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A Report on the Implementation of the Blooming Biology Tool: Aligning Course Learning Outcomes with Assessments and Promoting Consistency in a Large Multi-Section First-Year Biology Course

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A Report on the Implementation of the Blooming Biology Tool: Aligning Course Learning Outcomes with Assessments and Promoting Consistency in a Large Multi-Section First-Year Biology Course*

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Abstract

The objectives of this study were to investigate the alignment of exam questions with course learning outcomes in a first year biology majors course, to examine gaps and overlaps in assessment of content amongst the sections of the course, and to use this information to provide feedback to the teaching team to further improve the course. Our ultimate goal was to provide students with learning outcomes that would clearly indicate the content and the level at which they would be expected to learn the content for this course, regardless of the section in which they were registered. We took an evidence-based approach to course evaluation and employed the Blooming Biology Tool to compare the learning outcomes and the exam questions of the course, investigating whether the cognitive skill level of each learning outcome as written matched the level at which it was assessed. We identified misalignments and recommended revising the learning outcomes to better reflect the intended level of learning for the course. We also investigated student performance on exam questions of different cognitive levels and found that students scored statistically significantly higher ($p < .05$) on questions in which learning outcomes were tested at the stated cognitive skill level compared to at a higher level.

Les objectifs de cette étude étaient (1) d'examiner la correspondance entre les questions d'examen et les résultats en matière d'apprentissage pour un cours de première année d'une majeure en biologie, (2) d'étudier les écarts et les chevauchements en matière d'évaluation du contenu des

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sections du cours et (3) d'utiliser ces informations pour fournir de la rétroaction à l'équipe des enseignants afin d'améliorer le cours. Notre but ultime était de faire en sorte que les résultats de l'apprentissage des étudiants indiquent clairement le contenu à apprendre et le niveau cognitif qu'ils devraient avoir atteint, peu importe la section à laquelle ils s'étaient inscrits. Nous avons utilisé une approche basée sur les données probantes pour évaluer le cours ainsi que l'outil de taxonomie de Bloom appliqué à biologie pour comparer les résultats d'apprentissage et les questions d'examen du cours. Nous souhaitions ainsi vérifier si le niveau de compétences cognitives tel qu'il est écrit pour chaque résultat d'apprentissage correspondait au niveau auquel il était évalué. Nous avons découvert des correspondances inadéquates et avons recommandé de réviser les résultats d'apprentissage pour mieux refléter le niveau d'apprentissage souhaité dans le cours. Nous avons également étudié la performance des étudiants aux questions d'examens en fonction de différents niveaux cognitifs et avons découvert que les résultats des étudiants étaient significativement plus élevés sur le plan statistique ($p < 0{,}05$) pour les questions où les résultats d'apprentissage étaient vérifiés au niveau des compétences cognitives déclaré, plutôt qu'à un niveau plus élevé.

KEYWORDS: learning objectives, assessment, biology, Blooming Biology Tool, large classes

Learning outcomes describe what learners will be able to do on completion of a particular learning experience. Having well-articulated learning outcomes in a course eliminates student uncertainty and anxiety about what they are expected to know, helps students to prepare for assessment, and allows faculty to design assessment questions that are in alignment with the intended learning for the course. For course learning outcomes to be a useful tool for guiding student learning, these learning outcomes must list not only the topics that students will be responsible for learning in the course but also the cognitive level at which the students will be assessed for each of these topics.

One tool used to rank the cognitive level of learning outcomes is the cognitive domain of Bloom's Taxonomy, which ranks thinking and knowledge into six categories. The *Knowledge* (I) and *Comprehension* (II) levels involve mainly lower order cognitive skills such as recognizing, recalling, and explaining memorized information (Bloom, 1956). *Analysis* (IV), *Synthesis* (V), and *Evaluation* (VI) levels require the use of higher order cognitive skills such as problem solving and critical thinking (Bloom, 1956; see also Anderson & Krathwohl, 2001). *Application* (III) is often considered to be a transition between lower and higher order cognitive skills (Crowe, Dirks, & Wenderoth, 2008). Most biology questions at the *Application* level require the use of critical thinking and problem solving skills. For example, a typical *Application* biology question might provide students with an unfamiliar scenario and ask them to predict the outcome of altering one or more of the relevant variables. To answer this question, students cannot simply rely on memorization and understanding of previously learned concepts (lower order cognitive skills), but must be able to use what they already know to solve this novel problem. At this point, the use of lower order cognitive skills such as memorizating and recalling in the problem solving process is minimal, and higher order cognitive skills are the dominant skills used. To that end, for the purpose of our study, we considered the *Application* (III) level in the higher order cognitive skills category, which is consistent with other disciplines (e.g., Fuller, 1997).

The evidence-based approach to teaching and learning in biology has introduced tools to the teaching community to effectively evaluate their course designs. One such tool, recently published by Crowe et al. (2008), is the Blooming Biology Tool. The Blooming Biology Tool is an evaluation instrument derived from Bloom's Taxonomy and is applicable to any biology-related topic. Using this tool, assessment questions can be categorized into one of the six cognitive skill levels described above. Applications of the Blooming Biology Tool include aligning course assessment tools with teaching activities and learning outcomes, as well as helping students to enhance their study skills and metacognition (Crowe et al., 2008).

The importance of aligning course activities with assessments and learning outcomes has been well articulated in the literature (Bissell & Lemons, 2006; Crowe, et al., 2008; Ebert-May, Batzli, & Lim, 2003; Fink, 2003; Sundberg, 2002; Tanner & Allen, 2004; Wiggins & McTighe, 1998). A detailed report by Bateman, Taylor, Janik, and Logan (2007) documented a process that integrated the measurement of the assessment of outcomes with instructional objectives and the classroom assessments that are designed to measure the attainment of these objectives. A recent publication by Zheng, Lawhorn, Lumley, and Freeman (2008) examined Bloom's level of exam questions in first year biology courses, comparing the level of thinking required in these questions with questions from Advanced Placement (AP) exams, Graduate Record Exams (GREs), Medical College Admission Tests (MCATs), and first year medical school courses. The alignment of course material with learning outcomes and assessments becomes particularly complicated when the course has multiple sections. Maintaining consistency of content and assessment across multiple sections of the course requires that the instructors of the course communicate closely with each other and that there is a team-teaching approach, ideally towards a common exam. An example of a significant transformation of a multisection physics course is illustrated elsewhere (Gladding, 2007).

The Biology Program at the University of British Columbia is delivered through the Botany and Zoology Departments. It includes introductory biology courses in first and second year, core upper-level biology courses in genetics, evolution, ecology, cell biology, physiology, and biometrics, and elective courses in many subject areas of biology. Based on our own experience, in the last decade students have become increasingly adept at finding information electronically. It was reported that by far the most frequently cited school-related use of the web was to do research and/or get information (mentioned by 89% of the respondents) in a study conducted by Metzger, Flanagin, and Zwarun (2003). As a result of the type of examinations requiring students to respond to lower levels of cognitive thinking, students have become exceptionally good at regurgitating information on exams. However, they are increasingly lacking in written and analytical skills. Therefore, in first year courses, we have increased our emphasis on hypotheses testing and data analysis in lectures. To reflect this tendency, our exams have become more focused on application of information and less focused on memorization of facts. These exams are often more concept based than the exams that many students may have experienced in high school. In addition, most instructors now make use of content-based questions in web-based preclass assignments and in-class clicker questions. Thus, to help students prepare for concept-based exams, it is necessary to set clear learning outcomes for the students that align with the exam questions.

