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Applying a Linked-Course Model to Foster Inquiry and Integration Across Large First-Year Courses

Brian C. Husband, William J. Bettger, Coral L. Murrant, Kim Kirby, Patricia A. Wright, Steven G. Newmaster, John F. Dawson, T. Ryan Gregory, Robert T. Mullen, April Nejedly, George van der Merwe, Krassimir Yankulov, & Peter Wolf
University of Guelph

Abstract

Many first-year university courses are large and content-driven, which can contribute to low student engagement and difficulty involving students in the dynamic, cross-disciplinary nature of inquiry. Learning communities can address these goals, but their implementation often poses logistical challenges, especially in large courses. Here, we apply learning communities using a linked-course model to enhance student engagement and inquiry across three large, first-year biology courses. These three courses (Discovering Biodiversity, Molecular and Cell Biology, and Biological Concepts of Health) offer different contexts for biological inquiry, introduce key biological concepts, and are connected through jointly mapped learning outcomes, shared online skill workshops, and integrative learning communities composed of students from each course. Diverse modes of student learning are used across the three courses, and contemporary problems are explored within classes and small group seminars, which promote the development of skills necessary for inquiry. This course structure requires the coordinated scheduling of seminars and interdisciplinary projects but allows flexibility in the use of lecture periods and online content while offering increased resource efficiency. Collectively, these courses provide opportunities for integration, skill development, and problem solving. In contrast to many other forms of learning communities, this particular model promotes both a disciplinary foundation and cross-disciplinary applications for large numbers of students.

Résumé

Le nombre généralement élevé d'étudiants inscrits aux cours universitaires de première année ainsi que la nature même de ces cours, lesquels sont fortement axés sur le contenu, peuvent nuire à l'engagement des étudiants ainsi qu'à l'intégration de ceux-ci au processus dynamique et interdisciplinaire d'investigation. Les communautés d'apprentissage permettent d'atteindre ces objectifs, mais ceux-ci présentent souvent des difficultés logistiques en raison du grand nombre d'étudiants. Nous avons créé ici des communautés d'apprentissage en utilisant un modèle de cours inter-reliés pour favoriser l'engagement et le questionnement des étudiants inscrits à l'un des trois cours de biologie de première année présentant un effectif élevé. Ces trois cours (Biodiversité, Concepts biologiques de la santé et Biologie moléculaire et cellulaire) offrent des contextes différents pour l'investigation biologique, présentent des concepts importants de la biologie et ont en commun des objectifs d'apprentissage, des ateliers en ligne favorisant le perfectionnement des compétences, ainsi que des communautés d'apprentissage intégré composées d'étudiants de chaque cours. Divers modes d'apprentissage sont utilisés dans ces trois cours, et des problèmes contemporains sont explorés en classe, de même que dans le cadre de séminaires menés en petits groupes, lesquels cherchent à promouvoir le perfectionnement de compétences nécessaires en investigation. Cette structure de cours exige une organisation et une planification coordonnées des séminaires et des projets interdisciplinaires, mais permet une certaine souplesse dans l'usage des périodes de cours et du contenu en ligne, tout en permettant une utilisation plus efficiente des ressources. Collectivement, ces cours offrent des occasions d'intégration, de perfectionnement des compétences et de résolution de problèmes. Contrairement à plusieurs autres types de communautés d'apprentissage, ce modèle favorise une solide assise disciplinaire et des applications interdisciplinaires pour de grands groupes d'étudiants.

First-year curricula in many North American universities are changing in response to increasing enrolments and shrinking budgets for personnel and infrastructure (Wieman, Perkins & Gilbert, 2010). Increasing class size also creates pedagogical challenges to individualized education as student preparation and expectations are increasingly heterogeneous and the modes of interaction available to support larges classes are more restrictive (Gedalof, 1998). Simultaneously, factual information in all aspects of scholarship is expanding at an accelerating rate. It is perhaps not surprising, then, that many medium or large-sized institutions still offer large first-year courses with an emphasis on factual content and memorization (Lord & Orkwiszewski, 2006). While a sound disciplinary foundation is essential, the fixation on content has contributed to low student engagement (Rissing & Cogan, 2009; Deslauriers, 2011; Wieman, Perkins, & Gilbert, 2010) and a misrepresentation of the dynamic and interdisciplinary nature of inquiry.

