<u>*i*Sci</u> – Integrated Science Program

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I. Outlining the Problems

The Dean of Science, John Capone, identified two serious problems in science training at the University level. These problems have been developing gradually over many years, but possible solutions are only beginning to be discussed seriously in the academic community. The first problem is the dramatic increase in student numbers. Although the pursuit of universal access to university education has been a positive goal with many associated benefits, an unfortunate result is that the quality of science education has deteriorated for the type of student who used to be the focus of that education, namely the bright, motivated, creative student with a strong work ethic. Large classes have meant reduced access to faculty, limited research experience, lack of group identity, and a lack of adequate training in communication (particularly writing) skills.

The other main problem, equally serious, is that science education has become highly specialized and "disciplinized." This has happened partly in response to a decrease in the depth of coverage of core material in secondary school - there is a clear trend toward less intensive training in the standard University science prerequisites than in the past. However, specialization at the University level has been driven by the exponential growth of scientific knowledge. Although this specialization, like universal access, has had its advantages, the result is that students' skill sets have become equally specialized. Students often lack the ability to apply relevant ideas and knowledge outside their area of specialization. As just one example, there have been several recent reports decrying the lack of adequate mathematical and physical science training for life science students (e.g. BIO210, 2003; Bialek and Botstein, 2004; Bell, 2007). There has also been a recent attempt to compile examples of successful interdisciplinary laboratory courses (Karukstis & Elgrin, 2007). In the 21st century, the most successful researchers are very likely to be those who can connect and synthesize ideas from widely different disciplines as well as those who can think deeply within the traditional disciplines.

Although the philosophical pendulum is definitely swinging toward less specialization (at least at the Faculty level), there are still pressures from within specific Departments in most Universities to impose yet more-specialized course requirements on students. Fortunately, McMaster has a culture of innovation in education, and we have reached a critical mass of faculty members willing to break this spiral and move toward a better way of educating our students.

In 2005, the Dean put together a committee to outline a targeted interdisciplinary program, loosely based on the Arts and Sciences program (Jenkins, et al., 2006), which would address these problems. The committee had broad representation and was chaired by Bradd Hart from the Department of Mathematics and Statistics. On the basis of the final recommendation, a second committee, co-chaired by Ron Racine and Carolyn Eyles, was assembled to put together a detailed program description that could be taken through Undergraduate Council and to final approval. This Program Design Committee began work in September, 2006. The new program has tentatively been named *Honors Integrated Science* (*i*Sci).

II. Outlining the Solutions

The first committee did not attempt to design a detailed program. Rather, it attempted to identify and clarify the problems currently faced in science education, and it proposed and debated the options available to solve these problems. The committee focused on the educational principles that should be applied and identified the following goals for the *i*Sci program:

- To educate highly motivated students in a stimulating interdisciplinary research environment and to involve them in scientific research projects that use current research methodologies and approaches (Learning through Research)
- To provide an interdisciplinary approach to science in order to build respect across fields and appreciation of the links between scientific disciplines.
- To produce potential graduate students with highly developed scientific research and communication skills and uniquely equipped to contribute to cutting-edge research and development.
- To create a learning environment in which innovative styles of instruction, exploration and communication of scientific ideas can be developed.

The Program Design Committee then rolled up its sleeves and designed a workable program that would serve as a model for other programs, Faculties and Universities.

It was recognized early in the process of program design that it is not enough to simply convey the knowledge accumulated across scientific disciplines; the students must also learn how these disciplines create new knowledge. Given the collaborative culture that already exists in science, it should not be difficult to tackle complex, multidimensional problems in the context of undergraduate education. However, knowledge is currently too compartmentalized. Researchers from Discipline A often have very little understanding of the research design and control problems faced by their colleagues in Discipline B, and vice versa. This is an obstacle to optimal collaboration and productivity. Just as new ideas often grow from the findings of published research, new ideas can also come from new research techniques (so long as those techniques are reasonably well understood). Notably, a large proportion of Nobel Prizes have been awarded for new ideas and/or techniques that would best be characterized as interdisciplinary.

It was also clear to the members of both committees that an integrated sciences approach would only have a substantial impact on the students if it continued to be a major component of their program throughout all 4 years of undergraduate training -- as is the case for the highly successful Arts & Science Program at McMaster. However, the teaching of science using an integrated approach should complement rather than replace specialization. Interdisciplinarity will shape the attitudes, flexibility, and skills of students in ways that will augment their performance within their chosen disciplines, but we recognise that specific knowledge and skills (i.e., a certain degree of specialization) are required for access to graduate school. Consequently, we expect that most students will elect to use their electives to work toward a combined degree (e.g., *i*Sci plus Mathematics).

The *i*Sci program focuses on integrated learning of scientific knowledge and skills in the context of pertinent topics and projects. For some topics, a particular discipline may temporarily become the organizing hub around which the other disciplines contribute. For a nervous system-related topic, for example, the hub will be neuroscience, and psychology, mathematics, biology, physics, and chemistry will all contribute heavily. For most of the topics covered in this program, mathematics and physics will serve as implicit grounding disciplines. Furthermore, measurement, analysis and modeling will be ubiquitous components, regardless of topic.

Inquiry-based approaches will be used extensively in the *i*Sci program. These approaches blur the boundaries between research, teaching and learning. In effect, all instructional activities will prod the students into becoming more-active participants in their own education. Students will be involved in individual and team research projects from Level I onwards and will have opportunities to work within the field and research laboratories of faculty members, and in industrial, government or community placements. Research findings will be communicated to peers, instructors, and members of the broader community in a variety of ways. Written communication of research results will be encouraged through the embedded scientific literacy program (see below) and an annual *i*Sci Research Forum will be held in the spring. Students will also be encouraged to present their research at national and international scientific meetings.

Inquiry-based learning will be an important component of the *i*Sci program but some learning will take place in more traditional lecture, tutorial and laboratory settings. Presenting material in a traditional lecture format is often the best way to ensure that difficult concepts are clearly explained and a body of knowledge is covered in a well organized manner. We recognize that some concepts and skills need quite a lot of repetition to be mastered. For example, one cannot be proficient in mathematics by doing just a few sample math problems. Students must solve many problems of each type, with spaced repetition, before the appropriate skills can be mastered. Nevertheless, we will endeavor to place a good part of this repetition within a motivating research context, and early training in Matlab will provide students with the opportunity to repeatedly relate mathematical functions with graphical representations. This will add a strong "empirical" component to the study of applied mathematics, which should help to make some of the most-difficult material more accessible to the students.

