Discovery: Differential student impact is evident within an inquiry-focused secondary/post-secondary collaborative STEM program (Evaluation)

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Abstract

Secondary school science, technology, engineering, and math (STEM) curricula generally focus on delivery of knowledge in an effort to ensure achievement of learning outcomes related to important scientific concepts, in preparation for post-secondary study. Considering a global learning environment of rapid technological change at the cutting edge, this knowledge quickly loses its relevance to application, highlighting the importance in focusing on development of a critical thinking framework for students. In 2016, graduate students at the University of Toronto created *Discovery*, a collaborative educational program focused on developing and reinforcing critical thinking skills of secondary school students through inquiry in the context of biomedical engineering in a post-secondary setting. The outcomes of a previous longitudinal study in a single school, where a high degree of objective student performance and subjective metrics of engagement were observed in the mastery-based *Discovery* setting, also revealed the value of this differential learning environment for students who struggle in a traditional knowledge-focused STEM classroom. Following 5 terms of activity impacting approximately 500 students, the program has now expanded to include participation of a second school from a different socioeconomic region identified as having fewer external challenges to learning, allowing for assessment of cultural impact of learning. Preliminary assessment of multi-school participation (1 term) presents very different student outcomes, as students from the new school demonstrated no difference in performance between traditional classroom and *Discovery* settings, and notably lower engagement in the inquiry-focused program structure. This differential impact may result from cultural elements; in this study, we attempt to explain this gap in benefit from, and acceptance of, a problem-based learning framework using grade data, student surveys, and formal educator interviews. In keeping with available literature, our findings suggest that higher perceived challenges to engagement in the traditional knowledge-based secondary STEM setting may predispose students to mastery-based curricula focused on solving open-ended problems, which by their nature reward “grit” or resourcefulness. To date, student and educator engagement and enthusiasm reinforce that the *Discovery* platform blurs the gap between secondary and post-secondary learning meanwhile fostering development of critical thinking skills crucial for the success of future STEM generations. Our current findings suggest learning culture influence, presenting opportunity to tune program structure to meet individual student learning needs. We anticipate continued positive impact of this program on secondary school science student outcomes in future offerings, regardless of school of origin or previous program participation.

Introduction

In the modern economy, careers requiring proficiency in science, technology, engineering, and mathematics (STEM) are commonplace and tend to offer high remuneration [1]. Furthermore, one could argue that a basic STEM literacy, regardless of career, is a crucial foundation to being a well-informed citizen. However, advancement in STEM is subject to student attrition at every level of education in which it is not mandatory (i.e., engaging in university-preparatory biology,
chemistry, and physics in high school, to onset of undergraduate education, to graduation with a bachelor’s degree) [2].

Currently, engagement gaps exist in STEM that can be stratified by external challenges impacting student success, including socioeconomic status (SES) [3]. Students from families that can provide greater opportunity (i.e., financial, parent involvement, parent education level, extracurricular opportunities) tend to achieve higher academic outcomes [4] and higher retention in STEM [5-6]. Consequently, one can discern gaps in student success tied to external challenges are sociological in nature, perhaps from a lack of available resources and networking. Therefore, to encourage STEM engagement regardless of external challenge, strategies must be employed to enhance equitable participation in STEM education.

Common strategies to foster persistence in STEM ostensibly centre around increasing intrinsic student motivation, or “grit”, for individuals identified to have external barriers to learning. Therein, focus tends to be on additional resource deployment or encouragement to persevere through challenge for specific students. However, not all strategies need focus exclusively on the individual student; a powerful means to enhance a student’s academic interest and performance is through the culture and environment of the classroom [7-8]. In fact, one could speculate that individual focus on particular students by an educator need be optimized, as social implications could have detriment to equitable goals. Therefore, this sum of interpersonal interactions between students and the educator, in its optimal form, would allow for shared experience and achievement between students, spurring peer support and engagement of more reticent students. Previous studies have identified the immediate academic environment as a powerful resource to secondary student retention. Students at an alternative learning center that outperformed learning expectations set by SES identified several factors to their persistence in school, including connecting to real life issues, student autonomy, and a relaxed environment where their input was valued [9]. This suggests that offering a similarly non-competitive, constructive environment for exploration of STEM can be an empowering strategy to increase student engagement.

To this end, project-based learning (PBL) may synergize with, or contribute to, a positive classroom culture. PBL is a mastery-focused, rather than knowledge-focused, pedagogical strategy where mastery represents an approach-oriented goal as opposed to an avoidance-oriented goal (i.e., avoiding failure). Mastery offers the benefits of higher intrinsic motivation, enjoyment, self-efficacy, and deep learning or conceptual achievement for its own sake [8]. In contrast, a performance-based approach emphasizes competition between students and is not only less predictive of STEM success [8], but also less conducive in principle to a constructive and equitable classroom culture.