The literature (e.g., AAAS, 2009) offers various strategies for promoting deeper understanding, integration, and retention in first-year courses through active learning (Summerlee & Murray, 2010). For example, advances in blended courses and use of personal response devices offer alternative modes of interaction that may facilitate learning and allow more meaningful interactions among faculty and students (Mazoué, 2012). At many universities, an emerging strategy for enhancing student engagement is through learning communities, in which students share a common, integrative experience with students from distinct programs or courses (Tinto, 1995; Cross 1998). There are many kinds of learning communities, and they have been shown to deepen learning and increase social engagement and retention (Soven, Lehr, Naynaha, & Olson, 2013). However, they typically reach relatively small numbers of students at one time. For example, some institutions now augment the large first-year core courses with smaller first-year seminar courses, in which faculty seminar leaders explore a topic of broad significance. The approach inspires first-year students to make the transition to independent learning through a focus on real-world problems and promotes active inquiry, creativity, and teamwork (Murray & Summerlee, 2007). This model has many virtues, but it is faculty-time intensive and may be difficult to implement with large numbers of students and across specialized training programs.

Here, we present a design for large first-year courses, based on a linked-course model, to encourage student engagement and integrate learning goals across disparate fields of science. We apply this model at the University of Guelph, Canada, a medium-sized (~20,000 undergraduates), research-intensive institution with an annual student enrolment in first-year science courses of 1800–2000 students. Prior to this restructuring, first-year biology at Guelph was organized more conventionally as two stand-alone courses. Each course consisted of two to three lecture sections, each of ~600 students, and four laboratory classes offered in alternate weeks. Lectures were presented three times per week, lasted 50 minutes in duration, and were organized into four sequential topics—each representing different life processes (e.g., evolutionary context, cell structure and communication, physiological response to environment, reproduction, ecology)—taught by four different instructors. Laboratory classes were loosely associated with lecture material. Over time, some laboratories were converted to tutorials due to costs and low student engagement. In general, students found the content broad and superficial and much of the laboratory materials disconnected from lecture topics.

In this paper, we show that the linked approach, including shared online skill modules and cross-course multidisciplinary learning communities, can provide an efficient framework for enhancing student engagement by increasing active investigation of contemporary problems and social learning, creating opportunities for deeper learning within sub-disciplines, emphasizing skills and attributes of biologists, and introducing problem solving through integrative approaches. Because of its potential for use in other foundational courses, we describe our model's pedagogical rationale, basic course structure, key elements of implementation, resource efficiencies, and methods of assessment. We also provide a brief summary of the assessment of student learning and satisfaction, which, based on initial results, has been promising. These results are consistent with those of other post-secondary institutions that have emphasized biological inquiry, interdisciplinary approaches, and learning communities in biology (Briscoe & LaMaster 1991; Bohmer & Waugh, 1997; discussed in Tinto, 2003; Mathews et al., 2010; Goldey, et al., 2012).

Curricular Goals

In this particular case, curriculum reform was driven by the fundamental need to enhance student engagement and learning. Institutional surveys (e.g., National Survey on Student Engagement) indicated that students are neither engaged nor challenged by first-year science curricula. To address this concern, we identified four key goals for a new first-year biology experience: (a) create opportunities for deeper learning within core sub-disciplines in biology; (b) introduce key concepts of biological science through active examination of authentic, contemporary problems; (c) develop general skills and attributes of practicing biologists; and (d) promote integrative habits of mind when addressing complex societal problems related to biology.

Linked-Course Structure

Our curriculum model is organized around three courses reflecting distinct sub-disciplines: "Discovering Biodiversity," "Molecular & Cellular Biology," and "Biological Concepts of Health" (Table 1). The courses, which represent the major axes of research in life science at the University of Guelph, have separate credit values and provide distinct contexts for exploring methods of inquiry, problem solving, introducing key concepts and controversies in biology, and building eight skills and attributes valued by all three sub-disciplines (Table 2).

Table 1.
Three linked first-year biology courses at University of Guelph.
Each course represents a different sub-discipline and a different context for learning about the cultures, controversies and modes of biological inquiry.

Course	Focus	Concepts
Molecular & Cellular Biology I	Cellular and molecular bases of life	1) Living things share common molecular properties. 2) The cell is the fundamental *functional* unit of life. 3) Managing energy is foundational to life and evolutionary success. 4) Genes are the fundamental *information* unit of life. 5) Passing on information propagates life.
Discovering Biodiversity	Population, community and organismal biology	1) The meaning of biodiversity and significance of contemporary biodiversity issues. 2) Processes by which biodiversity originates and is inter-related (evolution, tree thinking, natural selection). 3) Complexity of organisms and importance of organization and regulatory processes (structure/function, development). 4) Nature of interactions among organisms.
Biological Concepts of Health	Organism physiology, health and disease	1) Definitions of health and illness have physical, mental and social dimensions. 2) The adult life stage has the properties of a homeodynamic system. 3) The coordinate control of complex physiological systems enables the process of health 4) Quantifying (measuring) health is a complex task filled with uncertainty.

