Undergraduate Specialist Program in Pathobiology at the University of Toronto

Douglas M. Templeton, PhD, MD1 and Avrum I. Gotlieb, MD, CM, FRCPC1

Abstract
Following a merger of the Departments of Pathology, Clinical Biochemistry, and part of Medical Microbiology, our faculty agreed to deliver a new, unique undergraduate program “Specialist in Pathobiology” at the University of Toronto, in order to teach current concepts of mechanisms of disease to students selected from the large undergraduate science population. The emphasis was on molecular and cellular aspects of pathogenesis and not on the clinical practice of laboratory medicine and pathology. Based on the then new Department of Laboratory Medicine and Pathobiology, we drew upon our large faculty and new recruits in both basic and clinical science to deliver a new curriculum that is unique and dynamic. We began admitting students in 2000, and we have now graduated our 15th class. In this study, we describe our philosophy and goals for the program, and report its success based on student outcomes and innovative course offerings.

Keywords
disease mechanisms, pathobiology, pathology education, undergraduate education

Introduction
Science students entering their undergraduate years at the University of Toronto (UT) are generally differentiated into those that will pursue Bachelor’s degrees in the life sciences or the physical sciences. Some of the students registered for the 4-year degree are selected to enroll in Specialist programs that are equivalent to an Honours degree at most Universities. The terminology at UT reflects the notion that in a 4-year program, sufficient time is available for students to specialize in a deeper study of a particular discipline. Students in the Life Sciences stream at UT usually choose a Specialist program as a “second entry” program at the end of their first year. These students are registered in the Faculty of Arts and Science. Because of the preeminence of the UT Faculty of Medicine as Canada’s largest medical school, a number of the scientific disciplines reside in this Faculty, and while its raison d’être (vis à vis teaching) is training for the medical profession, it has long recognized the broader mandate of educating undergraduate students registered in Arts and Science.

In view of the above considerations, the Faculty of Medicine at UT is nominally divided into the basic medical science departments (eg, Biochemistry and Physiology) and the clinical departments (eg, Medicine and Surgery). It is a reasonable generalization that emphasis on academic research and teaching has been more focused in the basic medical science departments. This is reflected in a higher ratio of PhDs to MDs in these departments, and at times during the Faculty’s history academic tenure has been restricted to those in the so-called basic medical sciences. Perhaps understandably, then, until September 2000, teaching of undergraduate science students by faculty in the clinical departments was quite limited, and

1 Department of Laboratory Medicine and Pathobiology, University of Toronto, Toronto, Ontario, Canada

Corresponding Author:
Douglas M. Templeton, Department of Laboratory Medicine and Pathobiology, University of Toronto, 1 King’s College Circle, Toronto, Ontario, Canada M5S 1A8.
Email: doug.templeton@utoronto.ca
Specialist programs were the exclusive domain of the basic medical sciences. Thus, it was the new clinical Laboratory Medicine and Pathobiology Department that broke this tradition by introducing a basic undergraduate program with support from the Provost’s Academic Priority Fund to recruit additional tenure-stream basic scientists.

In the 2000/2001 academic year, the Department of Laboratory Medicine and Pathobiology became the first clinical department in the Faculty of Medicine to offer a full Specialist program through the Faculty of Arts and Science. The existing Specialist programs offered by the basic medical sciences departments at that time were in Biochemistry, Physiology, Pharmacology and Toxicology, Nutritional Sciences, Immunology, Molecular Genetics and Molecular Biology, and Microbiology. At the time we introduced this program, the Faculty of Arts and Science was looking to enhance the undergraduate experience at the UT by offering more Specialist programs, so our initiative was welcomed. Our aim was to take advantage of the resources and expertise of the medical school to present a unique program in the basic science of human disease; our hope was that it would provide a selected group of interested students with a sound foundation in life and biomedical sciences that would enhance their future education as either research graduate students or students in the health professions.