Ideally, the *i*Sci program would be residential, as this will enhance attempts to fully immerse the students in their own educational experience. The inquiry and problem-based nature of all projects will have their optimal effect if the students feel a strong sense of community and ready access to colleagues when grappling with the thornier elements of their assignments or as a sounding board for their latest ideas. We do need to be careful not to isolate the *i*Sci students from other students, many of whom will be as bright and motivated as they are. We want the *i*Sci students to develop a strong sense of community, but we don't want them to feel that they are somehow superior to students in other programs. On the other hand, students graduating from the *i*Sci program should have a very different approach to science compared to students graduating from discipline-based science programs. Again, the demonstrated success of McMaster's Arts & Science Program over the past 25 years is a striking argument for the effectiveness of creating a small, closely knit intellectual community of students.

It is expected that *i*Sci graduates will more fully appreciate the type and range of scientific information and analyses required to solve complex problems. They will have a broad understanding of science along with specialist knowledge in their chosen field. They will also have well-developed scientific and life-long learning skills and will know how to ask questions, how to acquire, critically evaluate and analyze data, and how to communicate their research findings to others. These students will be ideally prepared to be future scientific leaders.

The *i*Sci program should function with some degree of autonomy within the Faculty of Science. It should have its own Director and Administrative Assistant and requires dedicated space for administrative offices, a library/common room, seminar room, and casual meeting and discussion spaces. Students entering the program should have a minimum average of 88% and will be required to complete a supplementary application before acceptance. The supplementary application questions and guidelines for reviewers has already been completed and is attached in Appendix XX.

III. Outline of the Proposed Program

The proposed *Integrated Science* program is a unique, interdisciplinary, research-based science program targeted toward highly motivated, high achieving students. The 4-year, direct entry program takes an exciting new approach to the study of science at the undergraduate level and will provide students with knowledge, skills and tools to excel in their future careers.

A major part of the program, from Level I, will center on supervised inquiry-based learning. The learning experience will be heavily project-oriented, rather than course oriented. At all stages, the supervised learning will also be interdisciplinary, and lab projects will generally be supervised and graded by at least two faculty members. A number of excellent software packages have been developed over the last decade that make it easier to simulate real life research problems and tools and get away from cookbook labs.

In Levels I and II, the curriculum content will be taught in a fully integrated way, unlike any program that currently exists in Canada. Essential knowledge and skills from each of the fundamental scientific disciplines (Biology, Chemistry, Computer Science, Earth Science, Mathematics, Physics, and Psychology) will be linked partly through ‘thematic modules’ (see below) that emphasize the overlapping content between discipline areas. The development of mathematical tools and techniques will occur in the same class time, and with the same instructors, as the "applications" from biology, chemistry, and physics. For example, when the conservation laws of energy and momentum are introduced, students will immediately see the mathematics of gradients, level curves, scalar fields, the solutions of multiple equations, and will be introduced to major software packages such as Matlab. When harmonic motion is introduced, so will solutions to differential equations. In this way, students will be exposed, not only to the details of each subject area, but also to the connections and interactions between them. Much of the learning in the *i*Sci program will be inquiry-based and students will be involved in interdisciplinary research projects throughout the program. There will be a strong emphasis on ‘hands-on’ (experiential) learning involving field and lab work and opportunities for internships with industry and government agencies. Links and interactions with the local community will be encouraged through creation of a ‘Program Advisory Board’. In Levels III and IV students will be able to combine the ‘core’ *i*Sci program with an ‘associated’ science discipline through selection of appropriate electives in a similar way to the McMaster ‘Arts & Science and Another Subject’ program.

Level I *i*Sci will be covered in one innovative 24-unit course that will include a fully integrated delivery of Biology, Chemistry, Mathematics, and Physics (see “Strategies for Integration” below). Also included will be brief elements of Earth Science, Astrophysics, Psychology, Neuroscience, and Computer Science, which all rely heavily on the first four disciplines. The essential Level I knowledge base for all of these areas (required by all students for a seamless access to Level II) has been identified by representatives from each discipline and will be included in the 24-unit integrated science course.

a. Core Content and Integration Strategies

It is essential that *i*Sci students acquire the core knowledge required to function effectively in this and other programs and to develop optimally as research scientists. Consequently, the committee has spent considerable time identifying core content in each discipline. Before we can devise integration strategies, we must know what it is that we are attempting to integrate. A summary core content map is attached in Appendix I. This includes topics such as thermodynamics in physics, vector calculus in mathematics, reaction kinetics in chemistry, and genetics in biology.

Following the identification of core knowledge requirements, we tackled the problem of integration. The committee felt that the most-efficient approach would be to first deal separately with the integration of mathematics and physics on the one hand and life sciences and chemistry on the other. Once this was done, we tackled the somewhat more-difficult objective, which was full integration.

i. Physics and Mathematics:

First year Physics and Mathematics courses traditionally occupy themselves with Classical Mechanics and Calculus, respectively. The historical development of these two topics makes them particularly well-suited for integration. This is not what is presently happening in the majority of university programs in science and engineering. Mathematics professors, following the rigidity of their textbooks, move from one type of functions to another in compartmental fashion. A typical progression would begin with functions from the real line to the real line, their limits, derivatives and integrals, and proceed to scalar functions of several variables, their graphs, partial derivatives, gradients, tangent planes and multiple integrals; vector-valued functions of one variable and the curves they trace, their tangent vectors, lengths, and line integrals; and finally, vector fields, their divergences, curls and Jacobians, and surface integrals.

When examples are needed to clarify a concept, mathematics professors resort to Physics. However, they often use concepts out of context, drawing incorrect logical relations, or introducing concepts at the wrong time relative to when they are covered in the physics course being taken by the students at the same time. As a result, when an example is introduced too early (e.g., when the fluid mechanics notion of circulation is introduced before the difficult concept of fluid velocity is explained) it confuses rather than clarifies a mathematical concept. Conversely, when an example is introduced too late (such as conservative forces and path independence for line integrals), the mathematical concept appears as a superfluous complication for something already understood by the students in what appear to be simpler and more intuitive ways.

Conversely, physics professors, embedded in the enormity of genuinely deep and interesting concepts that need to be conveyed to students in the short confines of first year, either neglect the mathematics that is being developed in calculus as being unnecessarily complicated or mistrust the extent to which students really can learn a mathematical concept. As a result, the necessary mathematical background is developed ad-hoc, with a mixture of timidity and dismissiveness that under-utilizes the techniques actually learned by students in calculus.

An integrated approach to Classical Mechanics and Calculus in Level I easily avoids these negative results. Starting with the premise that students are admitted to the *i*Sci program already knowing the fundamental concepts of one-variable calculus and vectors in three-dimensional space (as learned either through the high-school Calculus and Vectors course or equivalent remedial modules prior to the beginning of the *i*Sci Level I course), the order of subsequent Calculus topics can effectively be chosen in accordance with the logical development of physical concepts.