Table 2. *Skills and attributes of inquiry introduced and assessed across three linked courses in biology*. The first six attributes are introduced in free-standing, interactive, online workshops. Students from all courses can access these as needed. Then, each skill is reinforced and more fully assessed in small-group seminars within at least one course. The last two skills are taught and assessed within the interdisciplinary, cross-course project

Skill / Attribute of Inquiry	Key Elements	Course for reinforcing & assessing skill
1. Method of Biological Inquiry	Modes of inquiry, hypotheses & predictions, experimental design, constructing arguments, bioethics	Discovering Biodiversity
2. Numeracy	Variability, descriptive statistics, comparing groups, accuracy and precision of facts	Discovering Biodiversity
3. Independent Learning	Learning styles, active reading, listening and note-taking, learning with peers, assessment techniques	Biological Concepts of Health
4. Oral Communication	Planning a presentation, delivery styles, using visual aids	Biological Concepts of Health
5. Information Management	Identifying and accessing information sources, referencing information, assessing quality of information	Molecular & Cellular Biology
6. Written Communication	Structure of scientific papers, using outlines, logic and constructing arguments, plagiarism	Molecular & Cellular Biology
7. Team Work	Planning, task management, professionalism, collaboration	Discovering Biodiversity Molecular & Cellular Biology Biological Concepts of Health
8. Integrative Analysis	Formulating question, concept mapping, identifying interactions	Discovering Biodiversity Molecular & Cellular Biology Biological Concepts of Health

All three courses use a "blended" format (Young, 2002; Garrison & Vaughan, 2008), combining online activities, interactions with faculty during two 50-minute classes per week, and a weekly 50-minute seminar for small group (~30 students) interactions. The "Health" course also has two interactive laboratory experiences. The manner and degree to which these modes of learning are used differs among courses. For example, the "Biodiversity" course places greater emphasis on online tutorials, videos, and self-assessments;

conversely, the "Health" course places increased emphasis on seminars and labs. In general, students use online materials to prepare for classroom activities and for developing rudimentary skills of inquiry for work in small group seminars. The hybrid format encourages students to complete more content-driven instruction outside of class and allows instructors to place more emphasis during class meetings on motivation, demonstration, and interaction among students (Yin & Fan, 2011; Carlgren, 2012).

The three courses are linked in multiple ways. Disciplinary knowledge is organized around 18 central concepts that define modern biological science (National Research Council 2003), with particular emphasis on three unifying concepts: evolution, cell theory, and homeostasis. The 18 concepts are mapped across the three courses because a broader understanding of the unifying features of life arises from teaching biological concepts in multiple contexts (National Research Council, 2003). Concepts may be introduced in multiple courses and reinforced at a higher cognitive level in at least one. For example, concepts related to evolution and common descent are introduced in all courses, but are further reinforced at higher cognitive levels within the course "Discovering Biodiversity." Similarly, concepts of cell structure and function are reinforced within "Molecular and Cellular Biology" and energy, feedback systems, and homeodynamic states are reinforced in "Biological Concepts in Health." Importantly, in all cases, the concepts are explored through contemporary, discipline-specific problems.

To further support problem solving, the three courses provide opportunities to develop general skills of inquiry through a common biology practicum. The practicum consists of eight freestanding online workshops and a multidisciplinary project shared by all three courses. The workshops provide introductions to each of eight skills (Table 2). While still under revision, when completed, these workshops will offer guided instruction on key elements, opportunities for practice or reflection, and assessment through self-quizzes in a uniform presentation style. The workshops will be available at a time that is most appropriate during each course. In addition to these workshops, the six skills are further developed and reinforced in face-to-face seminars within at least one of the three courses (i.e., two skills per course) through a project, assignment, and assessment (Table 2). Two skills have been assigned to each course according to their suitability for the content and activities. A student who completes all three courses (~75% of enrolled students) will initially take an introductory online skill workshop and then apply that skill in an assessed assignment for all six skills of inquiry. Although students in all courses have access to the online workshops, the assessment associated with a self-evaluation exercise is available only within the specific course that reinforces that same skill during the seminars.

