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mkropins@sfu.ca
www.math.sfu.ca

Date: November 30, 2017

Attn: Glynn Nicholls, Director,
Academic Planning and Quality Assurance

Subject: Mid Cycle Review Documents

Attached please find the Mid-Cycle Report for the Department of Mathematics which details our progress with the Action Plan stemming from the 2014 External Review. The assessment of our Educational Goals is also attached.

MC

Mary Catherine Kropinski, PhD
Chair, Dept of Math

External Review Update for the Department of Mathematics	
Action	**Progress Made**
1. Programming	
1.1.1 Undergraduate	
• Industrial Math Program (i.e., Operations Research, OR) in Surrey: 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.	In 2015, the Department had plans to hire a research faculty member in OR and thereby reinforce the OR program in Surrey; however, this was position was frozen due to budgetary restrictions. Since that time, Science has cut back other programs in Surrey, most notably decommissioning the lower-level cohort programs and moving the MSSC program to Burnaby. The Operations Research Program has not grown for the past few years and currently has very few students. In this context, the Department is again investigating whether to rebase this program in Burnaby, with a final decision anticipated in January 2018. If it is decided that the OR program should move, the current space issues for the Department (item 5 below) would become even more pressing, because there is no space available in Burnaby to accommodate the research faculty associated with the program.
• Joint Major programs: 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.	On track for September 2018.
• Honours program: 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.	The Honours program now has a thesis requirement. Students complete a 16-week research internship, and then write a 30-page thesis document and give a 20-minute oral presentation. These requirements are evaluated in the 5 credit MATH 499. It has been offered each fall since 2015. Alongside this, students take MATH 498 which is a mathematical communication and research methods course. Students are walked through the process of transforming their research into written and oral communications. They receive feedback on their documents, and learn basics of public speaking. Six students have completed their thesis so far, with five more enrolled this fall (2017).

• Review and tweaking of undergraduate course content: 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).	SFU-developed notes have been produced and introduced to the biology calculus stream (math 154, 155). The local production involved consultation with the biology departments. A similar initiative involving the SIAT program in Surrey is underway.
1.1.2 Graduate	
• Pure Math Graduate Program: A faculty committee will review and update course offerings and degree requirements for the pure math graduate degrees. March 2015.	The requirements of the MSc Pure Mathematics specialization were modified with a goal of emphasizing core courses to better build a cohort, and to ensure enrolment in core courses. Specifically, the breadth requirement was made explicit, and students must have courses from a certain selection. Reading courses are more carefully vetted to avoid dilution of the core courses, a problem that was identified in the review. A new faculty in pure math, Nathan Ilten, has increased the graduate algebra offerings, with a selection of graduate courses in algebraic geometry. These courses are in high demand, are very popular, and have had a positive effect on graduate recruitment.
• Pure Math Grad Qualifying Exam: 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.	The previous exam, MATH 898 was replaced with two shorter, more focused exams. The first, MATH 895, explicitly concentrates on core topics expected to be mastered from undergraduate. The topics are aligned with our undergraduate offerings, and the questions are comparable to exam questions students in our 300-level courses might encounter. The second exam, MATH 896 is a topics exam and will contain questions from the student's broad area of research. The last offering of MATH 898 is Spring 2018, and the single remaining student of that regime will write the exam. Aside from him, the remaining

	students fall under the new requirements, with MATH 895/896. The first offering is expected for Summer 2018. A GSC subcommittee is actively preparing the exam this semester.
• M.Sc. for High School Teachers: 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.	This was looked at further and it was found that we would be competing with existing successful online offerings and that it would be difficult to meet the staffing requirements.
2. Research	
• The Department will work on a strategic research and hiring plan with a five- to ten-year horizon. 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.	A five-year strategic research and hiring plan is expected to be developed as a part of the 2018-2023 Academic Planning exercise.
3. Administration	
• "Faculty exchanges" between Surrey and Burnaby: 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.	Consideration of such a program will be delayed until a decision is made about where to base the OR program. We are currently examining mechanisms to get more Burnaby-based faculty to teach in Surrey. This will be put in place for the 2018-2019 teaching assignments.
• Academic Advising: 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 10,000 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	The role and job description of the Advisor was reviewed in October 2017 due to new hiring. The Advisor continues to participate in the planning and coordination of recruitment, orientation and student success initiatives. The Advisor also supports and consults with the department undergraduate studies committee on curricular matters.