One good example of the above is our Biology 121 course. This course is a first-year, multisection course, which introduces ecology, evolution, and genetics; it is a required course in the UBC Biology Program and is also required in programs in other faculties (e.g., Forestry). This course consists of 10 lecture sections, each section taught by a different faculty member, and is offered to about 2,000 students annually. Recently, within the context of curriculum revisions in the Biology Program at UBC, a team of faculty members teaching Biology 121 developed learning outcomes for the course. (These learning outcomes are provided in the Appendix.) The first objective for our study was to apply the Blooming Biology Tool to evaluate the alignment of these course outcomes with the exam questions in the different sections of this course. Our second objective was to use the results of this evaluation to revise the course learning outcomes to better reflect the intended learning as well as to promote consistency across all sections of this course. Our third objective was to analyze students’ final exams to investigate whether the cognitive skill level of an assessment question affected student performance on that question and whether assessing a given learning outcome at a higher cognitive skill level than stated would impact student performance. We tested the hypothesis that students would earn higher marks on questions that were in agreement with the cognitive skill level of a learning outcome than on questions that were at a higher cognitive skill level than stated in that learning outcome. The results of this study have been valuable in helping our faculty members make informed curricular decisions with respect to the course and will potentially alleviate the frustration of both students and faculty due to the misalignment of learning outcomes and assessment. The ultimate goal of this contribution is to share our experiences with other educators, demonstrating the feasibility of using this process to align a course or program curriculum with the intended student learning experience.

Methods

Data Collection

In this study, we used Biology 121 course learning outcomes, midterm and final exams provided by the instructors of four different sections of the course (Sections A, B, C, and D, arbitrarily labeled to preserve anonymity, offered from January to April of 2008), and student grades that corresponded to each question on the final exam from Section B. We followed an ethics protocol on a companion study to measure student attitudes and beliefs approved by Behavioural Research Ethics Board as required by UBC, and we used only those students who consented for their grades to be used in this study. The flowchart of the process is shown in Figure 1. Original learning outcomes and the exam questions were rated for their cognitive skill level. The exam questions were then mapped onto the learning outcomes in order to align them. The course learning outcomes were then revised to better reflect the intended cognitive skill levels to be measured in the course. Exams were open-book in Sections A and C, and were closed-book in Sections B and D.

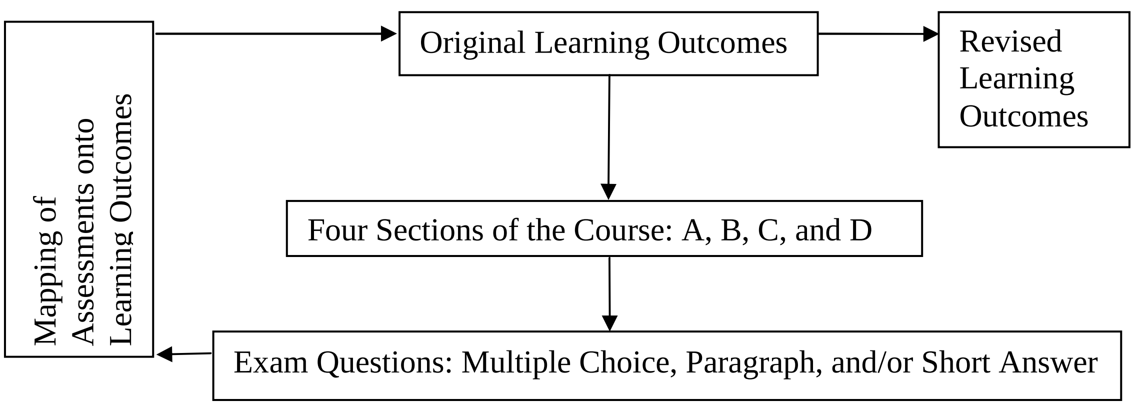


Figure 1. The summary flowchart of the course evaluation process employed in the study.

We recorded the number of marks allotted to each question and the total marks for each exam. Because the mark total for each exam did not add up to 100, we totaled the number of marks available for all exams and calculated the relative weight of each exam question to calculate the percentage of the total available exam marks for each question in that section. For example, in Section B, there were a total of 204 available exam marks (midterm 1, 50 marks; midterm 2, 36 marks; and final exam, 118 marks) that a student could earn. Therefore a “one mark” exam question was worth approximately 0.5% of the total available exam marks for this section.

We categorized exam questions into three types: multiple choice, short answer, or paragraph. For our purposes, we defined multiple choice type questions as questions for which students had to choose one or more correct answers from a list of several possible answers. We defined short-answer type questions as questions for which students were required to write a response ranging in length from one word to several sentences, draw a graph or diagram, or produce a concept map. We defined paragraph-type questions as questions for which students were required to write a response longer than several sentences and for which some portion of their mark for that question would be based on their writing style. We then further grouped short answer and paragraph answer questions into a single group called written answer questions and compared them with multiple choice questions as explained in the Comparison of Multiple Choice and Written Answer Questions Section below**.**

Based on the relative weight of each exam question, we calculated the percentage of all available exam marks tested using each question type in each section. We compared these percentages amongst the four sections to determine if students were tested to the same degree with the same question types in different sections of the course.

Blooming Exam Questions

For each section, we rated each exam question based on the six cognitive skill levels originally described by Bloom (1956) using the Blooming Biology Tool as a rubric (Crowe et al., 2008). This process of rating is referred to as blooming. This tool provides biology-specific criteria for blooming questions (multiple choice and written answer) at each cognitive skill level and includes specific examples of commonly used questions. This tool allowed us to bloom any biology question independently and consistently by simply determining where it best fit in the criteria. The example questions provided in the tool further served us as a guide in this blooming process.

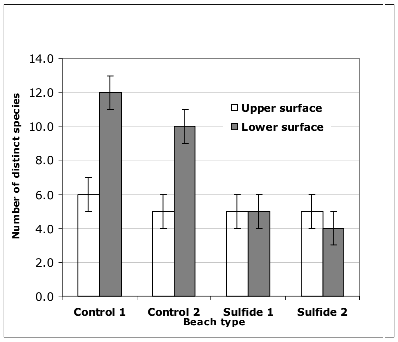
We considered all of the cognitive skills a student would need to employ to correctly and completely answer that question, relying on the marking key provided by the instructors, and assigned the highest cognitive skill level required to that question, consistent with the procedure described by Crowe et al. (2008). For example, consider the question "Why can't natural selection act on rocks?" This question requires that students know the definition of natural selection (*Knowledge* - I), be able to explain the process of natural selection in their own words (*Comprehension* - II), and apply this general information to the specific situation involving rocks (*Application* - III). We therefore categorized this as an *Application* (III) question. Additionally, we also considered how the material that was being tested in a specific question was presented in class by the instructor (Crowe et al., 2008). For example, a question requiring students to design an experiment would normally be categorized as a *Synthesis* (V) question (Crowe et al., 2008). However, if the exam question asked students to design an experiment, but the instructor had already presented the design for that experiment in class, then students need only recall that information–a *Knowledge* (I) question (Crowe et al., 2008).

Based on the Blooming Biology Tool, we classified questions in the first two levels of Bloom's Taxonomy, *Knowledge* (I) and *Comprehension* (II), as questions requiring only lower order cognitive skills, and *Analysis* (IV), *Synthesis* (V), and *Evaluation* (VI) as questions requiring higher order cognitive skills (Crowe et al., 2008). We also considered *Application* (III) questions as requiring higher order cognitive skills (as explained in the Introduction section) since most biology questions at this level require students not only to apply information that they have learned but also to use their critical thinking skills. For example, Exam Question B in Table 1 requires students to predict the likelihood of a captive breeding program to restore the population of an endangered species. To do this, they must consider how various factors such as inbreeding and genetic drift will impact the allele frequencies in this population and whether this restricted genetic diversity will prevent this species from surviving. They must first identify which factors are relevant to this specific situation and understand how each of these factors would affect gene frequencies in a population, which would require only recall and basic understanding of these concepts. However, they must then draw conclusions through critical thinking, weighing the relative impact of each of these factors to make a prediction about the outcome of this scenario.