The last two skills of inquiry (e.g., team work and integrative analysis) are reinforced in all three courses and are assessed in the last three weeks of the semester through what is considered a capstone interdisciplinary, inquiry-based project. In one of the most impactful elements of the linked model, students from each course work in teams on a complex problem—also called an inquiry-based learning scenario (Summerlee & Murray, 2010)—from multiple perspectives (Figure 1). The problem changes each semester but generally has widespread societal impact in the area of health (e.g., malaria or influenza) or sustainability (e.g., food crops, aquaculture, or pollinators) and is amenable to analysis from biodiversity, molecular, and health perspectives. Course seminar groups are reorganized into multidisciplinary teams of roughly three to four students from all three courses. These groups work together on the identified problem by refining a question, identifying relevant concepts and considering how current practices facilitate or impede development of solutions, and posing new approaches to resolving the problem. Because this final case is broad in scope, it requires students to integrate the concepts and approaches unique to the disciplinary themes of each course. Students bring the expertise from their own course to the group work and develop an integrated perspective, conveyed in a poster presentation at a symposium in the last week. Since this is often a student's first exposure to group work at the university level, we have developed a grading rubric with individual and team components, but the assessment is weighted heavily to individual elements. This reduces the difficulties sometimes associated with team dynamics in the classroom; nevertheless, challenges can still arise in some groups (10 of every 300 groups). In these cases, the teaching staff directs teams to the online workshop on teamwork and either advise or intervene on a case-by-case basis.

Through a combination of online tutorials, lectures, and small group interactions, the linked course model provides the advantages of a small university seminar course, while addressing many of the needs of a large first-year biology program. Students have weekly opportunities to interact in small groups (~30 students) with students of varied background. In the last three-week case study, students are working together in small groups (3–6 students) drawn from each of the courses. The final inquiry-based learning project provides opportunities for students to direct their own learning on a topic of broad significance and to be creative in their methods of communication. These elements are the hallmarks of many small, seminar-style undergraduate learning communities (Summerlee & Murray, 2010; Gottesman & Hoskins, 2013). The fundamental difference is that the linked model can accommodate significantly more students and thus provides a uniform experience for students of all programs and abilities.

Assessment of Student Learning

Students in all three linked courses are given feedback on their learning using a diversity of mechanisms. For instance, students who prepare by reading online case-study materials for lecture and complete online skill workshops are rewarded with small grade incentives associated with self-evaluation quizzes. In seminars, students complete assignments corresponding to the skills being developed within each of the three courses. For example, the seminar assignment in the "Molecular & Cellular Biology" course involves identifying, locating, and writing a description of an article from the primary literature. In "Biological Concepts of Health," students work on disease cases and ultimately give an oral presentation to their classmates. In "Discovering Biodiversity," students develop hypotheses and predictions and conduct a field study on diversity over a few weeks in a campus woodlot. Lecture activities are assessed through one or two midterm exams (depending on course) and a final exam. All exams are a mix of multiple-choice and short-answer questions and strive to evaluate a range of cognitive abilities, from description and recall to problem solving. Further, the integration of topics across all three courses is assessed in the interdisciplinary project, in which students analyze a real-world biological problem and present their integrative analysis and group position/conclusion in a public poster presentation. In all instances, graduate teaching assistants are instrumental in completing assessments using rubrics that have been developed by the individual and cross-course teaching teams.

Logistics and Implementation

Students taking the biology courses at the University of Guelph come from a diverse set of specializations (> 40 majors) in eight different degree programs, which heightens the challenge of achieving consensus around how to present first-year biology. Since specializations range from physics and biomedical science to wildlife biology, psychology, and English, the desired balance of breadth versus depth, ecological versus molecular, conceptual versus practical, and the total footprint in the first-year curriculum differs substantially among majors. A modular approach—where each course represents a particular sub-discipline, is offered in both fall and winter semesters, and can be taken in any sequence—is therefore well suited to accommodate this heterogeneity. This structure allows individual curriculum committees to decide how many and which of the biology courses are appropriate for their students. Usually, students in the life sciences take all three courses (Figure 1), one in the fall and two in the winter, and enrolment is managed so that these students can take the course as a cohort. Students in non-biology majors may take one or two of the courses in the linked model.

