Are We Doing Any Good? A Value-Added Analysis of UBC’s Science One Program

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Abstract
Science One is a full academic year interdisciplinary alternative to the traditional first-year experience in the Faculty of Science at the University of British Columbia (UBC). Anecdotal reports suggest that alumni/ae of the program do very well in upper-level classes and many become successful graduate and medical students. The high faculty/student ratio makes the program an expensive one, however, and thus we have sought rigorous evidence of the benefits to our students. Our approach has been a value-added one; we have compared high-school and upper-level undergraduate grades for students in all UBC’s first-year science programs. We have found a clear signal that there is a large benefit to participating in Science One, and conclude that this arises from a combination of the recruitment of enthusiastic students who are up for a challenge, the Science One admissions process, and taking the program itself.

Science One consiste en une année scolaire interdisciplinaire complète qui représente une variante de l’expérience traditionnelle vécue en première année à la Faculté des sciences de l’Université de la Colombie-Britannique (UBC). Des rapports isolés suggèrent que les anciens étudiants du programme obtiennent de très bons résultats dans les cours de niveau supérieur et plusieurs obtiennent leur diplôme avec succès et étudient en médecine. Cependant, le ratio élevé enseignant/étudiant fait en sorte que le programme coûte cher, c’est pourquoi les auteurs ont cherché à obtenir des données probantes sur les avantages qu’il présente pour leurs étudiants. Ils ont employé la méthode de la valeur ajoutée; ont comparé les notes obtenues au secondaire et celles des étudiants de premier cycle inscrits à des cours de niveau supérieur dans tous les programmes scientifiques offerts à l’UBC. Ils ont découvert que la participation à Science One est très bénéfique et ont conclu que cela résulte d’une combinaison entre le recrutement d’étudiants enthousiastes qui souhaitent relever un défi, le processus d’admission à Science One et le fait de suivre le programme.

Keywords
interdisciplinary, science, first-year, value-added analysis

Cover Page Footnote
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In 1991, the Faculty of Science at the University of British Columbia (UBC) began to develop an interdisciplinary first-year program to train new scientists to tackle problems that require tools from more than one discipline (Benbasat & Gass, 2002). Named “Science One” and first implemented in 1993, the program is currently a learning community of 75 students and 9 faculty members that emphasizes the scientific process and the interrelationships between disciplines (biology, chemistry, mathematics, and physics are the core disciplines in the program) while giving students the essential technical skills to complete focused majors or honours degrees. Unlike solo-taught courses, instructors in Science One have the opportunity to interact in class with scientists from other disciplines, creating a teaching environment in which they can develop themes that run across those disciplines. Although it may be possible for one scientist to present such ideas, bringing several experts into the classroom enriches the discussion and allows students to ask questions that require expertise in several disciplines to answer.

Beyond UBC, the idea that such interdisciplinary programs have value is widespread. At other institutions, there are many integrated science programs focused on one area of science: many in biology are listed in the National Research Council’s Bio2010 document (CUBE, 2003). Specifically, there are programs in mathematics and physical science (e.g., the Integrated Mathematics and Physical Science Program at Dartmouth; Hansen, 1998) as well as in engineering (e.g., IFYCSEM at Rose-Hulman, Indiana; Froyd & Rogers, 1997). However, few consider as wide a field as Science One. The closest such program of which we are aware is the Dalhousie Integrated Sciences Program (DISP, 2012) at Dalhousie University. The DISP has options that integrate courses from up to nine science disciplines with scientific writing and philosophy.

Given the widespread implementation of interdisciplinary courses and programs it appears that many people believe there is value to teaching science and engineering in this fashion. There is some existing evidence that suggests that this might be the case.

An early observation of faculty teaching Science One was that the social interactions (student-student and student-faculty), that are much enhanced in an interdisciplinary setting, are a critical part of the learning environment for student success (Benbasat & Gass, 2002). Other studies in high school settings (Linn, 2000; Venville, Rennie & Wallace, 2004) have indicated that integrated learning activities in science improve students’ effectiveness when they solve novel or open-ended problems and improves their success in learning new scientific knowledge. A case study of the physics component of the Integrated Math, Physics, Engineering, and Chemistry Curriculum at North Carolina State University (Beichner et al., 1999) presents evidence that students in their integrated courses substantially outperformed students in the traditional program.