Prospective students commonly ask “what is the difference between ‘pathobiology’ and ‘pathology’?” Many later add the words “pathophysiology” and “pathogenesis” to the question. Pathology can be defined as “the medical science concerned with all aspects of disease, but with special reference to the essential nature, causes, and development of abnormal conditions, as well as the structural and functional changes that result from the disease processes.”1 As a medical practitioner, the pathologist uses this science to achieve diagnoses that contribute to patient management and prognosis; recognition is key. This is not a goal for the science student. We can define pathobiology for them as “the study of disease mechanisms and processes; whereas pathology is concerned with understanding causal relationships and diagnosing disease, pathobiology more broadly encompasses the mechanistic basis of disease, stressing the stepwise biological events, as well as the medical aspects of pathogenesis.”2 As graduates, they will use their knowledge to help elucidate processes by which diseases arise (pathogenesis). Although aspects of pathophysiology are woven into our courses (it is meaningless, for instance, to teach cardiovascular pathobiology outside the context of circulatory physiology and hemodynamics), our focus is on cellular and molecular events, as insight at this level has revolutionized the way we research and manage disease.

The basic sciences of biochemistry, physiology, histology, cell biology, immunology, and microbiology come into play in pathobiology. One generalization is that those disciplines teach science students the “normal,” whereas in contrast we teach the abnormal in each case. This poses a somewhat philosophical question in the design of a pathobiology program: should it teach the normal and aberrant side by side—perhaps an unrealistic objective—or rely on each of the other disciplines to provide a foundation for the students, who then learn only about disease from us and draw their own comparisons? We have chosen the pragmatic compromise of requiring a number of basic courses in other disciplines and reinforcing this knowledge in our own introductory course using examples of disease processes. The higher level courses deal more exclusively with the investigation of disease but continue to reinforce basic concepts of human biology. The approach is necessarily interdisciplinary, and Laboratory Medicine and Pathobiology is in the enviable position of having a very heterogeneous faculty whose research programs introduce students to the broad scope of basic medical research.

Methods

Aims and Rationale

The seeds of a program in Pathobiology germinated with the founding of the Department of Laboratory Medicine and Pathobiology in the 1990s but were debated by scientists, clinicians, and educators in the precursor departments of Pathology, Clinical Biochemistry, and Microbiology. Four considerations impelled us forward as the new department was formed.

1. Teaching of knowledge of Pathobiology to create informed citizens play an appropriate role in the university. Over the past several decades, improved techniques in molecular biology have yielded tremendous insights into the molecular and genetic basis of numerous diseases. With the genome in hand and proteomics developing apace, we can only expect this course of discovery to accelerate. It behooves society to expend resources on research to take advantage of this opportunity and on a health-care system to exploit the results for better diagnosis and treatment. Ethical and political aspects of health issues are debated daily in the media. To contribute to informed decisions, citizens must have some understanding of basic discovery research and the basis of human health and disease; what is feasible and what is not. It is opportune, then, to introduce a program that teaches the mechanisms of disease in the undergraduate curriculum.

2. The University has an obligation to use its academic resources in an effective way to benefit its undergraduate students. Universities have an obligation to use their intellectual resources to the best advantage. Departments of Pathology and Laboratory Medicine present a unique resource for teaching Pathobiology. The medical specialists concerned require analytical, knowledge-based skills common to those required in basic, translational, and clinical research. Such departments in major academic centers are characterized by basic and clinical scientists working more closely together than in most settings and thus afford the science student unique opportunities for broad intellectual
growth. Pathologists and laboratory physicians are custodians of human biological material and have an understanding of how to use this material to generate new knowledge of the pathogenesis of disease. These skills should be taught to future basic researchers and not be reserved only for physicians-in-training. And, pathologists and laboratory physicians have the knowledge to teach undergraduates the clinical, anatomical, and histopathological analyses of animal model systems that are essential to study human disease.