*Discovery* uses a PBL approach to encourage secondary students in Grade 11 or 12 university-preparatory biology, chemistry, or physics classes at two participating schools to develop STEM skills through iterative course-long learning. Notably, the program has been developed to align with the Ontario Grade 11-12 science curriculum [10], whereby the first “strand” or broad area of focus with specific expectations for each course is “Scientific Investigation Skills and Career Exploration”. These expectations comprise both inquiry and research skills, as well as the identification of career paths related to the field of science being studied. Expectations are set so
as to most effectively bridge the gap to post-secondary STEM education, however educators involved in Discovery program design describe continuing difficulty in effectively meeting these expectations using available resources and traditional classroom settings. In a university setting, these resources are readily accessible, both in terms of materials and equipment for inquiry, as are graduate student volunteers with a variety of backgrounds and ambitions that serve as a means of career exploration. Therefore, in the Discovery framework, students are presented with capstone-style projects with a biomedical engineering theme (a cross-disciplinary field requiring integrative thinking and skills) and work in groups (3-4 students) throughout the semester. This includes three iterative visits to university teaching spaces to garner a scientific conclusion to research questions presented at the beginning of term. Throughout, the students are guided in project conception, execution, and interpretation by undergraduate and graduate instructors. Students present their findings as a final poster at a research conference-style symposium.

This program has demonstrated impact on students, both academically and with respect to learning attitudes. Overall, students responded favourably and performed better in Discovery-related deliverables than would be predicted by their class marks (all assessments performed by classroom educators). Furthermore, post-experience surveys suggested that in addition to general or transferrable skills, students gained increased confidence by overcoming failure, troubleshooting, and completing a significant research project [9-11]. Recently, program expansion has allowed for inclusion of a second school with significantly different external learning challenges, as quantified by the Learning Opportunities Index (LOI; a school board measure [12]), presenting an opportunity to investigate whether learning opportunities and culture of a school cohort affect observed program impact.

Herein, we compared metrics of student performance and engagement between school cohorts of externally quantified differences in learning opportunity within an experimental STEM learning environment (Discovery). Our findings indicated a differential experience in Discovery between student groups when comparing objective grade data, anonymous student surveys, and retrospective interviews with participating secondary school educators. Given significant differences in quantified LOI between the school cohorts, we attribute part of this marked disparity in impact to the difference in external challenges students face in their learning. We also qualitatively assessed the degree of reinforcement and attitude propagation within each cohort as potential mechanisms for the enhancement or suppression of student interest on an individual basis. This study may offer insight into the value of strategic targeting of differing student demographics to systemically enhance STEM performance and interest during key points in students’ early careers, such as the end of secondary school and during the transition to post-secondary study.

Methods

Ethical statement

All data collection involving students was approved by the University of Toronto Health Sciences Research Ethics Board (Protocol # 34825) and the Toronto District School Board External Research Review Committee (Protocol # 2017-2018-20). Parental consent to data collection was obtained for each student prior to commencement of programming. All data was
anonymized by secondary school classroom educators prior to assessment to maintain student confidentiality. Students without parental consent to data collection were not accounted for in student counts or metrics of performance, nor were they administered surveys.

**Students and instructors**

*Discovery* participants included university-preparatory biology, chemistry, and physics students from two schools in the school board (“School A”, N=77 students; “School B”, N=53 students). When quantified for SES factors, these schools scored in the second from bottom (“School A”) and top (“School B”) quintiles in the 2017 Learning Opportunities Index for secondary schools within the board (LOI; lower LOI is correlated to lower SES), respectively. LOI ranks an aggregate of “external challenges affecting student success” [12] and serves as a measure of characteristics of the concerned students’ environment by neighbourhood, not the physical area of the school catchment or surroundings. The variables used to calculate LOI include median income, percentage of families whose income is below the low-income measure, percentage of families receiving social assistance, adults with low education (no secondary school diploma), adults with university degrees, and lone-parent families. Aggregate neighbourhood data was selected by student postal code and collected from corresponding Statistics Canada data on tax returns and commercial demographic data.

Student participants were enrolled in Grade 11 (School A and B) or Grade 12 (School B) science classes, and *Discovery*-related deliverables incorporated into the overall course assessment confirmed participation in the program. These deliverables were graded by class specific educators and made up 10-15% of the final course grades. Prior to this study, School B participated in 5 prior semesters of *Discovery*, meaning that some students may have participated in upwards of three previous semesters of programming; analysis was performed blind to this possibility.

*Discovery* instructors were volunteer trainees (i.e., graduate and undergraduate students or postdoctoral fellows) from the faculty. Prior to student interaction, instructors participated in a full-day training session with School A and B educators exploring pedagogical techniques, as well as the technical specifics of the project to be executed during the semester.