Benbasat and Gass (2002) described the early years of Science One, the first program of its kind in North America, in detail and presented a qualitative analysis of the successes and impact of the program at that time. This paper addresses the seemingly logical next question: how might we quantitatively measure the impact that Science One has on students?

**Structure of the Program and Learning**

Science One is structured as a single 27-credit course (of a 36-credit typical first-year load), taught over two semesters, that integrates biology, chemistry, mathematics, and physics. At UBC the program is formally equivalent to two regular three or four-credit courses in each of
Mathematics, Physics, Chemistry and Biology. The students are selected competitively based on their grades and interest in science which is demonstrated based on a required essay and their science-related extra-curricular activities.

During each week of the academic year, students attend 12 hours of classes that are led by one or more faculty members and include extensive peer instruction and group activities. In addition, there are two tutorial hours per week during which 24 students meet with one or two instructors for a structured activity; two hours of “small groups”, in which 8 to 10 students work with one instructor; and nine hours of discipline-based labs. Each of these components represents a distinct opportunity for integrating disciplines.

To give the course a clear interdisciplinary feel, at least two faculty members share the classroom at one time. Even during classes in which one faculty member is the primary instructor, the presence of another faculty member, usually from a different discipline, can create a vibrant dynamic, especially where there are exchanges of differing viewpoints. We have observed that when the students see how mathematicians and scientists talk to each other, for example, the students quickly become engaged in discussion. The importance of these interactions was clear from the outset of the program and has been addressed in detail by Benbasat and Gass (2002).

With the recognition that undergraduate research can play a substantive role in the development of novice scientists (Hunter, Laursen & Seymour, 2006), Science One students are required to complete two independent research projects, one each term. These two research projects are an integral part of Science One; together accounting for 10% of the course mark (i.e., roughly equivalent to a conventional one-term three-credit course). The first project is a literature review and is for many students their first foray into primary literature, whereas, for the second project, students undertake a quantitative scientific measurement. There is an extensive peer-review process for both projects. Each of the program’s faculty members is assigned approximately 17 projects to help shepherd to completion. Because of the free-rein style of the experimental project, many of the initial ideas for experimental research are not practical (i.e., too expensive, dangerous, or simply logistically impossible) but over several weeks their ideas are molded into feasible research projects. The results of the research projects are presented in 10-minute talks at a spring research conference that the students organize themselves. Program faculty members have anecdotally reported that the best of these projects are on par, in terms of quality, with senior thesis work.

Science One students do most of their laboratory work with students in the traditional laboratories. However, part of their biology laboratory work is completed at the Bamfield Marine Sciences Centre on Vancouver Island. This three day trip is near the beginning of the academic year and serves to build a strong sense of community within the program. To supplement the formal laboratory, Science One students complete experimental activities that can be done in- or outside of class and which address concepts and techniques in mechanics, electromagnetism, and microscopy.

One of the key differences between a Science One class and those in the traditional programs is that two faculty members co-teach each discipline. In order to encourage high-performing research faculty to participate, we pair them with instructional faculty from their departments. Having two people teaching each nominal subject allows for considerable flexibility. The instructors also teach courses in their home departments, providing an active link between teaching ideas in Science One and in the traditional courses at UBC. For example, peer-instruction, a regular feature of Science One classes from the start, has now been introduced into
traditional classes by faculty who have learned the techniques in Science One. The instructors provide continuity of experience to the program since they are seconded for five-year terms, while the research professors are asked to commit to three-year teaching terms. These teaching teams allow professors to maintain their research programs. For example, a physics professor recently in the program, whose research depended on ever-shifting NASA launch schedules, would not have been able to accept our invitation to join Science One without this pairing.