3. Recruiting future research and clinical trainees is desirable. Committed academics feel a strong enough affinity for their own discipline to want to recruit future colleagues with similar leanings. We survey an undergraduate population that will contribute in the future, each according to his or her abilities and intellectual needs, to research (as graduate students), to medical care (as residents in training), or to both as physician scientists. We wonder what is a desirable balance for our Pathobiology program to achieve between graduates pursuing professional or further research training. We hope that some will stay with us as graduate students, and others eventually return as Residents in pathology and laboratory medicine; we will not be disappointed if some choose alternative careers in public health, public service, industry, or other academic or nonacademic pursuits. This raised a major consideration for us as we planned a medically based program in an undergraduate science faculty: to what extent do we attract only those undergraduates desiring to enter Medicine? If some students are dissuaded from choosing medicine in favor of graduate studies, and conversely if others who were not considering medicine come to see it as an appropriate option for them, then we would feel we had enlightened our students to a variety of possibilities afforded by academic careers in the biomedical sciences. Our data on outcomes (see below) suggest this is the case.

4. A new Department of Laboratory Medicine and Pathobiology should maximize its potential as a unique teaching resource. Thus, we sought to use this program to bring the discipline closer together to strengthen teaching and research. Because we are a department that harmoniously combines basic and clinical research, our faculty enjoyed teaching medical students, science students, and both. Many of the basic scientists in our clinical department who train health-care professionals welcome the opportunity to interact as well with basic science students, with whom they may share a common background and future. It is hoped these clinical physicians will feel closer to the academic core of the University through this program. A Specialist BSc program opens doors for our faculty to interact with students and colleagues from all walks of academic life, as science students also require credit courses in the physical sciences, arts, and humanities. This positions us not only to build bridges with other professional faculties but with the full academic life of the University.

We educate these selected students in the foundations of pathobiology, with the expectation that most of them will contribute to the society through academic and nonacademic careers in the many facets of the medical and biological sciences.

**Historical Development**

For one of us, the idea of an undergraduate program in molecular medicine directed to science students began with the perceived need to reorganize a core graduate course in clinical biochemistry along molecular lines that better suited the thesis research in which our graduate students were engaged. After unsuccessful attempts to offer a joint graduate/undergraduate course—the focus on research and a perception of being judged equally with PhD students was daunting to even the best prepared undergraduate engaged in a demanding full 4-year program—we instituted a separate undergraduate Fourth-Year course in “Mechanisms of Disease,” modeled on the lines of the lecture-oriented didactic expectations of the undergraduate student of the time. This class was offered for 5 years and typically enrolled 80 to 100 students per year. Most of these students were motivated by interest and not restricted by the demands of the structured curricula of other specific Honours/Specialist programs. Observing the top students in the class, however, convinced us of the need for a more extensive program that would better cater to those intending to pursue graduate-level research. In addition, Pathology and Microbiology offered successful single courses in the Faculty of Arts and Science, again without a programmatic focus. The opportunity to meet the needs of interested students in a programmatic context arose when our Department merged and we were able to recruit a complement of basic science tenure-stream faculty to mount the new undergraduate program, and at the same time grow our research capabilities significantly.

An important development facilitating a Pathobiology Specialist program was a significant restructuring of the curricula in several of the basic sciences. Chemistry replaced its traditional First-Year course in general chemistry with 2 half courses, one of which was an introduction to organic chemistry. Our students still take more advanced organic chemistry in the Second Year, but the First-Year introductory course provides sufficient background to begin the study of biochemistry. Thus, the introductory biochemistry course, traditionally given in the Third Year was moved to Second Year. The Second-Year Biology course requires First-Year organic chemistry and recommends biochemistry to be taken concurrently, allowing a more sophisticated presentation of a course entitled “Cell and Molecular Biology.” Most of our students take the nominally Third-Year human physiology courses in their Second Year. Thus, our students now complete Second Year with a strong foundation in physiology, cell biology, and biochemistry, in addition
throughout the academic year. This course covers aspects of
include those taken in our department.