Table 1
Examples of Recommended Wording Modifications to Better Align the Cognitive Skill Level of Learning Outcomes and Exam Questions, and of Streamlining Through the Merging of Several Related Learning Outcomes

Sample	Description	Cognitive skill level
Learning Outcome 1	Describe how biologists study the history of the diversity of life on earth.	II
Sample Exam Question A	Having reached the Planet Zogor in a distant galaxy, humans disagree as to the origin of life on the planet. Some say it was planted on many occasions from distant galaxies. Others think it arose and diversified on the planet. What biological data would you collect to prove or disprove either hypothesis? (Use the earth's biodiversity as a model.)	V
Recommended Learning Outcome 1	Design tests to investigate the evolution of unknown life forms, based on practices currently or historically used by biologists to study the history of the diversity of life on earth.	V
Learning Outcome 2	Identify the sources of variation within populations. a. describe the types of selection and determine how they affect variation in populations. b. Describe four processes that contribute to nondirectional changes in allele frequencies: genetic drift, gene flow, mutation, and inbreeding. c. Identify how each of these processes contributes to changing allele frequencies in a population.	a. II b. II c. I
Sample Exam Question B	Lonesome George (the last living member of a subspecies of Galapagos tortoise) may have a potential mate; a subspecies hybrid has recently been found. She is 1/2 of George's subspecies. If they do breed, do you expect that the subspecies will escape an extinction vortex? Why? (Diagram and explain an extinction vortex as part of your answer.)	III
Recommended Learning Outcome 2	Predict how sources of variation in populations (including different types of selection, genetic drift, gene flow, mutation, and inbreeding) will contribute to changing allele frequencies in a population.	III

Table 1 (continued)

Sample	Description	Cognitive skill level
Learning Outcome 3	Describe how abiotic and biotic factors affect population and community structure and evaluate the importance of these factors in specific communities.	VI
Sample Exam Question C	A study on the effects of sulfide on intertidal ecosystems scored intertidal organisms on the upper and lower surfaces of rocks on beaches with and without sulfide. The results of this study are shown in the following graph. Which of the following statements are supported by this data?  • Control beaches have more rocks than sulfide beaches. • Control beaches have more species than sulfide beaches. • Rocks from control beaches have more species on their lower surfaces than on their upper surfaces. • Rocks from control beaches have more biomass on their lower surfaces than on their upper surfaces. • Rocks from sulfide beaches have the same species on their upper and lower surfaces. **Figure A:** Number of distinct species on upper and lower surface of rocks in control and sulfide beaches. Data points are means of six replicate rocks, bars are 95% confidence intervals (if these do not overlap the means are significantly different).	IV
Recommended Learning Outcome 3	Analyze how biotic and abiotic factors affect population and community structure, and the importance of these factors in specific communities.	IV

The Blooming Biology Tool has already been used by others to rank hundreds of exam questions in the life sciences with great consistency (Zheng et al., 2008). To ensure consistency in our rating of exam questions, one rater bloomed all of the exams in this study, using the Blooming Biology Tool as a rubric (Crowe et al., 2008). To assess the intrarater reliability of this primary rater, we had this rater bloom one representative final exam (Section A) again, 2 months after the original rating. This final exam contained a total of 19 multiple choice and 9 short answer questions. This rater demonstrated a 90% agreement between the two ratings.

To confirm the reliability of these ratings, a second rater bloomed the same representative final exam (Section A) independent from the primary rater within the same time frame, also using the Blooming Biology Tool as a rubric (Crowe et al., 2008). These two raters then compared their ratings and agreed for 83% of the exam questions. For all questions where their ratings differed, these two raters discussed the ratings and came to a consensus. The primary rater then reviewed all of the original ratings, making adjustments as necessary to reflect the consensus reached through discussion with the second rater. Both raters were teaching faculty members in the Biology Program at UBC and already had extensive experience working together in writing and grading exam questions. They trained for this rating process by reviewing the Blooming Biology Tool, which provided specific examples from the biology discipline. They then practiced blooming sample exam questions using this tool as a rubric, comparing and discussing their ratings afterwards.

For each section, we determined the percentage of available exam marks that students could earn at each cognitive skill level. We combined all exam questions (midterms 1 and 2, and final) to produce the overall available exam mark distribution across each cognitive skill level for each section.

Measuring Assessment of Course Learning Outcomes

For each section, we mapped each exam question to the appropriate course learning outcome(s). We then calculated the percentage of all available exam marks allotted to each course learning outcome for each section. If a question tested more than one learning outcome, we divided the marks for that question equally amongst all learning outcomes tested. We compared these percentages amongst the four sections to determine whether students were examined on the same learning outcomes in different sections of the course and whether these learning outcomes were given approximately the same weight on exams in different sections of this course. These results allowed us to identify the gaps and overlaps in the examination of course content amongst the different sections of this course.

We then determined at which cognitive skill level each learning outcome was assessed in each section. Often individual learning outcomes were assessed in more than one exam question per section, and often not all questions assessing the same learning outcome were written at the same cognitive skill level. In this situation, we determined the cognitive skill level at which that learning outcome was most frequently assessed based on the mark value of each question used to assess that learning outcome. For each section, we then compared the cognitive skill level at which each course learning outcome was most frequently assessed to the level at which that same learning outcome was stated in the list of learning outcomes provided to the students that term.

Measuring Student Performance on Exam Questions

We used the average mark earned by students on each exam question to compare student performance on final exam questions of different cognitive skill levels for the 101 students in Section B who consented to let us use their grades in this study. We also compared the average marks earned by students on exam questions that assessed a given learning outcome at its stated cognitive skill level to the marks earned on exam questions that assessed that same learning outcome at a higher level. We used a one-sided Student's paired *t* test to compare the significance of the difference in exam marks between questions examining a given learning outcome at its stated cognitive skill level and questions examining that same learning outcome at a higher level and accepted a p value of $< .05$ as the level of statistical significance. Furthermore, we compared the performance on these questions for the top 25% of students in this section (the 25 students who earned the highest total mark on the final exam out of the 101 students who consented to let us use their grades in this study) and for the bottom 25% (the 25 students who earned the lowest total mark on the final exam out of the 101 students who consented to let us use their grades in this study).

Results and Discussion

Comparison of Cognitive Skill Levels of Midterm and Final Exams

Midterm exams. Figure 2 shows the available exam mark distribution across each cognitive skill level for midterm 1, midterm 2, and the final exam for Section B of the course. The percentage of available marks requiring the use of higher order cognitive skills increased from 28% to 56% between the first and the second midterms (see Figure 2). However, while the number of *Application* questions increased between the first (26%) and second (56%) midterm, the number of *Analysis* questions decreased (2% on the first midterm and 0% on the second midterm). In this section, there were no *Synthesis* or *Evaluation* questions on the midterms.

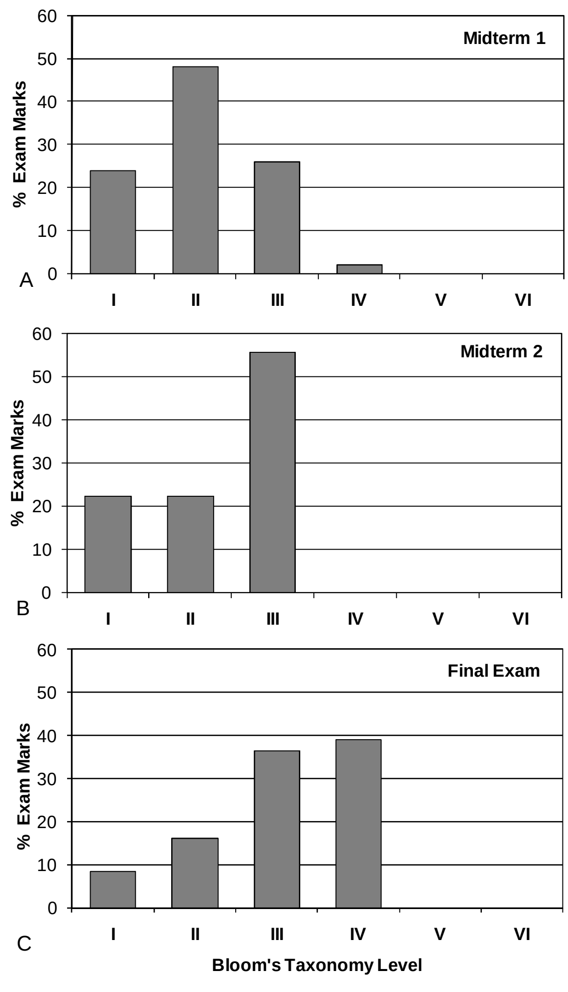


Figure 2. Available exam mark distribution across each cognitive skill level (i.e., Bloom's Taxonomy Level): Progression from midterm to final exam for a representative section of Biology 121 (Section B, Jan-Apr 2008). A: Midterm 1. B: Midterm 2. C: Final Exam. The six levels of the cognitive domain of Bloom's Taxonomy are: *Knowledge* (I), *Comprehension* (II), *Application* (III), *Analysis* (IV), *Synthesis* (V), and *Evaluation* (VI).