The tests in the program are structured to assess a creative approach to problem solving. With a relatively small class size (about 75, a third of the size of regular first-year classes) and controlled environment, there is more flexibility to be innovative in the examination questions than in traditional classes. A range of assessments approaches are employed including representation-translation problems, context-based reasoning problems, estimation problems, qualitative problems and essay questions, not simply multiple-choice tests common to the traditional programs (Redish, 2003). Although examinations are given separately in each discipline, cross-disciplinary questions are commonly included.

In terms of the grading scheme, the major project, laboratory performance, quizzes and class participation are considered before calculating a single, blended Science One mark at the end of the year. To be fair to our students, we ensure that their grades are comparable to those given in traditional UBC programs as we feel it would not be appropriate to require our students to do more work for lower grades. Even so, it is difficult to compare Science One marks to those of the traditional first-year courses because of differences in the material, grading structure, methods of evaluation (i.e., projects, research papers, and formal examinations) and teaching personnel.

In addition to formal tests for marks, diagnostic tests have been used to identify significant gaps in students’ abilities, gaps for both individual students and for the class as a whole. These diagnostic tests are generally given early in the first term to address the gaps as soon as possible. The diagnostics include the Force Concept Inventory (Hestenes, Wells, & Swackhammer, 1992), general reasoning tests (e.g., Lawson, 1978), general knowledge tests, and a genetics concepts test. The results from these tests suggest that Science One students come to us more knowledgeable in these areas than students in the traditional first-year science program.

In summary, the Science One program is designed to encourage students to think critically; construct logical arguments; ask focused questions; address complex interdisciplinary problems; and to communicate, discuss, and defend their findings, ideas, and vision. From interactive lectures through independent research projects, their creativity is nurtured and challenged. The anecdotal evidence suggests that Science One students are capable of achieving more than traditionally is expected of first-year science students and the aim of this paper to provide quantitative empirical support for this observation.

Impact on the University at Large

Although the focus of this paper is on the impact of Science One on its students, we believe it is important to recognize the impact of the program on the UBC more generally. For example, other cross-disciplinary programs in science and engineering have emerged at UBC since the launch of Science One and, anecdotally, the success of Science One has been influential in the decision to create these newer programs. Benbasat and Gass (2002) provide a detailed description of two of these programs: The first-year Coordinated Science Program (CSP) and the Integrated Sciences (degree) Program (ISP). Since 2002, UBC has also established
Engineering One, the second year MechTwo (Mechanical Engineering), the biophysics degree program, and a cross-institution UBC-BC Institute of Technology biotechnology degree program. The influence of Science One is also evident in the fact that the educational principles at its core became part of the Vision Statement for the University of UBC: Trek 2000 (UBC, 1999). Also, Science One teaching alumni/ae have been a force for improved teaching in numerous upper-year courses.

These impacts do not come without a cost. The cost per student of the Science One Program is approximately twice the average for a first-year student taking the traditional program at UBC. The main component of this cost difference is faculty members’ time: the program maintains a small student-to-instructor ratio and preparation of interdisciplinary team-taught classes is time intensive. Space commitments, the salary of an administrative clerk, and the operating budget all add to the cost. Although the administration supports the program, it is nonetheless important to be able to justify to the university community the higher cost of the program.

This study is designed to provide empirical evidence to support the impact of the Science One program on the participating students. As part of our accountability, both financial and pedagogic, we have undertaken an analysis of the performance of our students after their first year, to quantify how the program benefits them when they enter the larger university community.

Methods

Participants

Participants were approximately 6,000 UBC science students who entered the university in the years 2001 to 2005. Of these, 350 were Science One students, who came from the Metropolitan Vancouver area (68%), the rest of British Columbia (14%), the rest of Canada (12%), the USA (3%) and elsewhere in the world (3%). Forty nine percent were female.