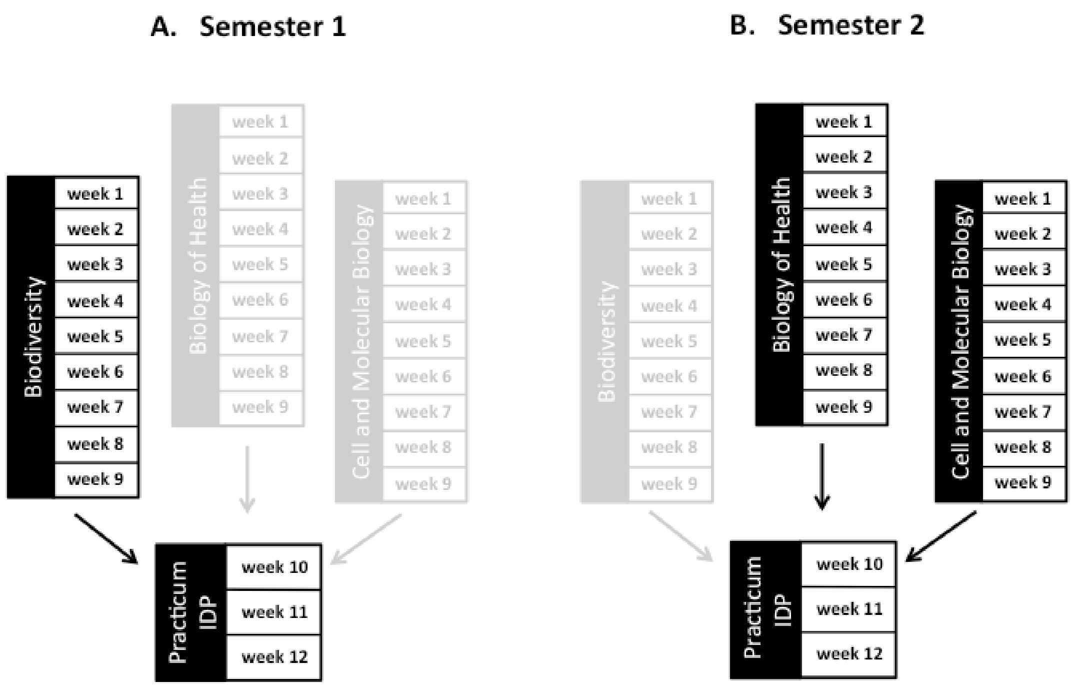

Figure 1. Schematic depicting a typical course sequence taken by a student over two semesters and the relationship of the interdisciplinary project (IDP) to each course.

A) In Semester 1, students register in a course (black) and develop disciplinary expertise in the first nine weeks. For weeks 10-12, the student is grouped (groups of 6–12) with students from the other courses and together they explore a real world problem in an area of health or sustainability. Students bring expertise in biodiversity, molecular and cellular biology, or health from their respective course to the problem and present their findings in poster format.
B) In Semester 2, students take the second (and third) courses, which focus on different aspects of biology. At the end of week nine, students are again assembled into interdisciplinary groups (one for each course) to explore a different problem and from a different perspective.

Administrative oversight of the courses was a major point of debate. Rather than administering them collectively through a single unit, we embedded the three courses into three different departments corresponding to the three sub-disciplines within the College of Biological Science. Each department is responsible for identifying faculty, staff, and graduate teaching assistants (GTA), although these individuals may come from other units. This administrative structure ensures that academic units take ownership of "their" course, and include it as an integral part of their curriculum planning, review, and revision. At the same time, having explicit connections between courses ensures the courses are functioning in concert and departments are considering the needs of more than their own majors. To maintain the linked functions and prevent course divergence, we employ a two-tiered oversight structure. Each course is developed and reviewed by a teaching team composed of faculty, staff, and students from the home department. In addition, two faculty and the staff member from these teams sit on a Joint Biology Committee, which reviews the activities of the entire first-year linked courses, shares individual successes and challenges, and oversees development of cross-course components (e.g., online skill workshops, interdisciplinary projects, alignment of lecture concepts, etc.).

In contrast to course oversight, scheduling of rooms is administered more centrally. Lecture periods are scheduled in classrooms with a capacity of 400–600 students through the university scheduling office. In some semesters, enrolment for individual courses can approach 1200 students, meaning that each lecture is given twice per week (i.e., multiple sections). Scheduling the 50-minute seminars for all three courses is more complicated because each course must use the same time slots so that students from all courses are available to form the interdisciplinary learning communities in weeks 10–12 of the course. Typically, such scheduling is done through a single office within the College of Biological Science, since it has authority over the biology laboratory space.

Resource Efficiency

At the University of Guelph, the total student enrolment per year in first-year biology courses has risen from ~3700 in 2010/11 to ~5500 in 2012/12, and, compared to the old model, the linked-course model offers a number of resource efficiencies that can accommodate even more students if necessary. We compared the three linked courses to the previous configuration of two independent biology courses under similar total enrolment (Table 3). Because of the number and flexibility of the new courses, as well as a lack of pre-requisite structure, the average enrolment per course is considerably less under the new model (x = 619 versus 925 per course). This results in fewer lecture sections required per course and fewer total lecture sections per year in biology. By reducing the emphasis on lectures from three 50-minute periods per week per section to two 50-minute lectures per section, we reduce the total number of lectures from 288 per year in the previous biology course to 168 in the linked courses. The shift also marked a decrease in the number of semester-faculty equivalents from eight in the previous course to only six or seven. We also reduced the emphasis on labs, replacing them with online and small-group seminars, after it became apparent that they were not the best mode for teaching skills of inquiry at the first-year level. Online and small-group seminars not only provide a smaller community of students (30 students per seminar class versus 60 per laboratory class) but meet for a shorter period each week. The end result is reduced investment in teaching assistants per course and similar total investment across all course offerings (~1 full TA [@140 hour/semester] per 76 students).