**Discovery programming and data collection**

Students visited university teaching facilities for three full-day sessions throughout the semester of study, according to the workflow summarized in Figure 1. The first visit required participation in a “skill lab” modeled after an undergraduate laboratory class workflow; students completed safety training and lab orientation before being provided with a set experimental protocol, prepared reagents, and definitive endpoints to measure. This session was designed to expose students to relevant considerations for open ended research design in subsequent sessions. Students were then provided with a “Request for Proposal” that presented a research challenge related to (but an extension of) specific class curriculum (biology, chemistry, or physics). Working in small groups, students completed a proposal with constructive review by both their specific classroom educator and *Discovery* instructor. The following two visits, spaced two weeks apart, allowed time for students to conduct their defined experiments, or build and
assess prototypes, under the supervision of instructors. Students prepared and presented posters in an academic-style symposium as a final outcome.

Student performance in Discovery was assessed by collected course and Discovery grade data. Course grades were composed of 16-47 assessment entries per student, including tests, quizzes, and assignments (opportunities for quantification of course zeroes). Discovery deliverables consisted of an essay, proposal, client meeting and report, progress report, poster content, poster presentation, and laboratory notebook grade (School B only). Trends in combinational performance for each cohort were used in comparative assessment strategies.
In addition, custom (identical between schools) pre- and post-program surveys containing both multiple-choice and short-answer questions were administered to assess student attitudes towards the *Discovery* program, and STEM in general. Pre-surveys were administered prior to assignment of the first *Discovery* deliverable (essay) and post-surveys were administered following the final symposium presentation. Surveys were administered in class by educators; however, participation was optional. Partially completed surveys were included in combinational assessments. Only multiple-choice responses were quantified for this study.

Qualitative perceptions of student learning and program impact were discerned by structured interviews with the Science Department Head for each school cohort following the conclusion of *Discovery* programming. Interviews preceded by a set list of questions, although in certain instances ad hoc follow-up or clarification questions were asked as appropriate.

**Statistical methods**

All student performance and engagement data, grouped by school cohort, were assessed for normality using D’Agostino & Pearson omnibus test. No set of groups passed normality, so all pairwise comparisons were made by Mann-Whitney U-test. Significance was set at $\alpha = 0.05$. All analyses were performed using Prism 5 (GraphPad Software, San Diego, CA).

**Outcomes**

**Student performance**

In the execution of *Discovery*, students from two secondary schools participated in iterative PBL with (a) direct relation to their specific course content, (b) access to diverse resources in a university learning environment, and (c) the focused mentorship of their classroom educators working in close collaboration with university trainee instructors. To assess the impact of *Discovery* on student learning, objective metrics of academic performance and engagement (i.e., student grades and attendance in both *Discovery* and the classroom) were collected (Figure 2). The specific educator of each class was the sole assessor of all *Discovery* deliverables, thereby creating consistency in assessment approaches for the students within each class.

Outcomes from quantitative academic achievement data suggest School A performance and metrics of engagement in *Discovery* differed from those of School B. In the programming term studied here, School B (involved in four previous programming terms) continued to show a disparity in classroom vs. *Discovery* performance. This is consistent with our previous findings and proposed mechanism of learning efficacy: *Discovery* and its project-based, mastery-focused approach engages students differently than traditional classroom learning [13]. This is not surprising, as many of the students previously studied were still present in the current cohort. Overall, student participants from School B demonstrated an average *Discovery* grade that was 14% higher than their respective class grades, with most under-performing students (less outliers) achieving disproportionately in *Discovery*. 
Figure 2. Student performance metrics in *Discovery* and the classroom, separated between School A (2nd from bottom Learning Opportunities Index (LOI) quintile) and School B (top LOI quintile). Final course (A) and *Discovery* (B) grades per student; when plotted by *Discovery* grade vs. course grade (C), the difference in intercepts of linear fits are highly significant \( p<0.0001 \). Frequency histograms of grades of zero (i.e., incomplete assignments, D), missed days of classroom instruction (E), and missed days of *Discovery* (F) by student between schools. \( N=77 \) and \( 53 \) for Schools A and B, respectively. P-values reflect nonparametric U-tests between schools.
Aggregate assessment of classroom performance from both schools presented consistent mean final course grades (excluding the 10-15\% Discovery portion) of 67\% (Figure 2A); given this similarity it was determined that further comparative analysis between school cohorts was justified. However, performance on Discovery variables was significantly different (p < 0.0001) between school cohorts; School A students averaged 67\% (remarkably consistent to their course performance) while School B students averaged 81\% (Figure 2B). This enhanced performance in Discovery was markedly different among School B students regardless of course grade; the linear regression line of Discovery grade vs. course grade of School A is vertically offset but parallel to that of either School B or the theoretical 1:1 line (i.e., students’ performance in class is completely predictive of their performance in Discovery). However, for School A there was no course-to-Discovery grade differential, such that course grade was predictive (R²=0.54) of Discovery grade and was not significantly different (p=0.87) from a theoretical 1:1 correlation between course and Discovery grades (Figure 2C).