Several years after the introduction of our Specialist pro-
gram, UT began allowing students to substitute a double Major
program, with fewer disciplinary requirements for each Major,
for a Specialist program. Our applications dipped, but we
retained our acceptance standards, and happily our enrollment
has rebounded to predouble Major levels (see Outcomes,
below). An attrition of the double Major for a number of
students was the opportunity for greater breadth in undergrad-
uate education. Pathobiology Specialists have come to under-
stand that specialization is not a barrier to breadth for
exceptional students and indeed feeds into it. At UT, the aca-
demic year consists for most students of fall and winter terms of
13 weeks each, and a half-credit is given for a course completed
during one of these terms. Graduation with a 4-year degree
requires completion of 20 full credits, with 13.5 specified as
requirements in our program (see Table 1). Most of our stu-
dents choose to take additional courses; in 2017, in 20 of 22
students graduating had taken additional courses, the average
being 23.2 credits. This also facilitates completing a Major in
addition to our Specialist; 18 of 22 students graduating in
Pathobiology this year (spring, 2017) did a major in addition
to the Pathobiology Specialist (often in Immunology but also in
Biochemistry, Physiology, Biological Chemistry, Neuro-
sience, Computer Science, and Statistics).

**Curriculum Design**

First Year in life sciences at UT could be considered as a
general year to bring students from diverse secondary school
backgrounds up to a common level in the basic sciences and
mathematics. Because we have felt it as most appropriate to
introduce core Pathobiology only in Third Year, after the foun-
dation courses, we did not consider previously a model of an
early introductory course followed by multiple in-depth studies
tied together with a capstone course in the final year. So, we
present a survey of pathobiology in 2 terms in the Third Year,
with a separate 1-term course in neoplasia, allowing room for
additional basic science courses. This is followed with Fourth
Year where students mostly study a series of special topics
within our Department. In common with other science pro-
grams, students are required to fulfill a breadth requirement
with 2 full course equivalents in the arts and humanities, but
many of our students take more. The required courses in a
typical program are listed in Table 1, but there is some flexi-
bility as to when the courses are taken. For instance, some
student take the Year 4 Research Program in Year 3, freeing
time for additional courses in year 4 that may or may not
include those taken in our department.

The Third Year presents a core introductory course running
throughout the academic year. This course covers aspects of
cell death and adaptation; tissue damage, healing, fibrosis, and
remodeling; pathophysiology of the blood and lymphatic sys-
tems; metal ion fluxes, balances, channels, and pumps; iron
metabolism, the hematopoietic system, and transfusion med-
icine; and introductory aspects of cardiovascular pathobiol-
ogy, endocrine diseases, neurodegenerative processes,
medical microbiology (bacteriology, virology, and parasitol-
ogy), genetics of disease, and toxicology. A laboratory com-
ponent is coordinated between this core course and the course in
neoplasia to provide 6 consecutive weekly sessions examin-
ing gross and microscopic specimens and histopathology.
These are especially well received by the students, who con-
sistently request more of these sessions. Fourth-Year courses

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**Table 1. Curriculum of the Program.**