Sections A and D also had two midterms while Section C had only one. Unlike in Section B, in Section D the percentage of available marks requiring the use of higher order cognitive skills remained unchanged from the first midterm (85%) to the second midterm (85%). Section A showed a decrease in the percentage of available marks requiring the use of higher order cognitive skills from the first midterm (67%) to the second midterm (54%); however, the percentage of *Analysis* questions increased from the first midterm (20%) to the second midterm (30%) while the percentage of *Knowledge* questions decreased from the first midterm (20%) to the second midterm (0%). All sections studied had *Comprehension*, *Application*, and *Analysis* midterm questions. However, only Sections C and D had *Synthesis* midterm questions, while only Sections A and B had *Knowledge* midterm questions.

Final Exams. The percentage of all available marks requiring higher order cognitive skills on the Section B final exam was 75%, which was substantially higher than for either midterm (28% and 56%) in this section. For this final exam, the percentage of available marks for *Analysis* was 39%, 36% for *Application*, 16% for *Comprehension*, and only 9% for *Knowledge*. The final exam had no *Synthesis* or *Evaluation* questions.

In Section A, the percentage of all available marks requiring higher order cognitive skills on the final exam (65%) was similar to that on the first midterm (67%) and higher than that on the second midterm (54%). In Section C, the percentage of all available marks requiring higher order cognitive skills was similar on the midterm (80%) and the final exam (77%), while in Section D, the percentage of all available marks requiring higher order cognitive skills decreased from the midterms (both 85%) to the final exam (74%). Students have over twice as much time available to write final exams as to write midterms. Because the additional time for the final exam gives instructors the opportunity to include questions that are more complex and require more in-depth analysis than do midterm questions, we expected that all sections studied would have a higher percentage of available marks requiring higher order cognitive skills on the final exam than on the midterms. However, for Sections C and D, the percentage of available marks requiring higher order cognitive skills on the final exam was equal to or less than that of the midterms. We anticipated that this would be due to the already high percentage of available marks requiring higher order cognitive skills on the midterms in Sections C and D. Additionally, the instructors in all sections of the course tried to always include a few *Comprehension* questions on the final exam to help students who were struggling with the course material, as these students generally performed better on *Comprehension* questions than they did on questions requiring higher order cognitive skills. Because of the difficulties in having *Evaluation* questions in the time-constrained setting of an exam, even a final exam, *Synthesis* was the highest cognitive skill level examined in this course. Therefore, for Sections C and D, in which instructors were already using *Synthesis* questions on the midterms, and were also minimizing questions requiring only lower order cognitive skills on the midterms, there was little room to increase the number of questions requiring higher order cognitive skills on the final exam as compared to the midterm exams.

Comparison of Cognitive Skill Level Distribution of Exam Marks amongst Four Sections

We combined the midterm and final exam data for each section in order to evaluate the overall exam mark distribution across each cognitive skill level for each section, then compared amongst the four sections to determine if students were examined at approximately the same cognitive skill level in these four sections of the course (Figure 3). Only Sections A (4%) and B (15%) had *Knowledge* exam questions. Section A had the highest percentage of *Comprehension* exam marks (34%), followed by Section B (25%), Section C (21%), and Section D (20%). Section D had the highest percentage of *Application* marks (55%), followed by Section B (37%), Section A (31%), and Section C (24%). Section C had the highest percentage of *Analysis* marks (40%), followed by Section A (23%), Section B (23%), and Section D (19%). Only Sections A, C, and D had *Synthesis* questions, and no sections had *Evaluation* questions. Section C had the highest percentage of *Synthesis* marks (16%), followed by Section A (8%) and Section D (7%).

In all four sections studied, the percentage of available exam marks requiring higher order cognitive skills was calculated to be between approximately 60% (Sections A and B) and 80% (Sections C and D). Although Sections C and D had a nearly identical percentage of exam marks requiring higher order cognitive skills, they differed in that only 30% of these exam marks in Section C were at the transitional *Application* level, compared to 69% in Section D. Similarly, Sections A and B differed in that only 50% of exam marks requiring higher order cognitive skills in Section A were at the transitional *Application* level, compared to 62% in Section B. Our findings revealed that the cognitive skill level of questions in this first year biology course at UBC is slightly higher than that of the first year biology courses in the three U.S. universities sampled by Zheng et al. (2008) in their study of undergraduate biology and first year medical school biology courses as well as of AP Biology, GRE, and MCAT exam questions. In our case, the *Analysis* level questions were approximately 30% on average as opposed to approximately 10% for the first year biology courses sampled in these three U.S. universities, while *Knowledge* level questions were ~8% on average in our case as opposed to 20% for them. The weight of the *Application and Comprehension* level questions was about the same in both cases.

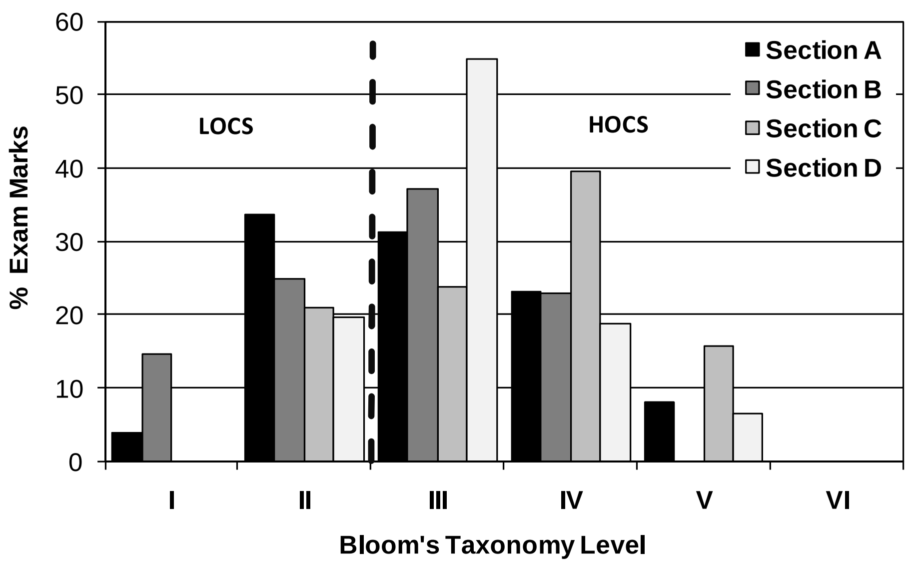


*Figure 3***.** Comparison of four sections of the course (Jan-Apr 2008) with respect to available exam mark distribution across each cognitive skill level (i.e., Bloom's Taxonomy Level). LOCS: lower order cognitive skills, HOCS: higher order cognitive skills. The six levels of the cognitive domain of Bloom's Taxonomy are: *Knowledge* (I), *Comprehension* (II), *Application* (III), *Analysis* (IV), *Synthesis* (V), and *Evaluation* (VI).