The first part of the proposed integrated Level I course deals with one and two-dimensional kinematics, including trajectories, velocity and acceleration of particles in rectilinear or arbitrary planar motion. This immediately brings attention to a non-trivial mathematical topic: the dual role of two-dimensional vectors, on the one hand identified with pairs of points describing a path and on the other hand with the tangent to a path at a given point. Deep mathematical concepts, such as the distinction between vector spaces and affine spaces can be effortlessly addressed in this simple context. On a more-practical level, several examples of integration and differentiation of simple functions (polynomials, trigonometric functions, exponentials and logarithms) can all be given as one goes from positions to velocities to accelerations and back.

The second part of the proposed curriculum focuses on Newton's laws: the effect of forces on motion. On an elementary mathematical level, this presents an opportunity to review operations on vector spaces (e.g., addition of forces, decomposition in different components), as well as the introduction of the sophisticated concept of a vector field: the assignment of a vector (force) to different positions in space. The statement and applications of Newton's second law provides an introduction to simple differential equations. The rich example of a harmonic oscillator allows for the concept of general solutions to homogeneous first and second-order differential equations to be fully discussed. A damped oscillator is an ideal way to introduce particular solutions to an inhomogeneous differential equation. Several other interesting and intuitive examples can be explored at this stage, making full use of the physical intuition (pendular motion, resonances, etc) to explain mathematical properties.

Conversely, general mathematical results can lead to the analysis of unexpected physical regimes that students would likely not be able to derive from intuitive reasoning alone. This last feature (the discovery of effectively new physics from the use of mathematics) can be further enhanced by concrete applications of numerical algorithms, thereby introducing students to fundamental ideas in numerical analysis (errors, stability, convergence, etc).

Other major topics include conservation laws, fluid mechanics, gravitation, and rotational motion, all with their mathematical counterparts.

ii. Life Sciences and Chemistry:

The words "This is a worm" were uttered by many introductory biology professors from the 1960s through the 1980s to launch the academic terms at reputable institutions. The Life Sciences field was reinvigorated after the 1980s, following exciting advancements in technologies, notably molecular, genetic, and genomic methods. However, these innovations tended to find their way into introductory courses that still followed rather traditional strategies. The result was that statements like that above were transformed into “This is a *Hox* gene” -- contemporary, but uninspiring. The life sciences component of the integrated Level I course for the *i*Sci program has been designed to revolutionize introductory life sciences education, make it exciting, and to produce life science visionaries rather than trainees.

The Level I curriculum provides for students familiarity with fundamental principles in biology and chemistry while including complementary topics from computer sciences, Earth sciences, and psychology and, simultaneously, linking to fundamental principles in the mathematic and physical sciences. This integration will 'equip' students in the program with the same intellectual tools possessed by their peers in other programs, but the material will be presented in a completely synthesized, interdisciplinary context. The curriculum will include from biology the topics community and population ecology, cell function and structure, genes, amino acids, proteins, transcription, translation, Darwinian evolution, and population genetics. These naturally are associated with the chemistry topics reaction kinetics and rates, stoichiometry, acids, bases, pH, molecular structure, and simple organic reactions.

The Level I integrated science curriculum can also be organized around a series of fundamental scientific concepts. For example:

1. Concept: Energy and Entropy. As soon as the academic term begins (while the weather still is pleasant), a fieldtrip will be conducted in which students will be introduced in a practical manner to the principles involved in community ecology. Students will be led through Cootes Paradise, a local nature preserve that abuts on McMaster University campus. Energy will constitute the currency with which communities will be examined and analysed, which will provide an appropriate concept to link with the physics topics potential and kinetic energy and their associated mathematics, later during the term.

2. Concept: Change. Still early in the autumn term, a second fieldtrip will be conducted, in which students will be introduced in a practical manner to the principles of Earth science and stratigraphy. Students will be lead through local geological sites and quarries (McMaster University resides near the Niagara Escarpment, which provides abundant exposures of geological formations for students to explore).   Successional change will constitute the concept with which geological formations will be examined and analysed, and will provide an appropriate concept to link with the physics topics mechanical forces (which operate over geological time scales to elicit the patterns that students will observe) and Newton's Laws and their associated mathematics, later during the term.

Having examined change on a geological timescale, students will be primed to parallel how biological change is manifested over similar timescales, according to Darwinian natural selection. This will provide an opportunity for instructors to include the topic evolutionary psychology, which will empower students with understanding how complex behaviours originate and are modified over time.

3. Concept: Probability. Having become familiar with population-level thinking, students can start to consider change over shorter timescales. Population genetics (*e.g.*, Hardy-Weinberg-Castle equilibrium) and population ecology (*e.g.*, growth dynamics) will be introduced, each utilizing some previously established mathematical tools (*e.g.*, differential equations and harmonic motion, respectively) but also being utilized to introduce the concept of probability and expectation. (In addition, computer science techniques like simulation could be implemented to enrich students' repertoires and experiences - *e.g*., examining rapid population growth leading to chaos in a virtual world).

Probability will be used to link to thermodynamics and solving multiple equations simultaneously, which, in turn, can be utilized to link to the chemistry topics reaction kinematics and rates, stoichiometry, acids and bases, molecular structure, and simple organic reactions. Having established these links, the biology topics genes, amino acids, transcription, and translation can be integrated seamlessly.

iii. Full Integration:

Full integration of core science content is already beginning to be evident in the above descriptions. Ideally, most sections of the Level I course will be team taught by at least two instructors at any one time. For one set of lectures, the team may comprise a physicist and a biologist. For another, the team might include an Earth scientist and a mathematician. Yet another section might require a physicist, mathematician and a neuroscientist. What will make this work is the extensive interdisciplinary collaborative experience that is already common at McMaster University. Together with the excitement and commitment that this program has engendered, we are fully confident that it will not only be implemented as described, but will continue to develop effective integration strategies that may be applied to other courses and programs.
Of course, "full integration" does not mean all disciplines contribute to all lectures/discussions. In some cases, the focus will be on integration between 2 or 3 relevant disciplines. In others, there may simply be reference to relevant topics from other disciplines. Inevitably, there will be sets of lectures where the focus has to be on difficult concepts or skills within a specific discipline. Nevertheless, in all cases, there should be a natural segue into the application of the newly acquired knowledge and skills to other topics and other disciplines. For example, following a set of 3 lectures on a topic in mathematics, the instructor may be joined by a computer scientist and a neuroscientist to demonstrate how the recently learned knowledge can be applied to the modeling of neural networks and how that modeling can, in turn, be applied to solving problems in neuroscience and engineering.

iv. Integrating Themes

In addition to the many examples, problem sets and laboratory assignments that will draw heavily on cross-disciplinary, collaborative research problems, we intend to use a set of integrating themes or threads that will serve to further drive home the importance of multi-strategy and multi-discipline approaches to solving problems large and small. Some of these themes have a distinctly physical science flavor and some lean more toward the life sciences, but, in all cases, they will include input from all disciplines. These are not courses. They are theme areas that can be revisited periodically in any course throughout all 4 years of the program. The themes also provide an opportunity to draw from various departmental colloquia and Origins Institute speakers that pass through the University. Some examples of themes that could be used to foster integration of course content are listed below; descriptions of the content of two of the themes are also presented.

