The Dimensions of Graduate Education in Biomedical Informatics and Computational Biology

The Biomedical Informatics and Computational Biology (BICB) graduate program is an interdisciplinary graduate program that offers Ph.D. and M.S. degrees. The program attracts students across a broad range of prior experiences and disciplines. Because of the breadth of the field, the program is highly individualized, and students have few courses in common. Each student individualizes their plan of study in close collaboration between the faculty adviser(s). Therefore, to develop a plan, a student must be able to articulate their goals. Likewise, to guide the student successfully, faculty must gain sufficient knowledge about the student’s goals and abilities. Sustained and multi-faceted mentorship is particularly important for Ph.D. students. While there are differences in the expectations for a M.S. versus Ph.D. degree, many of the outcomes are similar and only vary in degree.

This document articulates the different dimensions of a successful graduate education in biomedical informatics and computational biology, and was developed in consultation with the graduate faculty and graduate students of the BICB program. The dimensions are (1) Scholarly Formation, (2) Communication, (3) Leadership and Collaborative Skills, (4) Professional Responsibility, (5) Cultural and Global Awareness, and (6) Personal and Professional Management Skills. Scholarly formation is the primary outcome of graduate education; the other dimensions may vary in importance depending on the student’s goals.

Overall Assessment and Milestone Achievement
Since the program is highly individualized, each student should develop a plan to define their own goals and objectives based on this document and develop measurable outcomes. The plan should include a timeline that indicates when the student plans to meet the major program milestones. This plan should be reviewed at least annually by their faculty adviser and the program director during the annual evaluation. The program will develop a way to assess the goals during the annual evaluation.

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1 The dimensions were developed in the document Initial Ideas for a Pilot Program to Develop Graduate Student Learning Outcomes, authored by the Graduate Student Learning Outcomes Assessment Committee. This committee was established in Fall 2012 by Henning Schroeder, Vice Provost and Dean of Graduate Education.

2 The Graduate School publishes Degree Completion Steps for the different degree types and the program lists milestones in the Graduate Student Handbook.
1. Scholarly Formation

Biomedical Informatics and Computational Biology (BICB) are highly interdisciplinary fields. Working in these fields requires a knowledge base spanning the foundational fields of the mathematical and computational sciences and the life/health sciences. Prior to entering the program, students typically gained a strong knowledge base at the baccalaureate level in one foundational field (primary field) and some familiarity with the other foundational field (secondary field).

Foundational Field Competency

BICB graduate students must gain depth and breadth in both the primary field and the secondary field in order to conduct research, communicate with peers, and act as a translational conduit between the fields. Each foundational field is extremely broad, encompassing many sub-fields (disciplines). During graduate study, students must broaden their core knowledge in their primary foundational field, and significantly deepen their expertise in at least one discipline within their primary foundational field. Students should follow the same approach in gaining sufficient knowledge in the secondary foundational field, albeit to a lesser extent.

Knowledge and Skills

Life Science Skills

Knowledge in life sciences is essential. All students need a fundamental understanding of biology at the molecular and cellular level, and, depending on their area of research, also at the tissue and population level, to assign biological meaning to results of computational analyses. Furthermore, all students should have some experience with modern laboratory techniques and experimental processes to gain an appreciation of the “messiness” of experimentally obtained data.

The expectation for proficiency levels depends on the individual. However, in general,

- M.S. students with a primary foundational field in the life/health sciences should broaden and deepen their knowledge base across sub-disciplines, and reach expert level in sub-disciplines relevant to their research.
- M.S. students with primary foundational field in the computational sciences should obtain a broad understanding of biological processes, and proficiency in sub-disciplines relevant to their research.
- Ph.D. students with a primary foundational field in the life/health sciences should broaden and deepen their knowledge base in their chosen sub-discipline. These students should develop a level of mastery such that they can independently design and oversee the laboratory portion of experiments.
- Ph.D. students with a primary foundational field in the computational sciences should broaden their knowledge across sub-disciplines and gain proficiency in sub-disciplines relevant to their research so that they can independently interpret the biological meaning of the results from computational analyses.
Computational Skills

All BICB students need exposure to algorithms, statistics, and databases. They should understand the principle methodologies and algorithms in their chosen field. For example, students in biomedical informatics should be familiar with fundamentals such as dynamic programming, alignment algorithms, etc., and students in computational biology should be familiar with core methodologies in parallel and high performance computing. Furthermore, all BICB students should acquire and demonstrate advanced research skills and be ready to challenge existing practices. Furthermore, students should seek opportunities to apply their computational knowledge to domain applications.