All of these trends depict the resource advantage of the linked-course model when under similar enrolment pressure. This allows the new model to accommodate more students if necessary. In fact, at the University of Guelph, the total enrolment per year has risen from ~3700 students per year in its first-year (2010/11) to ~5500 in its second (2011/12), prompting an increased investment in personnel.

To support the increased number of seminars, promote and assess skills of inquiry, and coordinate the interdisciplinary project, we have retained a laboratory technician for each course. Their responsibility is to oversee the activities within the seminars, prepare materials, and train and provide guidance to graduate teaching assistants. We also employ a tri-course coordinator, whose role is to maintain cohesiveness among courses and provide additional coordination and logistical support for the interdisciplinary project. The linked courses also make better use of undergraduate mentors than the previous biology course. Two of the three courses make use of senior undergraduate volunteers to provide support beyond the responsibilities of graduate teaching assistants within the small group seminars and Supported Learning Groups (SLGs), which are peer-supported study sessions outside of class time. SLGs were made available through a central office in the library, which provides complete training and tracks the value of SLGs on an ongoing basis.

Effectiveness of the Linked Course Model

The impact of the linked-model on student learning and attitudes is being evaluated on a number of levels. For instance, students' knowledge of the core concepts and engagement are being assessed through a voluntary biology concept survey distributed at the beginning and end of the academic year. In addition to soliciting information about student background and perceptions of the role of biology in their lives, the survey assesses depth of understanding related to scientific method and three key concepts: evolution, cell theory, and homeostasis. It also evaluates student confidence in answering these questions. Finally, the survey evaluates student satisfaction with the overall course and with key components of the course, such as the interdisciplinary project, as well as the impact of the course on their choice of courses and programs. We are also seeking input from instructors of second and third-year courses as to the adequacy of student preparation. Finally, we are tracking the investment of resources in comparison with the earlier biology course. A full analysis and presentation of this assessment will appear in a future publication.

A preliminary analysis presented in Table 3 indicates that the resources initially invested in the linked courses are not substantially different than the total commitment to the previous two biology courses. However, we have been able to increase the quality of the small-group learning and shift the emphasis from memorization of content and formulaic laboratories to skill development, team-based problem solving, and applications of knowledge. Qualitatively, the new courses provide more explicit introductions and better reinforce the eight skills of inquiry, four of which (independent learning, oral communication, integration, and numeracy) were not introduced in the previous biology courses. Course content is also more focused, leaving room for interactivity and problem-oriented approaches.

The survey, applied before and after the first-year biology courses in the initial year of offering (2010/11), suggests that the linked courses have successfully improved student understanding of key concepts in biology. The mean percentage of students selecting correct answers for a set of concept-based questions increased in all categories tested

Table 3. *Allocation of space and personnel in the previous course structure (Biology I and II) and the new linked course curriculum.* Data are shown for a typical fall /winter cycle and are approximately based on the last year in which the previous biology courses were offered and the first year of the new biology courses. Course enrolment represents the sum of fall (Sept-Dec) and winter (Jan – April) offerings. Biology I is offered in fall as a large course (*N* = 1700) and in winter as a small (*N* = 150) "make-up" course. Biology II has the reciprocal arrangement: small (*N* = 150) in fall and large (*N* = 1700) in winter. Enrolment in the linked courses differs from previous courses according to the preferences of individual specializations and is more uniform between fall and winter semesters because there is no required sequence of courses. Number of lecture sections is determined by the maximum lecture hall size on campus (*N* = 600). Labs typically hold 60 students for three hours (two in the new courses), whereas seminars have 30 students for one hour.

	Previous Course Structure			Linked Course Structure			
Course Name	Biology I	Biology II	Total	Biodiversity	Health	Molecular/ Cell	Total
Course Enrolment*	1850	1850	3700	1258	1110	1345	3713
Lecture sections	4	4	8	2	2	3	7
# Lectures / section	36	36	36	24	24	24	72
# lectures	144	144	288	48	48	72	168
Lab sections[#]	30.8	30.8	61.6	0	18.5	0	18.5
# Labs / section	4	4		0	2	0	
Total # Lab / course	123.2	123.2	246.4	0	37	0	37
Hours of lab[&]	369.6	369.6	739.2	0	74	0	74
Seminar sections^	61.7	61.7	123.4	41.9	37.0	44.8	124
# Seminars /section	3	3		11	12	10	
Total # Seminars	185.1	185.1	370.2	461	444	448	1353
TAs[1]	25	25	50	17	15	18	49
Faculty instructor equiv[2]	4	4	8	2	2	3	7
Lab Coordinator	0.5	0.5	1	0.33	0.33	0.33	1
Lab tech				1	1	1	3
Senior course coord	1	1	1	0	0	0	0

(improvement of 11% for Scientific Method; 11% for Evolutionary Theory; 9% for Cell Theory; and 19% for Physiology), although the results did vary among specific questions. The demonstrated improvement in physiology was particularly strong relative to the previous biology course (7.3% improvement). Moreover, for all three categories, the linked courses improved student confidence (frequency of strong and very strong) in 9 to 21% of students, which is 7 to 10% higher than students in the previous biology courses. Additionally, 42% of students reported above average satisfaction, and the linked courses tended to increase student interest in biology and lead to program changes into biology more than the previous courses.