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.	
4. Working Environment	
• n/a	
5. Space	Space constraints have become a major issue in our Department. Our programs and demand for service teaching is growing; however, we have no space to accommodate new faculty, nor fill our teaching and graduate training needs. We have insufficient space for graduate students, visitors and postdocs, and the space we do have is fractured into isolated pockets. It is virtually impossible to house research groups in a cohesive fashion. These issues were greatly exacerbated when the Big Data Hub took over the IRMACS facility. The Dean of Science's office has initiated a consultation with Facilities to examine our current space holdings and make recommendations. It is unknown when this process will be completed.
• Individual office space: 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.	Subject to evaluation (see above).
• Math Student Support Centre in WMC: 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.	[math west] facility in the WMC had a soft opening in summer 2017. Fall 2017 was the first full usage term. The social learning space houses the relocated Q-workshop, some of the calculus support sessions, and graduate discussion groups. The MACM 316 computing office hours are now much more effective now that they are hosted in the collaborative computing space with MATLAB-enabled equipment. The advanced learning space houses both tutorials for MACM 316 and MATH 310 (8-10 tutorials in total) and several of our upper division courses. The open-

	area office hours in the community zone have been deemed successful. The 3-term usage plan has roughly 75% pre-scheduled events, with an increasing amount of spontaneous usage becoming part of departmental habit.
• Student Lounge ("Math Hangout"): 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.	Subject to evaluation (see above).
• Math Student Union Lounge: 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.	Student representatives from both Math and Stats consulted with a space planner from facilities this fall. Renovations are due to start next spring. Planned completion: May 2018.
• Geographic unification of graduate student space: 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.	Subject to evaluation (see above).

Educational Goals, Program Assessment and Quality Assurance in the Department of Mathematics

Introduction

Being one of the first departments to go through this process, we were initially overly ambitious. Since our proposal in 2013, we have edited our Educational Goals and streamlined the program assessment plan.

The only significant change to the Educational Goals is the removal of an emphasis on team work. We recognize this is an important skill but at present we do not have many appropriate places in the curriculum to include this. Instead we are currently focussing on enhancing communication skills. Wholesale change throughout the department is infeasible: each class feeds content into the next in a highly-structured way, and the content of so many of our classes is required by other departments. For instance, only six (MATH 208, 240, 242 and 252 and MACM 203 and 204) of our about 60 annual lower division course offerings typically have more than 15% math majors.

Our original proposal for program assessment had each performance indicator scored on a 0-4 scale for each student. This was eventually deemed too onerous to properly implement, and it was somewhat contentious. We have now moved to a Y/N indicator based only on course curricula. If the typical B student is expected to be successful on a given indicator the course is scored Y for that indicator. This means our preliminary assessment was done on courses and programs, and not on how students perform in the courses they choose. We shall address this issue before the next review.

Educational Goals

Mathematics is a mature discipline with very structured programmes. There are no external standards bodies imposing Educational Goals or Learning Objectives. We have settled on the following non-controversial Goals:

1) Graduates will be able to solve mathematical problems with mathematical techniques.
2) Graduates will be able to state, use and prove mathematical theorems.
3) Graduates will be able to formulate mathematical problems from plain language descriptions.
4) Graduates will be able to use software to formulate and solve mathematical problems.
5) Graduates will be able to communicate mathematical information effectively.

The first three are essentially the common themes of mathematics degree programmes as identified in the EU Tuning document[1], the fourth a requirement for the modern application of mathematical techniques and the final an oft overlooked necessary skill for all graduates.