Suggested themes:

- Deflecting an Asteroid
- Averting a Pandemic
- Teleporting a Spaceship
- Searching for Life on other Planets
- 'Terraforming' – Creating Another Earth
- Materials for the 21st Century
- Global Contamination
- Building a Brain
- Cancer – occurrence, diagnosis and cure
- Body Composition
- Mission to Mars

The following two examples of theme areas show how this integration strategy is intended to work.

1. Searching for Life on other Planets: This theme involves not only cross-disciplinary content, but also shows different levels of integration operating in different scales of research. On an astronomical scale, the most relevant questions are of physical and mathematical nature: the habitable zones around stars, the nature of orbits, the possibility of life other than in planets, and the consequences of gravity, angular momentum, and Kepler's laws to the sustainability of life.

On a planetary scale, there are opportunities for cross-disciplinary studies on the chemical and biological basis for life, as well as use of mathematics in explaining the probabilistic nature of evolution, in particular the effect of mutations in evolutionary timescales. Extrapolating from examples on Earth, geologists and biologists can present examples of extremophiles and investigate their implications on the understanding of conditions for life.

Thirdly, the search for life on other planets poses difficult experimental questions. Biologists and physicists need to work together on the issue of detecting signatures of life by means of physical phenomena, such as radiation. For sending actual probes to other planets, mathematicians and physicists need to address the problem of orbital transfer times and their implications on the samples to be brought back to Earth. This raises the question of performing measurements "in situ" and sending back only their results, as opposed to the actual organic traces and signatures of life. In such cases, mathematicians will need to assist biologists in the analysis of data pertaining to experiments done remotely, and the corresponding theoretical implications supported by such analysis.

2. Building a Brain: This theme is clearly anchored in the neurosciences, perhaps the most interdisciplinary of all the sciences, and it provides many opportunities for collaboration in both teaching and research. In addition to input from neuroscience, psychology, biology, computer science, mathematics, physics (including medical physics), and chemistry, it provides opportunities for input from health sciences, kinesiology, engineering, anthropology, and economics.

Within the Building the Brain theme, we can explore a variety of topics. One of these, the origins of brain and behaviour, will focus on the evolution of neural systems, behaviour and intelligence. This topic and topics in brain organization will be covered largely by the biologists, neuroscientists, and psychologists, with input from computer scientists and mathematicians. Topics in neurophysiology require an understanding of biophysics, membrane physiology, molecular biology, electricity, and a variety of modeling approaches and will be covered by neuroscientists, biologists, physicists, chemists, and mathematicians. Teaching students about perception will require input from biologists, psychologists, neuroscientists, chemists, and physicists (particularly for light, sound, electricity and optics). The same disciplines will be addressing problems in motor control, with additional input from engineering and kinesiology. Finally, topics in cognition and social behaviour will require input from psychologists, biologists, computer scientists, medical physicists, and mathematicians. Themes of this type can tap into the widespread interest in brain and behaviour and give the life science-oriented students additional motivation for mastering physical, mathematical, and computational science skills.

b. Workshops

Some core scientific skills, such as laboratory and computing techniques, are best introduced in specific workshops. In these workshops, the students can learn the techniques before their application in the context of the laboratory projects. The Level I integrated science course will include a series of workshops to allow development of the appropriate skills (e.g., Matlab, which will be used extensively throughout the program): Workshops will run approximately one hour in length, and the associated “laborials”, which consist of more hands-on and project-based activities, will run two hours in length. Some workshops stand as integral parts of the skill-building components of the program, while some will be available as remedial training for the students with a lower level of background knowledge.

i. Example workshops: *i*Sci *Computing Workshops and Laborials*

Our Computing Workshops and Laborials provide good examples of what we have in mind. There are 7 of these planned so far. They will be distributed primarily over the first 3 years of the *i*Sci program. The Workshops and Laborials include the following:

Workshop *i*Comp-01 – **Introduction to Computing**
Workshop *i*Comp-02 – **Computer as a WorldWideWebWindow**
Workshop *i*Comp-03 – **Understanding the WorldWideWeb**

Workshop *i*Comp-04 – **Computer as a Computational Engine**
Workshop *i*Comp-05 – **Computer as a Programmed Engine**
Workshop *i*Comp-06 – **Computer as a Research Tool**
Workshop *i*Comp-07 – **Computer Aided Research Instruments**

These workshops will move from a consideration of the *Computer in Modern Science Activity*, including philosophical concepts and a study blueprint, to training in the use of the computer as a computational engine and research device (e.g., we will cover computer interfacing for controlling instruments, monitoring their status, and collecting and analyzing data). The latter skills will be covered as required, probably in Levels II and III. The 7th Workshop will take advantage of the variety of applications of computers in collaborative research activities at McMaster University and will include sessions in the MRI research facility at St. Joseph's Hospital, the MNR reactor gold seed production facility, and the Accelerator (ion-human interaction). This will give the students an opportunity to see the application of high level applied mathematics and programming skills to solving complex problems with large data sets where there are many interacting variables.

c. Laboratories

Perhaps the most-serious deficiency in contemporary science education is the lack of effective hands-on research experience in Levels I to III (and even Level IV). Many of the lab courses that are offered are designed to present established phenomena and understandings, rather than to discover new knowledge. The goal of the *i*Sci degree program is to provide students with an environment in which original research is a major component of this program throughout all four years. Recent work has shown that it is possible to organize original research tasks for first year undergraduates. For example, in the life sciences at the University of Pittsburg, the Phage Hunters Integrating Research and Education (PHIRE) program was used to provide the support required for students to do original and meaningful research centered on bacteriophage discovery and comparative genomics (Hanauer, et al., 2006). We will use similar approaches in Level I. By Level II, these students will already have many opportunities to work closely with faculty supervisors in a truly collaborative research setting. Each laboratory sequence will begin with an introduction to basic skills, equipment, and instrumentation appropriate for that section.

i. Mapping: Earth Sciences, Physics, Mathematics

To support the projects that follow, it is necessary that students learn to measure location with some degree of precision. With a little ingenuity, even a GPS device can be a useful interdisciplinary laboratory tool. GPS devices work by calculating the distance between the device and some number (greater than 3) of satellites orbiting Earth. The GPS devices can be used in field trips in a variety of ways. They can be used to promote a sense of community in the program via a simple geocaching exercise (basically a treasure hunt). But they can also be used to teach a variety of topics in several science disciplines. They can be used as a tool to map geological formations and geomorphic features. Along with baseplate compasses, elementary E&M, declination, triangulation, and topography can be covered. To understand how the GPS devices work, it is necessary to discuss propagation of electromagnetic waves. A great deal can be learned by raising the issue of measurement accuracy and how it can be assessed. The GPS device tells us where we are by intersecting several different spheres with radii given by our distance to the given satellites. In fact, it can also tell us our "position" in a four-dimensional space, therefore telling us what time it is (provided the number of satellites is greater than 4). The experimental error for the measurement of distance propagates into the final error for the coordinates given by the GPS device. This can be tested in the classroom by having students a few meters apart, with different GPS devices, reading the exact same coordinates, which indicates the precision level for the instrument.