Making Change

Making change in a university environment is challenging at the best of times, especially in large first-year courses with students from multiple programs, instructors from multiple departments, and departments with contrasting disciplines all having a stake in the same product. Despite these challenges, we were able to successfully revise first-year biology as a result of several factors. First, faculty members were ready for change as a result of student surveys and an ongoing discourse about the need for change in the biology core, seeded jointly by the Dean and a review of first-year science held in 2007. Second, there was support from the Dean and Departmental Chairpersons for shifting to a specific model in which each of three departments took responsibility for developing and resourcing one course. Third, there was support for change from the central administration, which made it possible to move the proposal through the governance process relatively swiftly; from the initial stages of development to final approval, the process took only one year. Finally, and perhaps most importantly, the development of the courses, including the most innovative aspects, was conceived and achieved by a dedicated, knowledgeable, and enthusiastic team. As indicated, each course had a teaching development team composed of faculty, staff, and students. Senior members of each team served on a Joint Development Committee, which was chaired by the Associate Dean and designed the overall linked-course model. The Joint Development Committee also made difficult decisions as to which course elements were fixed, shared, or course-specific. Once these overarching decisions were made, the individual teams were responsible for designing the specific learning outcomes and course material for each module and identifying the modes of learning best suited to that material. In addition to managing all logistical and resource-related matter, the Joint Development Committee met frequently to address issues related to common learning outcomes, integration of courses with each other and the larger curriculum, coordination of concepts, and skill development. Ultimately, this hierarchical committee approach was instrumental to success because it ensured a common philosophy and explicit connections while remaining responsive to the idiosyncrasies of each sub-discipline.

Upon reflection, both team members and administrators were surprised and buoyed by what was accomplished through this transformation of first-year biology. The development process demonstrated the potential of collegiality, compromise, and a unified vision. Teams found ways to overcome their differences and make decisions by identifying alternatives, exploring their implications, and respecting the outcome selected. Through this process, the team formed a unique bond and discovered a new enthusiasm for effecting change that has subsequently filtered down to their respective departments.

Summary

First-year science courses in post-secondary institutions have a reputation for being large and predominantly content-driven, which contributes to low student engagement and a failure to involve students in the dynamic process of inquiry. To address this problem, we applied a linked-course model, in which students develop skills and knowledge of inquiry through the analysis of contemporary problems within three disciplines (biodiversity, health, and molecular and cellular biology) and, then, participate in an interdisciplinary, cross-course learning community. This approach requires integrated curriculum planning and scheduling, which helps to break barriers that typically exist among stand-alone courses and contributes to a greater degree of efficiency in use of space and personnel resources. Through a combination of online tutorials, lectures, and small-group interactions, the model fosters problem solving and creativity in relatively large courses and could be effective in any course for which a combination of disciplinary and interdisciplinary learning is sought.🍁

Acknowledgments

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Contact Information

Brian C. Husband
Department of Integrative Biology
University of Guelph
bhusband@uoguelph.ca

Brian Husband is a Professor and Evolutionary Biologist in the Department of Integrative Biology and Associate Dean, Academic, in the College of Biological Science at the University of Guelph. As Associate Dean, he led the development and implementation of the linked first-year biology courses. He continues to be involved in monitoring, assessment and improvement of the first-year biology curriculum and is particularly interested in interactive online learning tools, methods of teaching & assessing interdisciplinarity, and early detection of students at risk.

William Bettger is the Undergraduate Curriculum Coordinator for the Department of Human Health and Nutritional Sciences and is the Director of the "Biological Concepts of Health" first-year biology course. He has been involved in all phases of development of the "First-Year Biology Experience" at the University of Guelph and serves on all the tri-course design, development, and evaluation committees. Bill's primary interest in teaching and learning is in curriculum design and development, with an emphasis on the incorporation of independent learning, personal development, and career preparation into all stages of the University experience.

Coral Murrant is an Associate Professor in the Department of Human Health and Nutritional Sciences at the University of Guelph. She was involved in the design of the linked-course model for the first-year biology courses and particularly involved in the design and implementation of the "Biology Concepts of Health" course. Her research interests are two-pronged: (a) the relationship between active tissue and the microvasculature that ensures adequate delivery of blood flow to the tissue, and (b) evidence-based course assessment to better align course structure and assessment to the learning outcomes of the course. She is particularly interested in improving the assessment practices in large classes.