To identify whether our programs are meeting these goals we map the curriculum to the following indicators:

1) Graduates will be able to solve mathematical problems with mathematical

techniques.
- understands notation
- can identify relevant mathematical techniques
- shows proficiency in basic skills and concepts (eg 1xx and 2xx)
- shows proficiency in advanced skills and concepts (eg 3xx and 4xx)

2) Graduates will be able to state, use and prove mathematical theorems.
- knows definitions
- can identify and state relevant theorems
- can use known theorems to prove auxiliary results
- can conceive of and develop a proof

3) Graduates will be able to formulate mathematical problems from plain language descriptions.
- can proceed in a systematic manner
- can translate word problems into mathematics
- can model a complex situation

4) Graduates will be able to use software to formulate and solve mathematical problems.
- understands basic programming
- can modify existing code to solve a new problem
- can combine existing codes to solve complex problems
- can write short programmes to solve given problems or test concepts
- can use software to generate graphics for the analysis and communication of quantitative information

5) Graduates will be able to communicate mathematical information effectively.
- can effectively communicate mathematical information in writing
- can effectively communicate mathematical information verbally
- can create and use graphics to communicate mathematical information
- can effectively communicate quantitative information in an appropriate form

We have chosen to focus on fairly high level skills rather than discipline specific ones as our department has a broad range of programs covering many disparate areas of mathematics and we do not want to have distinct Educational Goals and Performance Indicators for different Majors.

Communication Skills

Our initial finding was that all our degree programs score very well on Goals 1 and 2, all at least acceptably on 3 and 4 and all needing additional effort towards goal 5. Far fewer classes than expected had an emphasis on communications skills with many assuming it was being done elsewhere.

We have four regularly offered upper division W-labelled courses:

MATH 208W - Introduction to Operations Research
MATH 380W - History of Mathematics
MATH 480W - The Art and Craft of Problem Solving

MATH 402W - Operations Research Clinic

The second course develops skills in writing about mathematics and mathematicians in a manner somewhat akin to a typical essay writing class, and the third focusses on writing solutions to challenging mathematical contest problems. In the first and last courses, reports are prepared on the modelling and analysis of a real-world operations research problem.

Many of our upper division classes also have poster presentations. We are currently working to standardize this practice and determine in which courses poster presentations would be suitable.

We identified that we had no class preparing our students for the communications requirements of graduate school nor for communicating technical results to a general audience. To rectify this gap, we developed MATH 498 - Communication and Research Skills in the Mathematical Sciences (taken alongside enrolment in the Honours Thesis), and we introduced report writing into MACM 316.

MATH 498 is a course for Honours students who have completed a research semester and teaches them how to write up and present their results. It has been an outstanding success leading to students being more competitive for fellowships and our graduate students are now asking for a similar class.

MACM 316 is taken by many of our majors but the class enrolment is dominated by students from Engineering Science and Computing Science. This course teaches students about using and analyzing algorithms to solve problems on the computer. Despite having enrolments well over 100 each semester, we now require students to write a one page report per week describing their solution to a given problem. The goal is to teach students to write about technical matters aimed at a non-technical audience.

Recently we have run MATH 381W - Mathematics Undergraduate Seminar - as a communications-focused selected topics class. We are currently investigating how to make this a regular offering with a fixed topic.

Lastly, an instructor recently ran an experimental version of MATH 345 in a flipped format with students making regular presentations. This also worked very well, and we are examining how to offer such a course again.

Summary and Future Plans

In summary, we identified deficiencies in the teaching of communication skills to our students. We have sought to remedy this by introducing a new course, a new report writing requirement and testing out a flipped format, presentation-focused class.

We will now look at actual student pathways through our programmes to ensure all future students are exposed in to communications-focused classes in the future. We hope to do this by extending the report witting introduced in MACM 316 to other classes and standardize poster or other presentations in certain 300 and 400 level classes. We are not interested in developing more W-labelled classes but rather to make communication a component of as many of our classes as possible.