This type of problem involves a discussion of both physics and mathematics, and it can be revisited as the students acquire more expertise. The exact way in which the accuracy calculations are performed require General Relativity corrections and are too intricate to do in class. But estimates tell us that not taking into account such corrections would quickly lead to an accumulated error of a few hundred metres.

ii. Earth and Sun: Physics, Mathematics, Statistics, Astronomy

2200 years ago the Greek scientist Eratosthenes correctly measured the circumference of the Earth by using nothing more than elementary geometry and astronomy. To carry out a modern version of his classic experiment, students would track the position of the Sun in the sky during the day and measure its highest angle at noontime. Many different such measurements would be collected together over weeks and months, from the largest possible variety of locations around the Earth (for example, from those who go to Florida during Christmas break or reading week, as well as those who stay home). All these measurements can be combined to deduce the latitude differences and the radius of the Earth. The necessary background for the analysis will involve understanding the details of the seasonal change in the Sun's latitude, which in turn involves calculating the combined effects of the noncircular shape of the Earth's orbit plus the tilt angle of its rotation axis. The more data and the more students involved, the better the experiment will work.

iii. Moments of Inertia: Physics, Computer Science, Mathematics (up to 1 week)

Patterned after one of the current physics labs, students could look at moments of inertia. They could add active rotational inertia component in bicycle wheels, gyroscopes, or even swivel chairs with students.

iv. Bacterial DNA: Geosciences, Biology, Chemistry (up to 6 weeks)

Several of the life-science oriented projects that are being planned for the Integrated Science program, focus on bacteria. Bacteria are relatively easy to handle, and their effects are relevant in all science disciplines. It would be straightforward to build on existing cross-faculty connections to develop laboratory projects in bioremediation

(Geography and Earth Sciences, Chemistry, Biology), virulence (Biology, Biochemistry), antimicrobials (Biology, Chemistry, Biochemistry,), membrane fluidity (Physics), and epidemiology (Biology, Mathematics). Topics such as microbiology, bioremediation, and the bacteria-antimicrobial resistance produced by antibiotics rank high in students' interest. They connect to problems of interest to everyone, including infectious diseases and environmental cleanup. Fortunately, we have ample expertise in these areas at McMaster University. Also, the recently successful CFI "Chemical Biology of Microbial Systems" will add more infrastructure and faculty in this area. What follows are examples of labs that could be used in the program. Only a few would be used in any given year.

The primary task in the Bacterial DNA lab is to determine the bacterial populations present in different environments. It brings together field techniques, including mapping and sampling, with molecular techniques such as cloning and characterizing bacterial DNA. Screening for bacterial DNA is a good undergraduate lab task, because bacteria are relatively easy to work with and bacteria species are so plentiful (e.g., a tablespoonful of soil can contain several 100 different bacterial species). This lab project truly offers students the opportunity to make novel findings, which is unusual for a Level I laboratory experience. This unit covers all Level I lab skills required in Geosciences and Biology (if protein standard curves are added), and several of Chemistry's required skills.

1. Field portion: Students collect several samples of water, soil, and vegetation from different areas. The local area and industries provide numerous options for these collecting trips, and different lab teams may choose different projects:

- Collect soil/water samples from nearby areas that have been heavily impacted by humans, such as Cootes' Paradise or Hamilton Harbour. Experiments could tie in nicely with a variety of ecosystem, demographic, economic, and industrial issues.
- Collect samples of locally grown fruits/vegetables grown under either conventional or organic conditions. Findings here could tie in with public health, ecosystem, and economic issues, including those relevant for agribusiness.
- Sample from icewine grapes before and after frost. Do bacterial populations vary with temperature, soil, season, grape, age? Findings tie in with significant local industry.
- Sample the excrement of McMaster's large goose population.
- Collect samples from feathers of migrating birds (banding stations at Long Point).

2. Lab portion: Students would characterize bacterial DNA present in different samples, thus learning how to 1) isolate genomic DNA, 2) estimate DNA concentration and levels of protein contamination using a spectrophotometer, 3) clone DNA into vectors, 4) do PCR, 5) sequence DNA, 6) work with genomic databases, and 7) do Gram staining. Students may also be able to transcribe and translate DNA and then do simple scans for function (i.e., grow on limited media, test for antibiotic activity, test for resistance to various compounds, etc).

v. Synthesize and test molecules: Chemistry, Biology (up to 3 weeks)

Part 1:
Synthesis of a simple bioactive molecule, such as acetylsalicylic acid (acetosal).

Part 2:
Apply synthesized molecule to cultured cells and measure effect. If acetylsalicylic acid, one possibility is to assay prostaglandin synthase via Western blot.

vi. Bacterial growth: Chemistry, Biology, Physics, Computer Science, Mathematics (up to 1 week)

In this technically straightforward, interdisciplinary lab, students would innoculate sterile suspension solutions with bacteria (possibly from Lab #1). They would then observe morphological changes in cells with growth and measure population growth using turbidimetry measurements. They will write their own simple programs to plot values and to determine goodness-of-fit to an exponential growth curve, and will determine over what range the spectrophotometer readings follow Beer's Law.

vii. Reaction Kinetics: Chemistry, Mathematics, Computer Science

a) Using persulfate-iodide reaction and reduction of iodine by thiosulfate, measure amount of free iodine left after consumption of thiosulfate by production of starch-iodine complex. Students record times to development of a blue starch-iodine complex for several different conditions. Determine the experimental rate law and the activation energy and Arrhenius constant for this reaction.

b) Measure spectra of known K3[Fe(CN6)] solutions (discussion of Beer's law). Run kinetics trials for oxidation of ascorbic acid by hexacyanoferrate. Vary NaNO3, pH and temperature to test effect on reactions. A biochemistry component could also be added with an additional section on enzyme kinetics.