Kim Kirby is a course coordinator at the University of Guelph, specializing in the delivery of large first and second year courses in cell biology, molecular biology, and genetics. She has been involved in the re-design of the first year biology experience from the beginning, including the development of the Online Skills Workshops and the Interdisciplinary Project.

Pat Wright is a Professor in the Department of Integrative Biology at the University of Guelph. From the initial stages of this project, she was a member of the College First

Year Biology Committee and the Integrative Biology committee that designed and created BIOL*1070 "Discovering Biodiversity." She has taught "Discovering Biodiversity" multiple times. Currently, Pat is Co-Chair of the Integrative Biology Undergraduate Curriculum Committee and has a strong interest in biology curriculum reform.

Steven Newmaster is a Professor in the Department of Integrative Biology where he has been teaching first-year biology for 15 years. He has been involved in the re-design of the first-year biology course "Discovering Biodiversity," where student-centered learning exercises have been used to increase student engagement in ecology, evolutionary biology, and physiology. Dr. Newmaster's scholarship on teaching and learning has focused on service learning, the mechanisms of effective learner-centered education, and ancient pedagogy of plant medicine where the repeated use of experiential learning objects is at the core of sustaining traditional knowledge systems.

John Dawson is Professor and Undergraduate Chair in the Department of Molecular and Cellular Biology at the University of Guelph, where he researches and teaches in the field of protein biochemistry. As Curriculum Chair, John was part of the original design team for the first-year biology courses at Guelph, providing input regarding the coordination of the interdisciplinary project. John's longstanding interest in higher education around the integration of technology in the classroom, capstone experiences, academic integrity, and learning outcome assessment have led to several teaching awards at the University of Guelph and invitations to speak across Canada.

T. Ryan Gregory is an Associate Professor in the Department of Integrative Biology at the University of Guelph. He teaches undergraduate and graduate courses in biodiversity, evolution, and philosophy of biology. His research focus is on genome size evolution. He has received several awards, including the 2003 NSERC Howard Alper Postdoctoral Prize, a 2006 American Society of Naturalists Young Investigator Prize, the 2007 Canadian Society of Zoologists Bob Boutilier New Investigator Award, and the 2010 Genetics Society of Canada Robert H. Haynes Young Scientist Award, as well as a 2008 University of Guelph Faculty Association Distinguished Professor Award for his teaching. He is currently Editor-in-Chief of the journal *Evolution: Education and Outreach*.

Robert Mullen is Professor, Research Chair, and Chair of the Department of Molecular and Cellular Biology in the College of Biological Science at the University of Guelph. His interdisciplinary research program involves collaborators from across Canada, the United States, and elsewhere in the world and focuses on various aspects of plant cell biology, including organelle biogenesis and the engineering of plant vegetative tissues for biofuel and bioproduct production. Dr. Mullen is also actively engaged in various teaching initiatives and activities at the University of Guelph, including curriculum development at both the undergraduate and graduate levels in the molecular and cellular sciences.

April Nejedly is currently the office assistant in the Animal Health Laboratory at the University of Guelph. As a course coordinator in the department of Integrative Biology she helped develop, instruct, and coordinate both distance and face-to-face courses while managing teaching assistants and student volunteer programs. Her training and passion lie in the application of pedagogical research.

George van der Merwe is an Associate Professor in the Department of Molecular and Cellular Biology. He participated in the conceptual design of first-year biology as three independent courses with an integrated project that ties concepts in all three courses together. In addition, he participated in the identification of central concepts to be taught in the first-year course "Molecular & Cellular Biology." His current focus in teaching and learning includes testing mechanisms to increase student engagement and interaction in larger first and second-year classes and effectively deliver science concepts to non-science students.

Krassimir Yankulov is an Associate Professor in the Department of Molecular and Cellular Biology. He participated in the initial design of the first-year courses. Recently, he has conducted studies on the use of peer review in senior university courses. He has also compared the performance of students with different learning styles in oral and written assignments. These studies have been published in journals such as *Biochemistry and Molecular Biology Education*, *American Journal of Educational Research,* and *Assessment and Evaluation in Higher Education*. This line of research will continue in the coming years.

Peter Wolf has been involved with educational development, continuing education, and distance education in higher education for over 20 years, first in the Ontario college system and then at the University of Guelph. Since 2014, Peter has been working at Queen's University as the Associate Vice-Provost (Teaching & Learning). Peter was instrumental in helping to facilitate the (re-) consideration of the first-year biology courses and their assessment.