The differences in exam mark distribution across each cognitive skill level amongst the four sections suggest that students in different sections of the course were not examined at an equivalent cognitive skill level. To alleviate the differences amongst sections, last year course instructors wrote several questions (equivalent to approximately 40% of the final exam marks) that would be common to the final exams of all sections of this course and implemented this change from January to April 2009. Our results confirmed the need for these common exam questions to promote consistency in assessment amongst the different sections of this course.

The format of these exams being either open-book (Sections A and C) or closed-book (Sections B and D) did not appear to affect the distribution of marks across cognitive skill levels. For example, although Section D had closed-book and Section C had open-book exams, the percentage of questions requiring higher order cognitive skills was comparable, and neither section had any *Knowledge* level exam questions.

Comparison of Multiple Choice and Written Answer Questions

The exams of the four sections studied varied not only in the distribution of exam marks across each cognitive skill level but also in the use of different question types. Section A had the largest percentage of exam marks for multiple choice (37%), closely followed by Section C (35%), and Section B (22%), while Section D exams had no multiple choice questions. Only two sections had paragraph exam questions: Section B (5%) and Section C (21%). Section D had the highest percentage of exam marks for short answer questions (100%), followed by Sections B (73%), A (63%), and C (44%). Because paragraph answers require students to demonstrate more developed writing skills than do short answer questions, while multiple choice questions require no writing skills at all, these differences in question type amongst the sections place a different emphasis on the assessment of student writing skills. To address this discrepancy, we suggested that the course teaching team consider writing a list of course learning outcomes addressing skills such as writing in addition to the existing list of conceptual learning outcomes.

For each section, we also determined the exam mark distribution across each cognitive skill level for multiple choice questions compared to other question types. We combined data for short answer and paragraph answer questions into a single category called written answer questions. For the three sections that had both multiple choice and written answer exam questions (Sections A, B, and C), 12% of all written answer marks were for *Synthesis* questions, while there were no multiple choice questions at this level (Figure 4). Only 14% of all multiple choice marks were for *Analysis* questions, compared to 36% of all written answer marks. More multiple choice marks were available (39%) at the *Application* level than were written answer marks (26%). Similarly, at the *Comprehension* and *Knowledge* levels, more multiple choice marks were available (36% and 11% respectively) than were written answer marks (22% and 4% respectively).

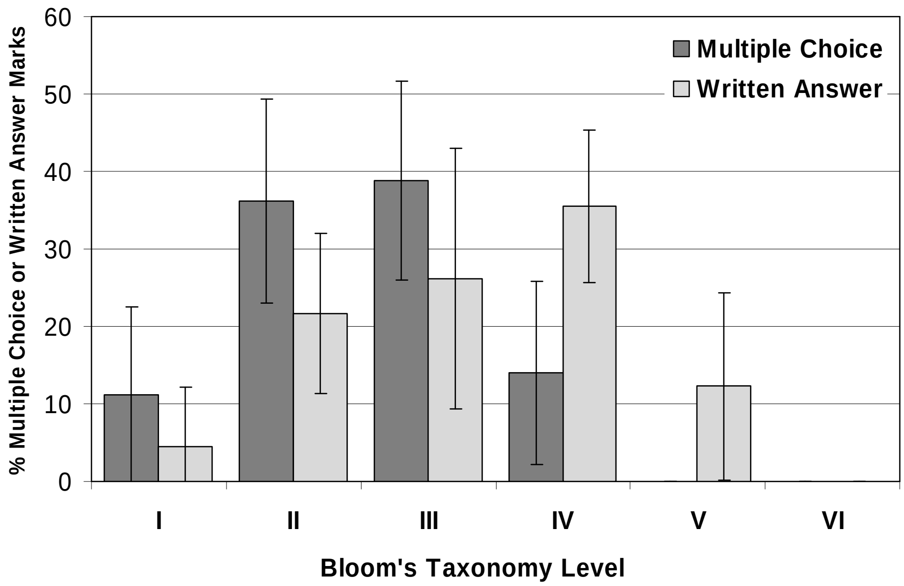


*Figure 4***.** Available mark distribution across each cognitive skill level (i.e., Bloom's Taxonomy Level): A Comparison of multiple choice and written answer questions (averaged data from Sections A, B, and C which had both types of questions in their exams, Jan-Apr 2008). Error bars indicate the standard deviation. The six levels of the cognitive domain of Bloom's Taxonomy are: *Knowledge* (I), *Comprehension* (II), *Application* (III), *Analysis* (IV), *Synthesis* (V), and *Evaluation* (VI).

Over half (53%) of the multiple choice marks were for questions requiring higher order cognitive skills, clearly demonstrating that it is possible to assess problem solving skills using multiple choice questions, as has previously been demonstrated for both biology (Zheng et al., 2008) and for physics (Scott, Stelzer, & Gladding, 2006). However, the percentage of written answer marks (74%) requiring higher order cognitive skills was still much higher than that for multiple choice questions in our case. Zheng et al. (2008) showed that tests with carefully crafted multiple choice questions like GREs and MCATs had as high or higher cognitive skill level of questions than that of first year biology courses. Our results are in alignment with those results. We propose two solutions to alleviate potential student performance discrepancies among different sections of the course: One is to increase the proportion of common exam questions as a short-term solution, and two is to create validated multiple choice questions as a long-term solution. We have recently initiated a research project to address the latter in our institution.

Cognitive Skill Level of Learning Outcomes

During the January-April 2008 term, Biology 121 had 57 learning outcomes addressing the topics of genetics, evolution, and ecology. Genetics had 20 learning outcomes, of which 12 were core and 8 were optional, while evolution had 22 learning outcomes, of which 8 were core and 14 were optional. Ecology had 13 learning outcomes divided into three subtopics: Patterns of Biodiversity, Population/Community Ecology, and Ecosystem Ecology. At the beginning of the term, instructors agreed to cover at least two of the three ecology subtopics, with the understanding that they need not cover all the learning outcomes in each subtopic so long as students were given a broad perspective on ecological issues. Because of this arrangement, none of the 13 learning outcomes in ecology could be fully considered core outcomes, nor could they be considered fully optional outcomes. For the purposes of our study, we defined all ecology learning outcomes as *core* outcomes. Under this definition, Biology 121 then had 36 core learning outcomes and 22 optional learning outcomes.

Of the 57 course learning outcomes, over 50% were written at the *Comprehension* level (Figure 5). As written, only 39% of the learning outcomes required higher order cognitive skills. However, in all sections studied, at least 60% of available exam marks required higher order cognitive skills. The number of course learning outcomes that were examined by questions requiring higher order cognitive skills was therefore much larger than what students would have expected, based on the wording of these learning outcomes. This difference could potentially confuse students.

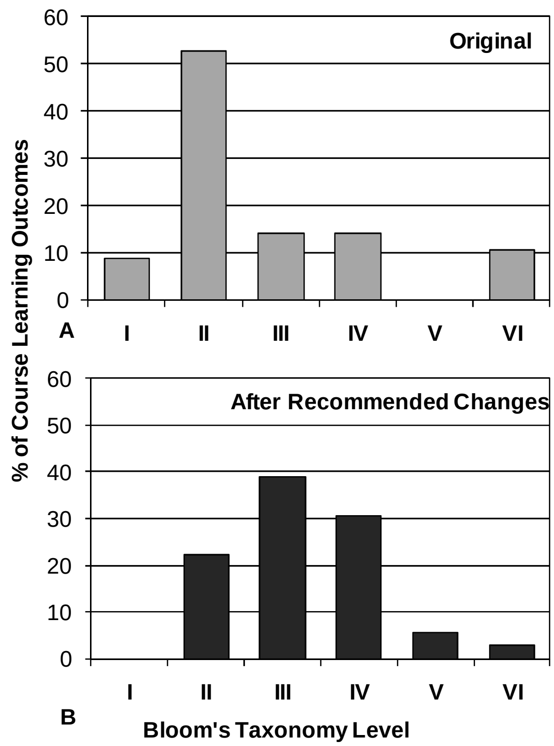


*Figure 5***.** Distribution of course learning outcomes across each cognitive skill level (i.e.,Bloom's Taxonomy Level): A comparison of original course learning outcomes (A) from Jan-Apr 2008 to recommended learning outcomes (B). The six levels of the cognitive domain of Bloom's Taxonomy are: *Knowledge* (I), *Comprehension* (II), *Application* (III), *Analysis* (IV), *Synthesis* (V), and *Evaluation* (VI).