viii. Heat exchange-metabolism: Physics, Biology, Computer Science (up to 1 week)

Stefan's Law measurements, and surface-to-volume measurements of heat loss, will be taken in the appropriate labs. The lab will deal with theoretical considerations of body size in biology (eg, "Kleiber's Law," "Allen's Rule," Bergmann's Rule") and will also include a section on enthalpy measurements.

ix. Photosynthesis: Chemistry, Biology, Computer Science, Physics, Geosciences (up to 3 weeks)

Students would prepare chloroplast suspension from plant material of different types (or collected in various locations, to involve Geosciences through mapping). Photosynthesis will be measured using Hill's Reaction (photoreduction of an artificial electron acceptor). The students would then write simple programs to analyze their data. This project could include experiments with temperature, light intensity w/ wavelength, or considerations of energy input to synthesize a mole of glucose.

x. Soil and water contamination: Chemistry, Geosciences (up to 4 weeks)

Students would collect water or rainfall from various sources at differing times (i.e., w/ different prevailing winds) and determine concentrations of nitric and sulfuric acid by pH measurement and by ion chromatography for nitrate and sulfate. Using soil or rock samples, students could test for leaching of metals over time in acidic solutions (e.g., by using spectrophotometric assay for Fe, or recovering Cu from samples). This could become a chem/geo/bio lab by growing plants in "acid rain," or in contaminated soil obtained at sites in the vicinity.

All project reports would be written up and "published" in the *i*Sci online research journal. Students would also be given many opportunities to present their research to their peers and the *i*Sci instructors. Both the writing and presentation tasks would receive extensive feedback and make up a major component of the literacy training that will be another unique feature of the *i*Sci program. Finally, when appropriate, we would return to earlier lab projects and relate them to current course themes or extend those projects with addition measures. This will bring home early the importance of careful observation and record-keeping.

d. Literacy

The *i*Sci program will also intentionally teach "literacy" in its broadest sense. This component will be one of its most-distinctive features, unlike any other science undergraduate program in Canada. The students will immediately start learning about the nature of scientific writing; ethical practices in research; cooperative project work; and the best use of research resources including the library and internet. Critical thinking and written communication skills will be particularly well developed through the scientific literacy program.

i. Plan for Embedding Scientific Literacy in Level I and beyond

Literacy is characterized by *thoughtful, well edited writing* and by *familiarity with the best writing in a student's field.* It is a powerful professional tool, and does not come about by accident. Steps towards fostering scientific literacy will be embedded within the core components of the *i*Sci program.

Developing literacy will help create an intellectual environment where analytical thought and inquiry are respected. If these goals appear front and centre in Level I, and if it is made obvious that they are backed up by a well designed curriculum and reinforced during each succeeding year of the *i*Sci program, we can look forward to training a remarkable cohort of young scientists.

1. Reading: Within each of our 'core' disciplines appearing in Level I (Biology, Chemistry, Earth Sciences, Mathematics, and Physics), we will select a small number of essays, articles or book chapters that address key ideas in the discipline *and* that are superbly written. Papers from the refereed research literature are likely to be too demanding for this purpose. However, there is now a vast range of well written, insightful literature in every field of science aimed at educated but general audiences. These could provide at least some of the primary sources for Level I readings and discussion. The selected readings will be assigned throughout the year, as part of the 24-unit course. They could all be made available at the beginning of the year as part of a 'coursepack' or offered online on the *i*Sci program website. These items could be historical in nature or considered as comments on current frontiers or connected to the philosophy and methodology of science. The only criterion is that they should be linked in fairly obvious ways to topics studied in Level I. One or two components of the 'coursepack' could be made available as summer reading before the students arrive to formally begin Level I.

2. Writing: Some of the students may come into the program already knowing how to write clear, concise prose. However, many will not have those skills and may not even realize what factors distinguish poor writing from good. Developing these skills should therefore be included at appropriate points throughout the Level I course and throughout the program (along with laboratory training and other professional skills and techniques). The Committee felt that writing skills should account for about 8% of the training in Level I.

The only way to learn to write well is to write frequently and with some regular form of guidance. Good writing is good writing, regardless of where in the academic spectrum it comes from. However, science writing differs from "creative writing" in the humanities in that it becomes easier and more purposeful if the students *have their own work to write about* (a lab experiment, the result of a project, or a literature search). In Level I they will have such work to draw on only towards the end of Term 1 and in Term 2. So, a sequence of writing assignments might look like this:

(1) Learn the principles: grammar, syntax, spelling, organization. Professional scientific writing needs above all to be clear, concise, and with logical flow. Learn about correct documentation of sources and what plagiarism means. Learn what constitutes acceptable sources for literature searches (refereed literature vs. Wikipedia).
(2) Illustrate quality of writing from *both* good and bad examples (What makes each item good or bad?).
(3) First writing assignment: A précis-like discussion of the previously assigned course readings (as described above), with some emphasis on the "take-home" messages and relevance to other knowledge that the student has acquired.
(4) Peer editing: The "writing class" will meet weekly with the instructor; divide up into peer groups of 5 students each who will work together throughout the term to read and criticize each other's work. These groups might be the same as the Project Working Groups carrying out stages of the Theme Project for the year. In

a broader sense, peer groups can create an ongoing interactive environment in which everyone is sharing their techniques, successes and failures. Because the *i*Sci students will be strong academically, we can expect them to reinforce each other in learning how to construct well thought out, well expressed arguments and summaries of their work. Accountability *to each other* is potentially the most powerful incentive for building the morale, and quality, of the *i*Sci program.

(5) Use the finished written assignments as bases for short oral presentations, again given in the weekly writing groups. In this way, many or most of the assigned writings can be discussed widely in the entire class. Use these sessions as opportunities to learn what constitutes valid scientific debate.
(6) Throughout the term, develop a major summary or report on the Theme Project. This work could easily be broken into stages and subgroups, but the end product should be a single, comprehensive document that has been "built" by the entire class. The document should be like a professional paper, with background, theory, new analysis, summary, and citations.
(7) In Term 2, go through the cycle again but with the stakes raised: assign somewhat higher-level readings and raise the standards for their writing.
(8) Finish the year with an *i*Sci Symposium Day in which all the instructors and students will present and review the results of the entire Theme Project.

At every stage, students in the *i*Sci program should be encouraged *to write for an audience.* In our normal undergraduate curricula, students write lab reports or essays that are read only once and by only one person: a TA or an instructor. The item is graded, filed away, and forgotten. In the new *i*Sci program, we have an opportunity to take a different direction. The students can write for each other and help each other become better writers. They can collect and publish their combined work (using media of their own choice!). Engagement, immediacy, and accountability in written communication will take a completely different form to that in other undergraduate programs.