Procedure

To assess the benefit (“value-added”) gained by students in Science One over traditional first-year programs at UBC, we have compared the performance of both groups before and after their first-year. Specifically, we chose to compare high school records and grades in upper-level degree courses for five groups of UBC science students: those who attended the Science One program, those who were accepted into the program but declined, those who applied to the program but were rejected, those who were waitlisted for the program and did not attend (i.e., they would have been acceptable except that the program was full), and those who never applied to the program (and, thus, were in the traditional first-year science program). A rigorous control group formed by removing students from Science One at random and placing them in other programs is plainly not possible, ethically or practically.

The focus was on high school and upper-year university grades and not grades obtained during Science One itself or other first-year programs because the non-equivalent nature of the programs would likely result in a differential impact on grades during that year. By considering incoming high school marks, this “value-added” approach also seeks to account for the obvious effect that if one accepts only above-average students into a program, they are likely to achieve above-average grades in their subsequent academic career, regardless of the program’s quality.
The second- and third-year courses we have chosen for this study are Biology 334 (Basic Genetics), Chemistry 203 (Introduction to Organic Chemistry), Mathematics 226 (Advanced Calculus I), and Physics 200 (Relativity and Quanta). These specific courses were selected because they are all core upper-year courses for students pursuing honours and majors degrees.

This institutional research was instigated by the Director of Science One at the time of this research (i.e., the sixth author) with the aim to document the academic gains believed to result from participation in the Science One program. The data were anonymous grades which were obtained in the normal course of the students’ admission to UBC and their subsequent undergraduate career and, thus, ethics approval was not required.

Results

The data comparing Science One to other students for the years 2001-2005 are shown in Figures 1 through 3. These figures compare marks achieved in key grade 12 courses (i.e., Biology 12, Chemistry 12, Mathematics 12 and Physics 12) with those in the large second and third year university courses in Biology, Chemistry, Mathematics, and Physics as described above.

The results are presented in three ways. First, Figure 1 shows histograms of marks in each of the chosen upper-level university courses, with former Science One students separated from those in traditional streams (“Other Students”). The error bars demonstrate one standard deviation statistical uncertainties. As demonstrated in the figure, the distributions of former Science One students’ grades are a different shape of those of the Other students, with a pronounced skew to the right of the distribution for all four upper-year courses. Former Science One students proportionately received more “A” grades (i.e. mark ≥ 80%) and fewer failing grades (mark < 50%) than their non-Science One counterparts.
Second, Figure 2 demonstrates the relationship between high school course marks and those achieved in the four corresponding upper-year university courses. The data are grouped by the students’ performance in the relevant high school course on the horizontal axis (e.g., Biology 12) and the mean marks for the corresponding upper-year university course in the vertical axis (e.g., Biology 334). As an example of how to read this bar chart, consider the last bin on the right in the biology chart. This bin refers to students who graduated from high school with 98% or higher in Biology 12; the former Science One students had an average mark in Biology 334 of (86 ± 4)%, whereas their non-Science One counterparts had a mark of (77 ± 2)% . This trend is repeated for all courses considered; in every case former Science One students outperformed their non-Science One peers with the same high school marks in the upper year university courses considered.
Third, in Figure 3 the mean grades in the select upper-year university Science courses are plotted against grades in the corresponding Grade 12 Science courses. For this analysis, the non-Science One students are divided into the following subgroups: (a) applied for but declined to join Science One, (b) applied for but wait-listed for Science One (i.e., acceptable had the Science One cohort been larger), (c) applied for but rejected by Science One (i.e., unacceptable in any case), and (d) did not apply for Science One. These groups allow the exploration of whether the earlier reported findings may be the result of the type of students who apply for the Science One program (e.g., their motivation) and not the program itself\(^1\).

On the scatter plots, the points show the means with one standard deviation error bars. The trendline shows the relationship between UBC and high school marks for “other” students, with the red dotted lines indicating one standard deviation limits on the slope of that trendline.