Assessment of Learning Outcomes

No section of the course assessed all 57 learning outcomes on its exams, and the assessed learning outcomes differed from section to section. Only 9 of the 57 learning outcomes were examined in all four sections studied. A further 9 learning outcomes were examined in three of the four studied sections, while 14 learning outcomes were examined in two sections, 17 were examined in only one section, and 8 learning outcomes were not examined in any of these four sections. In this study, we analyzed only exams, and not assignments. It is possible that in some sections, some learning outcomes were assessed on assignments but not on exams, which would lead us to underrepresent the number of learning outcomes assessed in those sections.

For each section, we compared the cognitive skill level at which each learning outcome was most frequently assessed to the stated cognitive skill level for that particular learning outcome. Figure 6 summarizes the difference between the assessed and stated level of the nine learning outcomes that were examined in all four sections of the course, organized into ecology, genetics, and evolution outcomes. Table 2 summarizes the differences in the cognitive skill level at which each learning outcome was most frequently assessed compared to the stated level for that particular learning outcome for each section.

Table 2
Summary of Differences in the Most Frequently Assessed Versus Stated Cognitive Skill Level of Learning outcomes for All Four Sections of Biology 121 (January-April 2008).

Section	Most frequently assessed cognitive skill level - at least one level higher than stated (%)	Most frequently assessed cognitive skill level - at least one level lower than stated (%)
A	30	9
B	25	32
C	36	24
D	48	16

Even with the considerable variation amongst the sections, several clearly visible trends emerged from this analysis. In general, for genetics learning outcomes, the most frequently assessed cognitive skill level was similar to the stated cognitive skill level, while for many evolution and ecology learning outcomes, the most frequently assessed cognitive skill level was noticeably higher than the stated cognitive skill level. For all three subject areas, the *Comprehension* learning outcomes were most likely to be assessed at a higher cognitive skill level. This result is not surprising, since over 50% of the course learning outcomes were written at this level. These learning outcomes almost always required students to be able to explain or describe a concept, while, on exams, these outcomes were often assessed by requiring students to apply this concept to a new situation where they had to make a prediction or solve a problem.

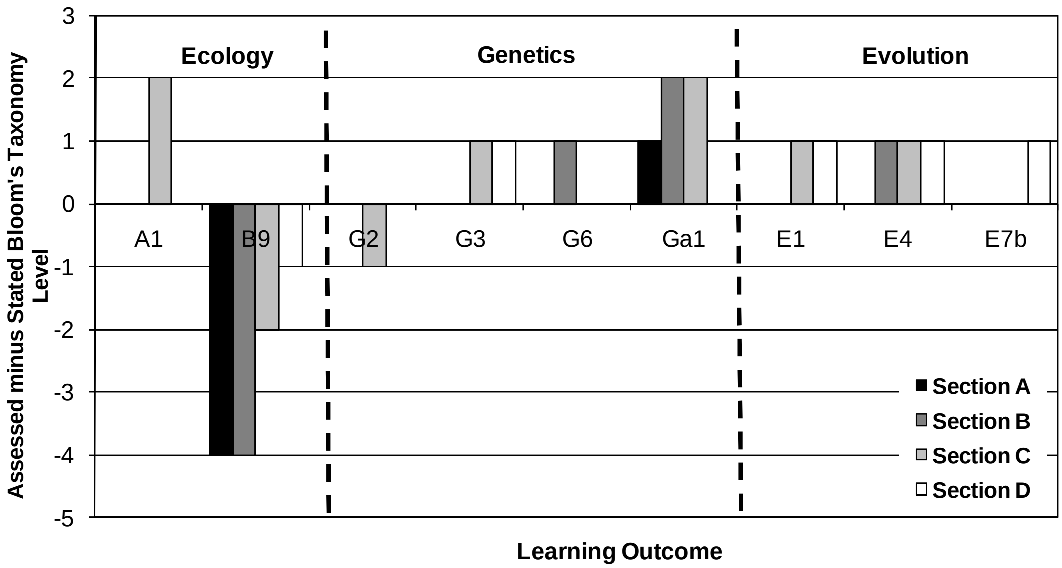


Figure 6. Differences between the assessed and stated cognitive skill level (i.e., Bloom's Taxonomy Level) of the nine learning outcomes that were examined in all four sections of the course, organized into ecology, genetics, and evolution outcomes (Jan-Apr 2008). Negative value indicates that the learning objective was assessed at a lower level than stated whereas positive value indicates that the learning outcome was assessed at a higher level than stated. A value of zero indicates that the learning outcome was assessed at the same level as stated.

The *Evaluation* learning outcomes were always assessed at a lower cognitive skill level. Because *Evaluation* questions often require in-depth analysis and complex comparisons amongst related topics, it is difficult to construct a question at this level that will fit within the time constraints of an exam unless students have had considerable opportunities throughout the term to practice this type of question. Therefore, it is not surprising that none of the sections studied had any *Evaluation* exam questions.

The Effect of Cognitive Skill Level of Exam Questions on Student Performance

Our preliminary results (from Section B) showed that students tended to perform better on exam questions with lower cognitive skill levels. For all 101 students in this section that consented to let us use their grades, the average marks on all *Comprehension* (64%) and *Application* (68%) questions were statistically significantly higher ($p < .01$ and $p < .001$ respectively) than on *Analysis* questions (58%). Our results suggest that the cognitive skill level of a question affected student performance similarly for students in both the top 25% and bottom 25% of the class (Figure 7). The students in the bottom 25% scored statistically significantly lower on *Analysis* questions (37%) than on *Comprehension* (48%, $p < .01$) or *Application* questions (52%, $p < .001$). Students in the top 25% of the class also scored statistically significantly lower on *Analysis* questions (76%) than on *Comprehension* (83%, $p < .05$) or *Application* questions (83%, $p < .01$).

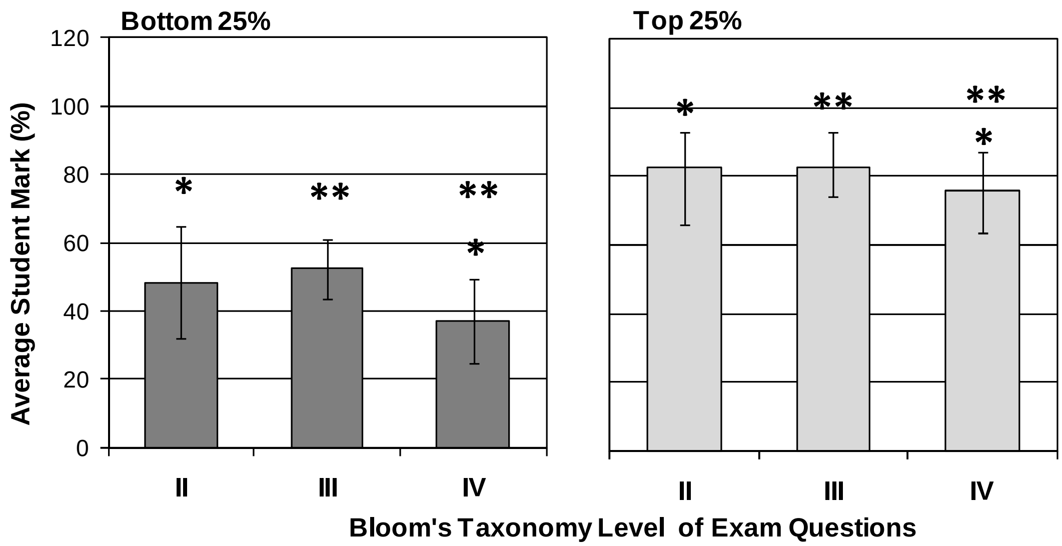


*Figure 7***.** The effect of cognitive skill level (i.e., Bloom's Taxonomy Level) of exam questions on student performance: average marks (%) on *Comprehension* (II), *Application* (III), and *Analysis* (IV) final exam questions for students in the top and bottom 25% of Section B (Jan-Apr 2008) ± standard deviation, n = 25 students in the top 25% and n = 25 students in the bottom 25%. Asterisks indicate statistically significant differences in students' marks between the levels compared ($p < .05$).