Teaching this component of the curriculum will need leadership from an unusual teacher-scientist willing to engage with the students, and to work with them as "another writer" who is also still trying to master the same art. In addition, we need TAs who can spend the time to evaluate the students' weekly writing. At the beginning, senior undergrads from Arts & Science can be used; once the *i*Sci program is mature, its own senior students can be used.

In creative writing, students are often encouraged to keep a journal for themselves as a way to have an ongoing record of personal thoughts, ideas, and rough drafts. This activity helps to keep the raw elements of writing constantly moving and developing. This approach can be readily adapted to the literacy component of the *i*Sci program. We will also use the newer digital media, including blogs and wikis, as forums for addressing a larger audience. The blogs allow for a more-personalized expression, while the wikis impose a greater degree of discipline. These approaches will be developed in collaboration with our library representatives and the helpful staff of the Learning and Technologies Resource Centre.

Of course, good communication skills require more than just writing. We will immediately start a tradition of an *Annual Poster Session* with an associated *Invited Lecture* near the end of Term 1. The poster session will give students an additional opportunity to share their research results. The invited lecture could be given by an instructor from within or outside of the *i*Sci program or by a visiting speaker. One of the objectives is to demonstrate effective presentation styles and techniques to the students and to show them the importance of being interesting (no doubt, they will come into the program having seen an ample number of counter examples). The poster session and invited lecture would be held on the last day of classes – late enough that it would not interfere with work on projects and assignments and early enough that students would not be distracted by exam preparation. All the students and instructors in the *i*Sci program will be expected to be present. The lecture can be followed up with a reception (very important to have food! "If you feed them, they will come") and maybe even a more-extended party will develop.

e. Quality Control

Given the high level of enthusiasm for the *i*Sci program expressed by the members of both committees, we expect a strong commitment to the program from those selected to teach in it. In fact, the program will provide the opportunity for many instructors to finally teach science the way they have always felt it should be taught. Both laboratory and writing assignments will frequently explore the boundary zones between scientific disciplines.

We also anticipate that the faculty who teach in this program will be talented teachers able to demystify complex material and exercise good judgment about difficulty levels and pace. Nevertheless, built into this program will be a strong collaboration with CLL, LTRC and the library. A program like *i*Sci runs the risk of becoming too heavy, even for highly intelligent and disciplined students. In addition to the careful selection of teaching themes, projects and labs, it is essential that the learning process itself remain enjoyable and inspiring for the students. The folks at CLL, LTRC and the library, along with the highly collaborative teaching approach, can help us to reign in any excess of exuberance on the part of instructors and keep our teaching strategies fresh. They can also help us to evaluate the progress of these students appropriately and to evaluate the effectiveness of the program.

i. Assessing the Student:

On the surface, it may appear that the structure of the *i*Sci program will make it more difficult to assess the student's progress adequately for their mastery of the core content from the specific disciplines, particularly in Level I. Effective methods of assessment are essential if we are to assign component grades to these students that will serve as the measure for their suitability for upper level courses outside of the *i*Sci curriculum itself. However, we intend that these students should master the same core content as other students, and we already have the tools in hand to adequately evaluate mastery of that material. It is always more difficult to evaluate the presumed enhanced ability of these students to integrate and use this knowledge. Fortunately, there are standard procedures for doing this as well, and the smaller cohort of students makes it possible to use a range of assessment tools.

ii. Assessing the Program:

In order to effectively evaluate the success of the *i*Sci program we must address the question "What evidence do we have that we did what we planned?" One of the fundamental goals of the *i*Sci program is to educate students in a stimulating research environment that provides an interdisciplinary approach to science. It is our belief that integration across disciplines will lead to enhanced effectiveness of science education. In this regard, assessment of the students' academic performance will go a long way toward evaluating the success of the program, but we must be cautious in our comparisons. These students are selected for entry to the *i*Sci program on the basis of their demonstrated abilities and commitment to science. We intend to include ample test items from the standard discipline-centered courses, so that these students can be directly compared for their mastery of core knowledge. However, they must be compared with the appropriate population. Thus, we will identify a cohort of students, distributed across our traditional discipline-based streams that at least match the *i*Sci students in their entering grade averages.

Of course, mastery of core scientific knowledge is only one objective of the *i*Sci program. The program also aims to graduate students with highly developed scientific research and communication skills. Determining whether *i*Sci students are able to use and apply their newly acquired knowledge and skills in an interdisciplinary research environment more effectively than other students is perhaps our biggest challenge. We are still working on the development of techniques that will allow us to evaluate the level of research skills and abilities of our students in projects that require cross-disciplinary investigations. We also need to be able to discriminate the research abilities of the individual student from those of research supervisors and mentors.

Another aim of the *i*Sci program is to create a learning environment in which innovative styles of instruction are developed and applied. We will encourage course instructors to engage in professional development activities that will allow them to investigate and develop a range of instructional styles. In order to evaluate success in this area, we will ask CLL and LRTC personnel to conduct regular surveys and site visits and to provide feedback to instructors and the Program Director.

We plan to incorporate on-going assessment and feedback mechanisms into the *i*Sci program structure from the very beginning. This will involve designing a system for conducting regular formal and informal surveys of in-program and graduating students, and eventually of our alumni. We are investigating a variety of survey tools, including interviews, focus groups, and web-based questionnaires that may be used for this purpose. However, we also recognize that we may not be able to fully assess the success of the *i*Sci program in terms of the impact our students have beyond graduation until at least five years after the program begins. Tracking and maintaining contact with our alumni is important to assess how effectively our graduates function as leaders and catalysts of change in the scientific world. We intend to use web-based platforms such as 'Facebook' to maintain contact with alumni.

f. Application to Other Programs

Successful implementation of a program like *i*Sci can only be done with a relatively small cohort of highly motivated and high achieving students. Nevertheless, once the program is up and running and the integration strategies have been finely tuned, this program can be used as a model for organizing more-traditional courses in the Faculty of Science. Although we see our program design as optimal for the instruction of integrated research science, there are many elements that may be applied to other discipline-focused programs and courses. Many of the tools and approaches developed for the *i*Sci program can be used to reorganise existing courses so that the interrelationships between scientific disciplines are clearer. Of course, this will require consultation between instructors from the different disciplines, but the existence of a proven program of integration will be a strongly motivating influence on other science instructors. The Dean of Science is fully committed to this objective, and will provide the leadership to ensure that it happens.

IV. Levels II, III and IV

The second year of the *i*Sci program includes 18 units of program coursework that will continue to emphasize integration and collaborative research. Again, physics and mathematics will be major components of the Level II course. For example, the Level II course will include quantum mechanics, relativity, linear algebra and chemistry (through quantum mechanics, itself, with more-advanced thermodynamics and some physical chemistry).