- M.S. students should broaden and deepen their knowledge base in relevant computational and mathematical sciences sub-disciplines. They should become familiar with software packages and be able to determine the advantages and shortcomings of specific methods and tools at hand to complete their tasks.
- Ph.D. students should broaden and deepen their knowledge base in relevant computational and mathematical sciences sub-disciplines, and achieve mastery in at least one relevant sub-discipline. Ph.D. students are expected to develop novel algorithms and methodologies to advance their chosen sub-field. Furthermore, these novel algorithms and methodologies should be applied to a real biological problem, and the results interpreted in terms of their biological significance.

Programming Skills

Programming skills are essential. In order to implement algorithms, students should become proficient in at least one scripting language (Python, Perl, etc.) and one high-level language (C, C++, Java, etc.). In order to perform basic to moderate statistical analyses and data mining, students should become familiar with at least one high-level technical computing language for programming, data analyses, and visualization (R, Matlab, SAS, etc.).

The expectation for proficiency levels depends on the individual. However, in general,

- M.S. students with a primary foundational field in the life sciences should develop moderately complex programming skills in order to use and modify existing tools.
- M.S. students with primary foundational field in the computational sciences should broaden and deepen their programming proficiency in order to develop new software tools.
- Ph.D. students with a primary foundational field in the life/health sciences should develop proficiency in current algorithmic approaches in order to solve problems in their sub-discipline, challenge current practices, and develop new algorithms.
- Ph.D. students in with a primary foundational field in the computational sciences should broaden their knowledge across computational sub-disciplines and gain a deep understanding in at least one computational sub-discipline. These students are expected to have an expert level of programming, and be prepared to challenge current practices and develop new algorithms.
Mode of Acquisition and Assessment
Breadth and depth of knowledge can be gained through course work, independent study, and research projects. Student should seek multiple ways of formal and informal assessment, including

- Regular discussions with their faculty adviser(s) and other committee members
- Discussions with collaborators and peers
- Formal assessment of coursework through exams and projects
- Oral or poster presentations at conferences
- Preliminary exams (Ph.D. only), thesis (Ph.D. and Plan A M.S.), project (Plan B M.S.), oral defense (Ph.D. and Plan A M.S.), and oral exam (Ph.D. and M.S.)

High-throughput Technology Competency
At the core of Biomedical Informatics and Computational Biology is the analysis of large amounts of data. The vast majority of the data come from high-throughput instrumentation. Therefore, students should gain familiarity with the different types of instrumentation and associated data, together with analyses methodologies. Students should gain a deeper understanding of the specific instrumentation and data they are working with, and need to gain practical experience with data, learn about the limitations of the current methods, and develop the ability to come up with work-arounds that are “good enough for practical purposes.”

Mode of Acquisition and Assessment
Students should demonstrate practical experience with both high-throughput technologies and analysis of associated data. This should be a key component of their research thesis or project, and should be directly assessed via final oral presentation and oral exam. In addition, Ph.D. students should demonstrate readiness to work with relevant large data sets by the time of their preliminary written and oral exams.

Critical Thinking
Students must develop the ability to evaluate and to give a balanced view of information relevant to their area of expertise. Thus, students must become familiar with multiple approaches to science, including familiarity with the scientific method and deductive approaches of the mathematical sciences. Furthermore, students must become sufficiently knowledgeable to be able to critique their peers’ work and self-critique their own work.

Mode of Acquisition and Assessment
- Journal Club discussions
- Colloquium reflections
- Discussions with peers, collaborators, and faculty
- Preliminary exams, thesis or project, and oral defense

Lifelong Learning
Biomedical Informatics and Computational Biology are fast evolving fields because new technologies continue to produce new types of data, which in turn drives the need for the development of new
analytical techniques that can extract knowledge from that data. Thus, BICB students need to develop a commitment and the means to life-long learning.

**Mode of Acquisition and Assessment**
This could be accomplished, for instance, by integrating self-directed learning in the program, such as encouraging students to take seek out the many informal and formal online learning opportunities, including You Tube videos, free online lectures, or MOOCs.

**2. Communication**
The program recognizes the diversity in preparation of students. Students range from coming directly after completing their first baccalaureate degree without having gained any work experience to having already completed advanced degrees and established themselves as accomplished researchers. There is thus no “one size fits all” approach to acquiring communication skills. Communication skills should include the ability to explain the proposal or project in layman's terms but also its place within the broader scheme of things.