Additionally, we will provide more opportunities for students to learn about using mathematics in industry (such as by offering MATH 208W in Burnaby), providing more computing experience to more of our students and revisiting teamwork. The latter two objectives can now be combined in the new **[math west]** teaching facility.

Quality Assurance

Program assessment is done to assist departments to continually improve their programs but also to maintain the highest educational standards. In the mathematics department, we do this by starting with the notion that no one owns classes. Most service courses are managed by Lecturers who look after the administration of the class, typically set the lecture schedules and, in some cases, set some of the homework. Textbooks are chosen by the curriculum committee. These measures help ensure that different offerings of the same class are as uniform as practical between different semesters and instructors. At the upper division, sequences for math majors are organized by groups of people who regularly teach classes in the sequence. They discuss requirements and curricula, while the textbook options are left to the instructor. People wishing to teach Selected Topics courses need to petition the curriculum committee explaining what they intend to do.

Mathematics is a very structured discipline with each course building on many preceding ones. Assessing student performance is thus simpler and less controversial than in many other fields. Written exam results are an effective proxy for student ability.

Reference

[1] - The document "Reference Points for the Design and Delivery of Degree Programmes in Mathematics" was prepared as part of the EU Tuning process whereby universities across the EU developed a common framework for degrees. Tuning is described as "a Process, an approach to (re-)designing, develop, implement, evaluate and enhance quality first, second and third cycle degree programmes".
(http://www.unideusto.org/tuningeu/images/stories/key_documents/tuningmathematicsfinal.pdf)

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MEMORANDUM

ATTENTION: Mary Catherine Kropinski, Chair, Department of Mathematics	TEL
FROM: Glynn Nicholls, Director, Academic Planning and Quality Assurance	
RE: External Review Mid-Cycle Report for the Department of Mathematics	
DATE: June 12, 2017	TIME

As per Senate guidelines, the Department of Mathematics is to report on progress being made in the implementation of the Action Plan that resulted from its external review in February 2014. This report will be presented to SCUP and Senate for information. The Chair will be asked to attend the SCUP meeting to provide comment and answer any questions about the update on the Action Plan. The Dean may choose to attend the meeting at her discretion.

In addition, as per the agreement with Senate, mid-cycle reports in 2017, following the requirement to develop Educational Goals for programs in the Department of Mathematics, are expected to have conducted an assessment of those goals/outcomes. Please include as part of this mid-cycle report submission a 2- to 4-page narrative description articulating the assessment process undertaken by the academic unit, and any changes or adjustments to the established educational goals, the assessment process, and/or the program curriculum that may have arisen as a result of the findings of the assessment. Should you require any assistance in preparing this part of your report, please contact your Educational Consultant from TLC.

Please submit your progress report, using the attached template, by Thursday, November 30, 2017 to Bal Basi at bbasi@sfu.ca. Also attached, for ease of reference, is the Action Plan that was approved by Senate on November 3, 2014.

Please contact me at 2-6702, glynn_nicholls@sfu.ca, or Bal Basi at 2-7676, bbasi@sfu.ca, if you have any questions or concerns regarding the external review update process.

Thank you.

Attach.

cc: C. Cupples, Dean, Faculty of Science

EXTERNAL REVIEW – ACTION PLAN

Section 1 – To be completed by the Responsible Unit Person e.g. Chair or Director

Unit under review	Date of Review Site visit	Responsible Unit person	Faculty Dean
MATHEMATICS	Feb 19-21, 2014	Manfred Trummer	**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.** *[<u>"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."</u> 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.** *[<u>"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."</u> 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.** *[<u>"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."</u> 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**
[signature]	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 any that meet 5 and 6 are an accident.

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.