| Required Courses                                                                 | Weight (FCE) |
|-------------------------------------------------------------------------------|--------------|
| **Year 1**                                                                     |              |
| Biology (cell)                                                                 | 0.5          |
| Biology (ecology and genetics)                                                 | 0.5          |
| Chemistry (general and physical)                                               | 0.5          |
| Chemistry (organic)                                                            | 0.5          |
| Mathematics (calculus)                                                         | 2 × 0.5      |
| Physics                                                                        | 2 × 0.5      |
| **Year 2**                                                                     |              |
| Biochemistry                                                                   | 0.5          |
| Biology (molecular and cellular)                                               | 0.5          |
| Chemistry (physical)                                                           | 0.5          |
| Chemistry (organic)                                                            | 0.5          |
| Molecular genetics                                                             | 0.5          |
| Genetics (evolutionary)                                                        | 0.5          |
| Physiology                                                                     | 2 × 0.5      |
| **Year 3**                                                                     |              |
| Biochemistry (advanced molecular biology)                                      | 0.5          |
| Biochemistry laboratory                                                        | 0.5          |
| Immunology or microbiology                                                     | 2 × 0.5      |
| Introduction to pathobiology                                                   | 1.0          |
| Neoplasia                                                                      | 0.5          |
| **Year 4**                                                                     |              |
| Four courses from:                                                             |              |
| Inflammation and infection                                                     | 0.5          |
| Immunopathology                                                               | 0.5          |
| Connective tissue disease                                                      | 0.5          |
| Cardiovascular pathobiology                                                   | 0.5          |
| Lymphatic pathobiology                                                        | 0.5          |
| Genetic models of disease                                                      | 0.5          |
| Neurodegenerative disease                                                      | 0.5          |
| Forensic pathobiology                                                         | 0.5          |
| Microbial pathogenesis                                                        | 0.5          |

*Abbreviations: FCE, full course equivalents.

1Student typically take 5 FCEs per year with most formerly 1 FCE course (e.g., in
the year 1 basic sciences) now split into two 0.5 FCE. Twenty FCEs are
required over the 4-year program, including, in addition to the required
courses, at least 1 FCE in each of the social sciences and the arts and huma-
nities. In year 3, students may take either 2 immunology courses or 2 micro-
biology courses, although some take both. Histology (0.5 FCE) and anatomy/
embryology (0.5 FCE) are recommended, but not required, in year 3 as some
students have difficulty fitting them into their program, especially, if they are
taking a major in another subject. In year 4, if the student takes the research
project (1 FCE) only 3 of the year 4 Pathobiology courses are required.

1Courses offered by the Laboratory Medicine and Pathobiology Department.
provide a more in-depth examination of cardiovascular pathobiology, immunopathology, inflammation, microbial pathogenesis, disorders of bone and matrix, lymphatic pathobiology, genetic models of disease, and forensic pathobiology.

Exercises are designed to introduce the students to critical evaluation of the primary scientific literature. In the Third Year, students write an in-depth critique of a recent journal article. Depending on their course selection, they prepare at least 1 research proposal in their final year. They are given tutorials in using the literature, searching electronic data bases, and proper use of citations. These tutorials are conducted by graduate student teaching assistants, most of whom are previous graduates of our program.

Participation in Departmental research activities is strongly encouraged. A Research Opportunities course is offered for full credit in the Second Year, common to all Life Sciences programs. A full credit is also given for a Fourth-Year research project which requires at least 1 full day a week throughout the year to be spent in the laboratory of a supervisor chosen from our graduate faculty. At the end of the year, a written report is presented and defended orally. Twenty of our 22 graduates in 2017 completed this optional requirement, several having taken it in their Third Year and following up with further noncredit research in their graduating year. Participation in a Laboratory Medicine and Pathobiology Summer Student Research Program is encouraged in part by a Faculty-wide Life Sciences Studentship. Because of the high academic standards for entrance to our program, most if not all of our students qualify for this award, and we offer partial stipend support to our students who qualify when they work with faculty in our Department.

For the past 3 years, we have presented an interactive half-day workshop on career planning in biomedical and life sciences research in our summer research program. This is part of the cocurricular and mentorship activities offered to our Pathobiology students throughout their undergraduate program. Our students also access relevant material from a career planning book published by one of us.3

Results and Discussion

The program has undergone 3 very laudatory, mandated, Provostial reviews as part of the 5-year Departmental reviews that occur at UT. The external reviewers and the Provost have noted that the program is "an excellent departmental offering” with “truly exemplary academic leadership” by the program director and “excellent teaching and innovative courses.” Our main student success metric is the success of our graduates as listed in Table 2. Our students show exemplary leadership skills and continue to be recognized with competitive leadership awards from the university.