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\(^1\) Note: The subgroups of the non-Science One students were not investigated in the previous analyses because the grade breakdown employed with those analyses would not allow for further division of the non-Science One group (i.e., the cell sizes would have been too small).
Consider the biology scatterplot in Figure 3. The unfilled square indicates the mean mark in Biology 12 and Biology 334 for non-Science One students. The solid line shows the trend relating the non-Science One students’ Biology 334 mark with their Biology 12 mark. The dashed lines show the one-standard-deviation uncertainties in the slope of this trend. The diamond indicates Science One students, who have Biology 12 marks on average two percentage points higher than their non-Science One peers, but an average Biology 334 mark about 10% (four standard deviations) higher than the trend line. Now look at the other three points, whose error bars indicate the uncertainties on the means. The students who applied for but were rejected by Science One are indistinguishable from the rest of the non-Science One students. However, those who were wait-listed by Science One performed almost as well as their peers who went through the program – with the proviso that the statistics on this group are small and the uncertainties large (their mean mark lies two standard deviations above the non-Science One trendline). The students who declined to join the program also did well (their mean mark lies one standard deviation above non-Science One trendline); their very high school marks suggest that they may have chosen more focused options at the university. Similar observations can be made...
about the Chemistry course. The numbers of students in Mathematics and Physics are too small to say anything substantial about those who applied for Science One but did not join the program. In each case, however, there is a clear advantage for Science One students, even comparing them with peers with the same high school marks. In the Mathematics case, Science One students actually had weaker high school marks than their peers, and yet still outperformed them in Math226.

To summarize the numerical evidence, ex-Science One students outperformed their peers with similar high-school grades from other first-year programs in Biology 334 by (9±2)%, in Chemistry 203 by (9±2)%, in Math 226 by (5±2)%, and in Physics 200 by (6±2)% in final grades from these courses. Students wait-listed but not accepted into Science One showed less significant gains over their peers who did not apply to Science One: in Biology 334 (10±4)%, and in Chemistry 203 (6±4)%. Students who were accepted into, but declined to join, Science One also showed slight evidence of gain in Biology 334, (6±6)% and in Chemistry 203, (1±3)%.

Discussion

The “value-added” analysis of Science One student academic performance shows that Science One students as a group outperform their peers from general first-year programs in the upper-level courses subsequently taken, even after their incoming high school grades are taken into account. In addition, there is evidence that students applying for the Science One program, who would have been accepted but for a number cap, also outperform their colleagues in those first-year programs.

It can therefore be concluded that taking the Science One program is a measureable benefit to students over that enjoyed by their peers in general programs. Given the extra resources available in the program, this is reassuring to those who support and fund the program. It is also reassuring to those teaching Science One and upper-level courses who have long felt this to be the case, based on personal interactions with the students. Finally, the evidence can be presented to Science One students who worry that their choice of a tough program is hurting their grade average.

Potentially important is the evidence that students who apply for but who not join the program also outperform their peers. Science One has never been pitched to prospective students as an easy option. Hence at the university admissions level, students looking for secure marks are going to avoid Science One. The program’s intake is thus already biased toward students more interested in science concepts than science grades. The message is clear: a program seeking students who are ready for a challenge should advertise their program honestly as a real challenge.

The conclusions are limited by statistics; this is unavoidable given the size of the program, and the impossibility of forming a rigorous control group. The longitudinal study is continuing. However, a much longer timescale is necessary to make a significant reduction in statistical uncertainties, and this reduction would be compromised by the inevitable changes in program structure, personnel and student demographics that would occur over time.

Conclusion

Anecdotally, there has been the perception since the implementation of the Science One program that students who complete the program have a clear advantage over their peers in
regular first-year UBC programs. Now we have numerical evidence that supports this impression. Former Science One students outperform their peers in all the core upper-level courses we have considered, when matched for final-year high school marks. However, given the data available to us, it is not obvious as to the origin of this advantage. Students who were accepted into Science One but declined to join the program also outperformed students who never applied, as did students who were acceptable to the program but were waitlisted due to the limitations of numbers. We conclude that the Science One advantage is some combination of the recruitment of enthusiastic students who prepared to face challenging first-year program, the Science One admissions process, and taking the program itself.

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