Students in Level II will have the background to explore more complex biological systems that deserve appropriate physical/mathematical treatment. So, the physical science content will be matched by a life sciences component that includes physiology, cell biology, microbial biology, and plant biology, as well as a neuroscience-biophysics component, which will include the electricity and magnetism content usually offered in Level I. This material will be introduced in the context of one or more neuroscience themes and will involve some linear algebra.

The components described above will take up about two thirds of the Level II *i*Sci course, with the understanding that they should cover enough discipline-based material to allow students to switch to other Honors Science programs if they wish. The other one third of the course will be heavily laboratory oriented and will include a thematic research project, workshops, journal club, and additional discussion of issues in scientific ethics. A series of workshops dealing with instrumentation will appear in Level III and augment the laboratory portion of the course.

V. Sense of Community: Space and Residency

Our goal is to nurture a strong sense of community and camaraderie amongst students, faculty and staff involved in the *i*Sci program, and many of the features of the program have been designed with this goal in mind. Two proven influences on developing and maintaining a sense of community in academic programs are physical space (the program's "home base") and residency.

a. The *i*Sci Home Base

Space needs for the *i*Sci program were defined after extensive discussions with the people who run the McMaster Arts & Sciences program. It is clear that their home space is heavily used by the students for a variety of academic activities. We have identified our space needs based on features that work in the Arts & Sciences program.

A minimal home base for the *i*Sci program would include offices for the program Director, Administrative Assistant, and Secretary. It is critical that the students have ready access to these key people in their academic lives. There should also be a well equipped seminar space, large enough to house 25 students and a general workspace-meeting space-lunch space that could serve a variety of purposes. In the Arts & Sciences program, many of the students use an equivalent space as their home base between courses and as a place to work on group projects.

The space should be available 24/7, so it needs to be secure. A small computer cluster housing about 3 computers is necessary, but sufficient, because most students now own their own laptop computers. Most students also now have wireless capability, so the *i*Sci space needs to have a node for a wireless connection. Other facilities include a copy machine, a FAX, and a printer.

b. Residency

In consultation with other programs that target smaller numbers of highly motivated students engaged in frequent problem-based learning and inquiry projects, the committee came to the conclusion that one of the most effective ways to instill a sense of community among the students was to make Level I of the *i*Sci program a residency program. We have learned that the number, intensity and quality of student interactions increase dramatically in residency programs. This is not surprising. Even faculty members who hold multidisciplinary interactions dear can find it difficult to engage their colleagues when they're only a building or two away!

VI. *i*Sci Orientation

Our efforts to instill a strong sense of community will begin even before the students attend their first lecture, during orientation week. A unique set of activities have been planned for the incoming *i*Sci students. There will, of course, be the usual orientation activities centered on university life and campus facilities, but what sets the *i*Sci orientation apart is that it is designed to introduce the students to the very new culture of interdisciplinarity and inquiry-based learning that is characteristic of the *i*Sci program.

a. Field Trip

The Hamilton area is home to several excellent locations that serve as natural laboratory settings to expose students to a variety of interesting, interdisciplinary research questions. The *i*Sci program will have the use of one of the McMaster University Research vans to bring the appropriate scientific instrumentation into the field at nearby locations such as the Royal Botanical Gardens, Cootes Paradise, or the Niagara Escarpment. The topics that can be addressed in this one day field workshop include simple exercises in Earth science, ecology and ethology. If the workshop runs into the evening, the students could end the day by looking to the heavens and considering some interesting aspects of astronomy. It is at this point, that the students will first begin their personal journal entries that will serve as an accumulating log of their experiences in and progress through the *i*Sci program and that will serve as part of the literacy training over the course of the program.

b. Introduction to McMaster's Major Research Facilities

Most Science students complete their undergraduate degree programs with little knowledge of the research facilities outside of their own particular field of study. This lack of familiarity with existing facilities often applies to their own discipline, as well. McMaster houses a variety of major facilities, including the fMRI at St. Joseph's Hospital, the particle accelerator, the center for minimal access surgery, the Shared Hierarchical Academic Research Computing Network (SHARCNET), to name a few. We have arranged for tours of these facilities to take place during *i*Sci orientation week. Each of the facilities will be briefly described by a local scientist who will outline some of the projects that make use of the facility. However, these will not be passive tours. They will include active-learning components that will engage the students more deeply in the exploration of these research tools. By the time these students have completed their tours, they will already know more about McMaster's research infrastructure than many of our faculty members.

c. Introduction to Literature Searches and Critical Appraisal Strategies

In addition to the usual introduction to library services, search engines, e-journal portals, and so on, we will provide some discussion around assessing the quality of retrievable information, including several examples of bad and good science and bad and good critical appraisal. This part of the orientation will cover two days and include several simple group exercises. Again, this could provide material for students to enter into their personal journals. The students will also be exposed to their first few examples of good and bad scientific writing.

d. Research Ethics

The pressures to produce are not unique to publishing research scientists – for the student, similar pressures take a step up in intensity as he or she enters University. It is not surprising that ethics, including research ethics, is accepted by everyone as an essential component of a student's training. However, the actual time spent on discussing ethics can be as little as one brief workshop in Level I. Recognizing the importance of instilling a strong sense of research ethics, the *i*Sci Committee has designed the program to include a continual dialogue with the students around this topic.

VII. Personnel and Administration

The *i*Sci program will be administered by a Director (with similar duties to those of the Arts & Science Program Director), a full-time Administrator, and a Program secretary. The *i*Sci Program Director will report to the Dean of Science. Undergraduate matters are dealt with by two committees within the Arts & Science Program and a similar structure is proposed for the *i*Sci program. One committee will consist of instructors and student representatives ('Council of Instructors') and will deal primarily with issues and proposals relating to course content, delivery and format. A second committee will involve elected faculty members from inside and outside the program, student representatives and invited members of local industry, business or government agencies ('Program Advisory Board'). The Program Advisory Board will deal with issues relating to program structure, design and development. It is anticipated that students will have considerable input into the program design.

The *i*Sci program will also require a number of dedicated and enthusiastic instructors who are able to communicate the excitement of interdisciplinary research science to students. We anticipate that the majority of instruction within the *i*Sci program will be conducted by tenured and tenure-track members of faculty who are excellent instructors and also have active research programs. The *i*Sci program will require 8 faculty members to be 'bought out' from their departmental units. We also require four Teaching Professors who will be responsible for teaching certain components of the *i*Sci courses, coordinating the teams of instructors, designing and conducting evaluation mechanisms and supervising students in research projects. The Teaching Professors will also be required to teach courses for Departments/Schools from which faculty members have been seconded to instruct in the *i*Sci program. We will also require an allocation of graduate and undergraduate Teaching Assistantships.

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