The number of students seeking admission to the program rose from 44 in its inaugural year (2000) to 123 by 2003. We do not have accurate data for the number of rejected applicants in intervening years, but applications peaked at over 150 in the midyears and have stabilized at about 60 in the past 5 years. A sharp dip in applications occurred in 2010 and corresponded to the University introducing the option of a Double Major to replace the Specialist, and this had appeal for many students. This situation has stabilized now with sufficient applicants of high quality to sustain our desired enrollment.

Figure 1 shows the class size each year, taken as the number of students in the restricted and mandatory year 3 class (LMP300, introduction to pathobiology), together with the minimum grade point average (GPA) accepted for that cohort as they entered year 2. Because only pathobiology specialists take LMP300, this is the best indicator of enrollment mid-program. As expected, the minimum GPA rose steadily from 3.11 in the first year of the program to 3.74 in its fourth. It then plateaued at 3.89 by 2006, where it has remained between 3.86 and 3.93 since. In the years from 2010 to 2013, corresponding to the decrease in applications, we decided to decrease our enrollment in order to maintain the GPA cutoff, and we have
seen a steady rebound in class size since then. Note that all values reported here are minimum GPA values for students accepted into the program. In all years, the top of the range is 4.0 and class average GPAs have not been calculated.

Numbers of students completing the program and graduating each year are expressed as % of the LMP300 numbers (Figure 2). Data are unavailable for the 2 earliest years of the program, but overall there has been a clear increase in the percentage of students graduating over the course of the program. In the past 7 years, graduation rates have been mean 92% (standard deviation 6). Generally lower rates of completion prior to 2011 reflect a change in the admission policies in Provincial medical schools (and notably at UT). Students could apply to medical school during Third Year, and some of the top applicants were accepted without completing an undergraduate degree. Today, the admissions process shows a clear preference for those who have, or will have, completed a degree at the time of entrance to the MD program, with the result that almost all our Specialist students complete our 4-year program.

A snapshot of immediate outcomes was provided during a Departmental review in 2013 in which we were able to contact 99 of 141 students (70%) who graduated between 2007 and 2012. Of these, 52 attended medical school, 33 entered graduate school, and most of the remainder followed other related pursuits. A detailed breakdown is given in Table 2.

Our Specialist students have created a community of young scholars through the Laboratory Medicine and Pathobiology Student Union that is entirely organized and run by our enterprising students. Laboratory medicine and pathobiology student union provides undergraduate student mentoring, social activities, outreach volunteer programs, and career development seminars for its members. Each year they organize and present an all-day symposium on a state-of-the-art topic in biomedical and life sciences research, with local and external speakers, which is attended by students and faculty from across many University Departments. The January 2017 Conference attracted over 400 registrants. This has become a highlight of our academic year.

**Conclusion**

An undergraduate program in Pathobiology for Arts and Science students has been successfully implemented at the UT and is in its 17th year. Taught by basic and clinician scientists, it consistently attracts applications from an adequate number of highly achieving and highly motivated applicants, from whom 20 to 30 are selected each year. We educate these selected students in the foundations of pathobiology, with the expectation that most of them will contribute to society through academic and nonacademic careers in the many facets of the medical and biological sciences. The great majority of graduates do proceed to further training in biomedical graduate research (MSc or PhD) or to medical school.

**Declaration of Conflicting Interests**

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**References**

1. Stedman’s Medical Dictionary. 27th ed. Baltimore, MD: Lippincott Williams and Wilkins; 2000:1332.
2. Duffus J, Templeton DM, Schwenk M. Comprehensive Glossary of Terms Used in Toxicology. Cambridge, United Kingdom: Royal Society of Chemistry; 2017:496.
3. Gotlieb AI. Planning a Career in Biomedical and Life Sciences: Making Informed Choices. New York, NY: Elsevier; 2015.