**General**
Students should be able to present their findings in written and oral forms, including quality journal papers, technical papers, conference abstracts, executive summaries, proposal, oral presentations, and poster presentations. It is important that both quality and timeliness of research communications are emphasized. For instance, in a professional environment, researchers are expected to produce an abstract or proposal within a much shorter time frame than is typical of assignments in a course or milestones in a graduate program. Furthermore, it is expected that students can write in clear and correct English.

Communication includes non-technical interactions, such as conversations between student and adviser, or supervisor and supervisee. Examples are communicating the needs to get a project done, giving updates on the progress of a project, and difficult conversations when expectations cannot be met. Students should also learn to get into the habit of suggesting solutions when problems arise and not simply mentioning the problems. Furthermore, students should be given opportunities to develop interviewing and networking skills, including the “elevator speech.”

Communication also includes gaining a deeper understanding on how scientists communicate the findings within their research community. Therefore, all students must become aware of the major peer-reviewed journals in their field. Furthermore, students need to gain knowledge about the journal publication process, from submission to publication. Finally, students must understand the standards of copyright and intellectual property.

**Mode of Acquisition and Assessment**
Different types of communication should be assessed via classroom presentations, publication in a peered reviewed journal, poster presentations, oral presentations at conferences, etc. The BICB Journal
Club offers feedback through peer review, and every M.S. student should present at least once, and every Ph.D. student multiple times to gain experience and receive feedback. The BICB Entrepreneurship and Leadership Seminar include professional communication. In collaborative projects, students should seek feedback from team members on their communication skills. Furthermore, to learn the ethical standards of professional publication, the BICB ethics course addresses various aspects and requires students to complete a plagiarism certification.

**Team Environment and Interdisciplinarity**
Because of the collaborative nature of the type of research conducted within BICB, it is important for students to realize the full breadth of communication needs. This ranges from keeping collaborators informed about progress to giving collaborators sufficient time to review abstracts submitted for presentation. Furthermore, many of our students will find themselves in infrastructure positions where they will serve research groups in their data analysis. It is important to develop the communication skills that help research groups connect the findings of the analysis to the interpretation.

Particular emphasis should be placed on communicating to diverse audiences to recognize that many of the interactions occur in an interdisciplinary space where few participants are knowledgeable across the relevant fields. This requires the ability to think in either field and to put findings in a context that can be understood by those who are not knowledgeable in both fields.

**Mode of Acquisition and Assessment**
In addition to coursework, much of this can be accomplished in the research lab a student joins. Furthermore, students should be given opportunities to present their findings in front of a research community, such as seminars or conferences. Students should also be given opportunities to communicate to non-technical audiences.

3. **Leadership and Collaborative Skills**
Collaborative skills are essential since much of the work is accomplished in teams, and bioinformaticians and computational biologists often play the role of the bridge between disciplines. To learn these skills it is important for students to get exposure to the full range of participating researchers, from clinicians to those managing the data.

Students will need to be prepared to provide leadership to teams of researchers with mutually exclusive knowledge and skills, and need to be comfortable with their own gaps in knowledge that are unavoidable when interacting across multiple disciplines. They need to learn how to recognize gaps in a team and be able to identify what skills are needed to fill the gap. This requires a higher-level understanding of what level of expertise and what skills are needed to accomplish the task at hand.

Students need to develop management skills and recognize different personalities on a team to develop successful teams. They need to develop the ability to define goals for a team and then manage the project to reach those goals in a timely manner.

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**Mode of Acquisition and Assessment**
These skills can be gained inside the classroom when working on group projects with rotating leadership roles, or outside of the classroom in extracurricular activities, including student government or volunteering in the community. Students should also be given opportunities to become active in the program through organizing and leading student activities. Students seek feedback from team members, (in particular, from experienced researchers) to assess and improve these skills.

**4. Professional Responsibility**
Professional conduct includes professional behavior in the workplace. Because many of the research projects our students are involved in and will likely continue to be involved in after graduation deal with sensitive data and have the potential for commercialization, it is important to gain an understanding of IRB, HIPPA, and intellectual property issues. Students also need to learn the standards of documenting their work.

Faculty should provide opportunities to prepare students to academic and non-academic careers. This includes not only exposure to the breadth of careers but also skills, such as resume writing and interviewing.

**Mode of Acquisition and Assessment**
BICB needs to continue to offer its own Ethics seminar that addresses professional conduct and the challenges specific to biomedical informatics and computational biology. The current Ethics course requires students to complete the basic IRB training.