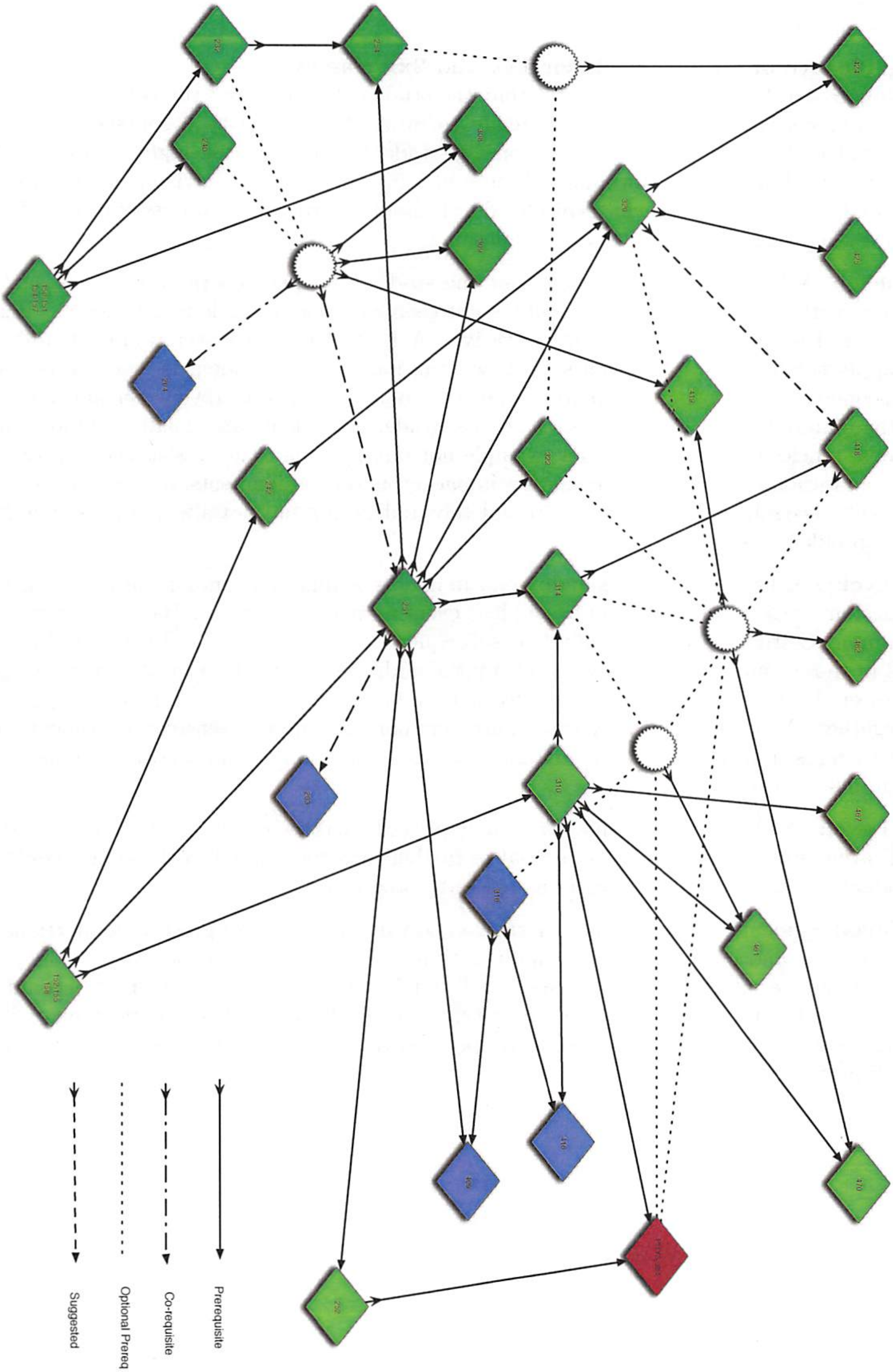

FIGURE 1. Flowchart leading to most 4xx classes taken by Applied Math students.

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 co-ordinators 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.