To gain further insight, we did a preliminary analysis for two learning outcomes that were assessed both at their stated cognitive skill level and at a higher cognitive skill level in Section B. One genetics outcome (Genetics 6) was stated as an *Application* outcome and was assessed in two *Application* final exam questions and in four *Analysis* final exam questions. One evolution outcome (Evolution 6) was stated as a *Comprehension* outcome and was assessed in one *Comprehension* question and in one *Analysis* question. Students in the top 25% of the class scored statistically significantly higher ($p < .001$) on exam questions where Genetics 6 was assessed at its stated cognitive skill level (90%) than on exam questions which assessed that same outcome at a higher cognitive skill level (79%). They also scored statistically significantly higher ($p < .05$) on the question in which Evolution 6 was assessed at its stated cognitive skill level (87%) compared to the question in which the same outcome was assessed at a higher cognitive skill level (75%). Although students in the bottom 25% of the class also scored statistically significantly higher ($p < 0.001$) on questions in which Genetics 6 was assessed at its stated cognitive skill level (62%) than on questions in which that same outcome was assessed at a higher cognitive skill level (36%), there was no significant difference in their marks on the two questions assessing Evolution 6 (Figure 8).

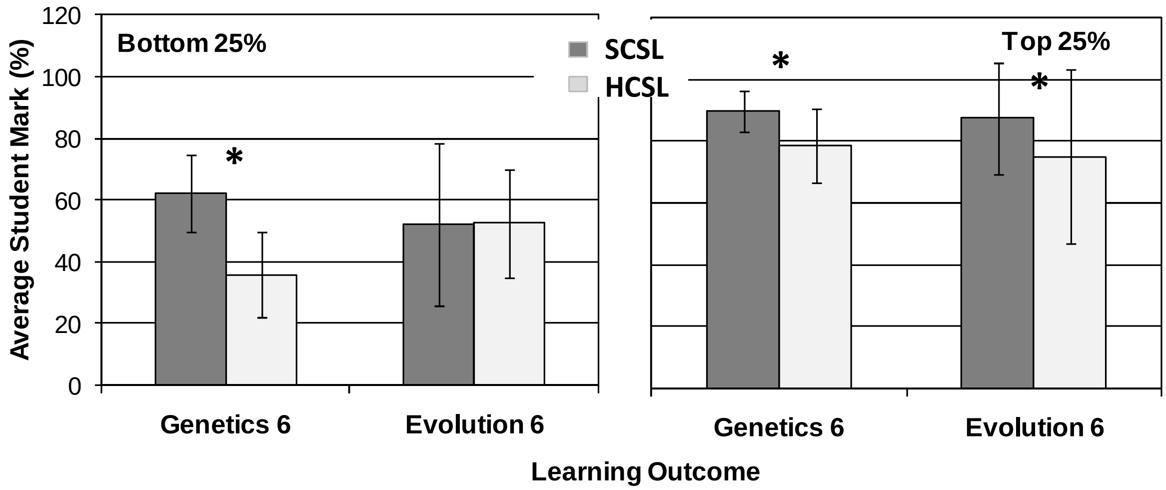


*Figure 8***.** Student performance on exam questions in which learning outcomes are assessed at the stated cognitive skill level (SCSL) versus at a higher cognitive skill level (HCSL) for students in the top (n = 25) and bottom (n = 25) 25% of Section B. Asterisks indicate statistically significant differences in students' marks between the levels compared ($p < .05$). Genetics 6 and Evolution 6 refer to learning outcomes presented in the Appendix. Error bars indicate standard deviation.

These differences in student performance could be partly attributed to the general effect of the cognitive skill level of a question. However, for students in the top 25% of the class, the difference between their average mark on all *Application* questions and on all *Analysis* questions was only 6.7%, while the difference between their average mark on the questions in which learning outcome Genetics 6 was assessed at its stated cognitive skill level and the questions in which the same outcome was assessed at a higher level was 11.1%. This discrepancy is even more exaggerated for students in the bottom 25% of the class, where the difference between their average mark for all *Application* questions and all *Analysis* questions (15.3%) is much less than the difference in their average mark on the questions in which Genetics 6 was assessed at its stated cognitive skill level as opposed to a higher cognitive skill level (26.4%). Our results suggest that for all students, assessing a learning outcome at a higher cognitive skill level than that suggested by the wording of that learning outcome may have a negative impact on their performance above and beyond the general effect of the cognitive skill level of a question. Our results reinforce the need to revise the learning outcomes such that they reflect the cognitive skill level at which they will be assessed. The reader is cautioned that in this study our sample size was small (i.e., only one exam). Thus, generalizing the hypothesis that "the differences in student performance could be partly attributed to the general effect of the cognitive skill level of a question" requires further analysis with a larger sample size (i.e., more questions on more exams). However, this analysis is beyond the scope of the present work. It would, however, be interesting to devise a study to test this hypothesis, since Blumberg, Alschuler, and Rezmovic (1982) did not find any relationship between student performance and the cognitive skill level of multiple choice questions when they examined the same factual content at different cognitive skill levels for basic medical sciences material.

Recommendations for Learning Outcomes: Wording Modifications to Reflect Intended Cognitive Skill Level

The original learning outcomes were assembled by a committee composed of several instructors in Biology 121; these outcomes were revised slightly after each term. After identifying all learning outcomes that were assessed at a cognitive skill level different from stated, we proposed modifications to the wordings of these learning outcomes to better match the cognitive skill level at which they were assessed in the majority of studied sections of the course. For most learning outcomes, our recommendations focused entirely on replacing the active verb with one that more appropriately reflected how students were assessed for that learning outcome. For examples of our recommended wording modifications, see Table 1. In the few cases where we identified concepts that were assessed in more than one section but were not mentioned in the course learning outcomes, we recommended modifying existing learning outcomes to include these concepts or adding an additional learning outcome to address these concepts.

Figure 5 compares the distribution across each cognitive skill level of the course learning outcomes as they were stated (January - April 2008) to that of the recommended learning outcomes (Figure 5). With the recommendations, the distribution much more closely resembles the distribution of available exam marks across each cognitive skill level for the four studied sections of this course (Figure 3). Even though it is unlikely that this course will examine any learning outcomes at the *Evaluation* level, after consultation with the course teaching team, we suggested keeping one learning outcome at this level to be assessed as an assignment, where sufficient time could be provided to students to address the complexity of an *Evaluation* question. Prior to this study, some sections of the course had open-book exams while the others did not. Although this did not appear to affect the distribution of exam marks across each cognitive skill level investigated in this study, the teaching team decided to allow students in all sections of the course to use one page of summary notes while writing the exams in order to provide a more unified learning experience for students. To accommodate this change in course policy, we recommended converting all *Knowledge* level learning outcomes to *Comprehension* level learning outcomes.

Recommendations for Learning Outcomes: Streamlining

When composing learning outcomes for a course, it is generally recommended to have no more than one learning outcome for each 50-minute class (Jackson, Wisdom, & Shaw, 2003). In a standard winter term at UBC, Biology 121 has approximately 36 scheduled 50-minute lecture classes. Allowing for the use of three of these class times for midterm exams and review sessions, this leaves about 33 classes available for teaching course content. Therefore, we suggested reducing the number of course learning outcomes from 57 to approximately 33. We made our recommendations for streamlining the course learning outcomes based on the results showing which learning outcomes were not examined by any of the four sections studied or were examined in only one of the four sections studied. We also recommended merging several related learning outcomes which were consistently examined in the same exam question for more than one section. For an example of a recommended merging of several related learning outcomes, see Table 1.