**5. Cultural and Global Awareness**
Students gain global and cultural competencies in a variety of ways. About half of the students in the program are already working in a diverse workplace and are often collaborating with others from different cultures. Students who graduated more recently from an undergraduate institution typically gained cultural competencies as part of their undergraduate education or living in a diverse student community. Despite the frequent exposure to different cultures, the program should continue to identify opportunities for students to increase their cultural competencies to be successful in a global work environment.

Increasingly, collaborative teams will span continents. Furthermore, the job market has become global. It is not rare to see jobs advertised in the U.S. that would require the applicant to be willing to move to a different country. Because English is the *lingua franca* of the scientific community, the need to become fluent in another language has decreased. Nevertheless, when interacting with international teams, team members need to be aware of idiomatic expressions that may be unfamiliar to some team members.
Cultural and global awareness includes becoming sensitive to differences in behaviors across cultures, such as dealing with stress, different norms for men and women, pressures to achieve good grades versus learning challenging materials, dealing with failure, and providing and receiving feedback.

ESL students face additional challenges. Studying in a language they may not be as familiar with and living in a different culture can be quite stressful. Advisers, peers, and course instructors can help ESL students to adapt to the American culture and to overcome the language barrier.

**Mode of Acquisition and Assessment**
The program offers a course in ethics where cultural and global competencies needed to succeed should be discussed. Since the student population in the program is diverse and international, the already existing diversity should be utilized to engage students in such discussions. Discussions could also include the different educational models.

**6. Personal and Professional Management Skills**
“Know thyself,” the ancient Greek aphorism, applies today as it did millennia ago. Students need to engage in self-reflection to learn about their strengths and weaknesses, get a realistic sense of what they can accomplish, and determine how their personal style matches with expectations in their work environment. While any student at the graduate level is expected to be self-motivated, faculty expect their students to achieve results with a level of supervision that changes as the student becomes more proficient. Certain attributes, like the ability to persist in achieving long-term goals, to overcome difficulties and failure, or to be flexible and adaptable when managing complex or uncertain projects, contribute to a successful career. To be able to account for multiple projects with different deadlines is expected in the workplace, which requires time management skills and the ability to prioritize and to switch quickly between projects.

Since research projects are of much longer duration and different complexities than course-related projects, additional skills are needed to successfully complete long projects. For instance, it is important to identify the difficult parts of a project and not to put them off until later. While this goes counter to human behavior that seeks rewards over failure, experience has shown that tackling the hard problems first helps manage time on a project.

**Mode of Acquisition and Assessment**
Faculty have a responsibility to find ways to gain a good understanding of their advisees’ capabilities so that the projects match the students’ skills. This should be done in partnership with the advisee and faculty should not hesitate to have difficult conversations with their advisees if it appears that the project is not a good match. The faculty can also contribute to personal and professional management skills by offering workshops on project management, how to be a PI, and how to be a mentor, as these are life-long skills. Conversely, faculty can benefit from workshops on advising skills.
Assessment of BICB Goals

The University of Minnesota is in the process of establishing Graduate Program Goals for all its graduate programs. The BICB program participated in the pilot and developed goals around six dimensions:

1. Scholarly Formation
2. Communication
3. Leadership and Collaborative Skills
4. Professional Responsibility
5. Cultural and Global Awareness
6. Personal and Professional Management Skills

To assess how well we meet the goals, we are asking all students as part of the annual evaluation to complete the following questionnaire (type into the gray-shaded areas—if you hit return, the gray-shaded area will expand).

Name:

Degree (check box): M.S. Plan B ☐ M.S. Plan A ☐ Ph.D. ☐

1. Scholarly Formation
   a. Based on your goals and the goals set out in the document, briefly describe whether your degree plan will enable you to meet the expectations in the three areas: (a) life science skills, (b) computational skills, and (c) programming skills. Reflect on how the program or you could help you achieve your goals better.

   b. Briefly describe to what extent your coursework and other experiences have exposed you to high-throughput technologies and data.

   c. Self-reflect whether your educational experiences in the BICB program have enhanced your critical thinking skills, in what ways, and what the program can do to enhance critical thinking skills.
2. Communication
   a. Briefly describe whether you have had opportunities to increase your communication skills during this past year while in the program.

   b. Briefly describe whether you had opportunities to communicate to diverse audiences during this past year while in the program.

3. Leadership and Collaborative Skills
   a. Briefly describe whether you had opportunities to work in teams during this past year while in the program.

The remaining three goal areas depend much on your personal goals and your preparation prior to coming to the program: 4. Professional Responsibilities, 5. Cultural and Global Awareness, and 6. Personal and Professional Management Skills. We simply ask you to self-reflect on their relevance to your goals in the program, and ask for your suggestions on how we can help you achieve them.