We further suggested that the course teaching team agree on approximately 30 core learning outcomes which would be taught in all sections of the course. We recommended leaving the remaining 3 learning outcomes open as optional learning outcomes that could be personalized by individual instructors to focus on their own specific areas of interest. We recommended that the instructors list only the optional outcomes they intend to cover in their own section, as opposed to the current practice of providing students with a list of all possible optional outcomes. This recommendation would help to prevent students from becoming overwhelmed by a long list of learning outcomes.

Recommendations for Presenting Learning Outcomes to Students

We suggested that instructors present the relevant learning outcome(s) to students at the beginning of each class and when announcing assignments. Before each exam, we recommended that instructors provide their students with a list of all the learning outcomes for which they will be responsible, to help guide their studying for that exam. This practice was also suggested by Simon and Taylor (2009), who found students valued learning outcomes the most in determining what they needed to know and were relieved at being given clear direction as to how to focus their efforts, both in lectures and in organizing their studying.

Implications for Teaching and Learning

One of the most important aspects of this study was to inform instructors of the moderate misalignments between learning outcomes and assessments, as well as inconsistencies in assessment amongst the different sections, thus enabling the teaching team to make informed decisions as they continued their improvement of the course. We kept open communication with the teaching team throughout the process and held several meetings from the onset of the study. Recently, we presented our results to past and present instructors of the course, discussed the implications of our results, and collected feedback from the instructors on how they would use this information to promote consistency amongst the different sections of Biology 121. We also presented our recommendations for modifications to the course learning outcomes based on our comparison of the stated and examined cognitive skill level of each learning outcome. These recommendations included modifications to the wording of these learning outcomes such that they would more clearly reflect the cognitive skill level at which students would be assessed as well as modifications to streamline the learning outcomes. In fact, by rewording and streamlining the outcomes and moving to more common exam questions we have been able to increase the support for all instructors in the course. This includes a central repository of resources such as an instructor’s guide to the learning outcomes, specific examples, and active learning activities that can be used in class, and clicker and exam question banks.

Conclusions

In this study, we took an evidence-based approach to teaching and learning within the scope of a first year biology majors course and demonstrated its feasibility to systematically evaluate course learning outcomes and exams using the Blooming Biology Tool (Crowe et al., 2008). By setting this precedent, we hope to encourage other science educators to consider the role of this type of analysis in the process of validating their own course or program curricula. We believe that the process we employed here is easily transferable to any course and would be a valuable exercise for any course teaching team to undertake.

In our study, we were able to identify gaps and overlaps and even slight misalignments between the course learning outcomes and exams, and we used this information to make recommendations to instructors for revising the learning outcomes to better reflect the intended learning for this course. Our preliminary results suggest that student performance was higher when the cognitive skill level of assessments matched with that of the stated learning outcomes. We therefore suggest to other science educators that employing this type of analysis to better align course learning outcomes and exam questions may help to improve student performance.

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Appendix
Recommended Biology 121 Learning Outcomes

ECOLOGY OUTCOMES

A) Patterns of Biodiversity

Students should be able to:

1) Describe the effect of global climate patterns and other physical and biological factors on the distribution of species.
2) Analyze patterns of biodiversity and community structure, given experimental data.
3) Analyze the impact of human population growth and consumption of resources on biodiversity and ecological stability, as well as the ability of conservation plans to offset these impacts.

B) Population/Community Ecology

Students should be able to:

4) Estimate the size of a population using different methods, including marked recapture.
5) Analyze the characteristics of a population, such as age, gender, health, genetic quality, as well as the predicted population growth, taking into account the factors that affect demographics.
6) Illustrate population growth using mathematical models, especially the logistic model and "boom and bust" cycles.
7) Determine the life history strategy of different organisms, with respect to fecundity and survivorship, given experimental data.
8) Analyze how biotic and abiotic factors affect population and community structure, and the importance of these factors in specific communities.
9) Analyze changes in community structure that occur as a result of a disturbance (i.e., primary and secondary succession).

C) Ecosystem Ecology

Students should be able to:

10) Predict the trophic level and energy source(s) of an organism, as well as the relative biomass of groups of organisms and the potential biotic interactions amongst organisms in a given ecosystem when provided with information about that ecosystem (for example, a food web).
11) Predict the impact on ecosystems of changes to any or all of the global carbon, nitrogen, and water cycles.
12) Evaluate ways to reduce the ecological footprint of a given individual (make the necessary calculations to determine the effects of modifying each of the factors that contribute to the ecological footprint of that individual, then evaluate which of these modifications will have the greatest impact).

GENETICS OUTCOMES

Students should be able to describe how Mendel's principles of segregation and independent assortment are a consequence of chromosome movement in meiosis.

Core Outcomes: Students should be able to:

1) Determine whether cells are haploid or diploid.
2) Illustrate with simple diagrams how cells produce daughter cells during mitosis and how diploid cells produce haploid cells during meiosis, including tracing the location of alleles during the process.
3) Demonstrate (using simple diagrams or calculations) how sexual reproduction contributes to genetic variation and to degrees of relatedness amongst parents and offspring.
4) Illustrate with simple diagrams how crossing over results in different gene combinations.
5) Illustrate how dominant alleles provide sufficient gene function to confer a phenotype even when only one copy is present, and how this differs from codominance and incomplete dominance.
6) Calculate expected frequencies in monohybrid, dihybrid, and multihybrid crosses.
7) Infer the mode of inheritance (e.g., number of genes, dominance, linkage, sex linkage), given data from experimental crosses.
8) Analyze data from a test cross to determine whether genes are linked, as well as the recombination frequency of linked genes and the arrangement of these genes on a chromosome.
9) Deduce from a pedigree whether a trait is autosomal or sex linked, dominant or recessive.

Additional (i.e., noncore) Outcomes:

a1) Integrate all of the above genetics learning outcomes as applicable into our current understanding of genetic diversity.
a2) Describe genetic sex determination in animals and the consequences of having genes on the X chromosome.
a3) Describe the events that occur during the cell cycle**,** how the cycle is regulated, and how errors in regulation can lead to cancer (if cancer is a topic you wish to cover).
a4) Assess the role of the environment in gene expression (can be linked to cancer if this a topic).

EVOLUTION OUTCOMES

Students should be able to describe evolution as a change in allele frequency.
Students should be able to explain how adaptation occurs by natural selection.
Students should be able to distinguish between shorter term events: microevolution– and longer term events: macroevolution–the pattern of descent.

Core outcomes: Students should be able to:

1) Predict how natural selection acting on individuals will affect evolution in populations.
2) Explain and give examples of how homologies (structural, developmental and molecular) provide evidence for evolution.
3) Predict the relatedness of organisms through interpretation of phylogenetic trees, including alternate representations of the same tree.

The focus of the Hardy-Weinberg equilibrium should not be the equation *per se* but rather the link it provides between genetics, ecology, and evolution.

4) Calculate the frequency of alleles contributed by a generation in a population, given information on the genotype frequencies of that population.
5) Analyze information on the genotype frequencies of a given population to determine whether or not that population is in Hardy-Weinberg equilibrium.
6) Predict how sources of variation in populations (including different types of selection, genetic drift, gene flow, mutation, and inbreeding), will contribute to changing allele frequencies in a population.
7) Explain how evolution is neither directed nor "progressive", drawing on examples from the history of the diversity of life on earth, such as the Cambrian explosion.
8) Design tests to investigate the evolution of unknown life forms, based on practices currently or historically used by biologists to study the history of the diversity of life on earth.
9) Given a specific example or set of data, assess plausible mechanisms of speciation.

Additional (noncore) outcomes:

a1) Describe the contribution of historical figures (such as Darwin, Wallace, Lamarck, Lyell, Malthus, Cuvier, Hutton, Linnaeus, and Mendel) to the theory of evolution.
a2) Explain with examples why islands and lakes can be evolutionary "hot spots."