Although School B had a significantly higher average of zeroes (incomplete assignments, tests, or quizzes) in class than School A (2.42 vs. 2.39, respectively, Figure 2D), this is likely a negligible difference when considered in context of classroom learning. Interestingly, 66\% of School B students had no zeroes at all compared to 44\% of School A students; this is consistent with a wider distribution of School B students where the significance is produced by outliers. Similarly, School B students averaged significantly fewer zeroes on Discovery-related deliverables compared to School A students (0.53 vs. 0.94, respectively). Students of School A tended (p = 0.091) to miss fewer class days than those of School B (7.2 vs. 9.9 days, respectively, Figure 2E). Finally, there was no significant difference between schools in missed Discovery days (Figure 2F).

Although School B had more course zeroes on average and tended towards poorer attendance, they had significantly fewer Discovery zeroes. Together, these data suggest that performance in the classroom was equal between schools, but that the cohorts benefitted differently from the Discovery PBL framework. This invites consideration of qualitative outcomes to student learning attitudes, and how these could be correlated to differing cultures of learning within the separate populations.

**Student and educator perspectives**

To discern student attitudes about Discovery and STEM in general, we administered surveys prior to and following Discovery programming (Figure 3). Explicit interest in STEM before Discovery participation was virtually identical between student cohorts (Figure 3A). However, School B students were more than twice as likely as School A students to declare a positive impact on their predisposition when asked about the impact Discovery had on STEM pursuits (Figure 3B). It is important to note this may simply be indicative of students already perceiving further STEM courses in their future regardless of Discovery participation (i.e., selection of “No Impact”), reflected in consistent indication of plans to take fewer courses after participating in Discovery. School B students were also about 20\% more likely to indicate interest in further participation in a future offering of Discovery (Figure 3C), despite also indicating a much higher perceived academic challenge (5-point scale) in completing relevant programming (Figure 3E). Considering relevance to skill development, students from both schools strongly indicated
(School B more than School A) that they were more comfortable with the idea of doing laboratory work in a post-secondary setting as a result of their participation in *Discovery* (Figure 3D).

![Figure 3D](image)

**Figure 3.** Student opinion survey results concerning *Discovery*, separated between School A (2nd from bottom Learning Opportunities Index (LOI) quintile) and School B (highest LOI quintile). Student responses to questions concerning interest in hypothetical future STEM course participation before (A) and after (B) participating in a semester of *Discovery*. C) Student interest in participating in a hypothetical future offering of *Discovery*. D) Student opinion of increased comfort due to *Discovery* participation in a future post-secondary lab environment. E) Student ranking of perceived challenge of the *Discovery* program on a 0-5 Likert scale. N=77 and 53 for Schools A and B, respectively. Percentages may not add up to 100% due to rounding.
Taken holistically, these data suggest that students in School A may have felt more comfortable in a STEM setting in general, regardless of the way the curriculum content was delivered. Considering this difference, reactions from School B suggest that students derived significant value from their participation in the *Discovery* program and identified skill development, despite finding the program difficult. It is unclear what contributed to the baseline confidence in School A students, or alternatively the lack thereof in School B. Initial confidence notwithstanding, *Discovery* was found to be more valuable on its face to the students of School B, such that they would willingly engage in the future with an experience that they found more challenging than students of School A. A relatively simple explanation might suggest that PBL appeals more to students who have previously experienced, and persevered through, unexpected challenge by engaging some of their non-academic skills (i.e., “grit”). In fact, educators from School B expressed informally that their students often face difficult living situations, and through lived experience have garnered resourcefulness, grit, and strategies to maintain optimism.

While differential outcomes among cohorts may be partially related to lived experience, it is likely that the full explanation of observed differential program impact is much more nuanced and further influenced by the culture of learning surrounding each student population. To garner a more holistic understanding of this culture, we interviewed the Science Department Heads of each school in an effort to define trends in student *Discovery* experiences ([Table 1](#)). Based on observed quantifiable outcomes, student perceptions, and anecdotal observation of student behavior in programming, interviews were structured around a few themes: student perceptions of learning opportunities available in both the present and the future; autonomy and perceived value facilitated by *Discovery* mentors; and interpersonal interactions with other students. Informal discussion suggests School A has greater access to other supplementary STEM activities and resources (beyond *Discovery*), as well as higher familiarity and comfort with laboratory environments. This is reflected in consideration of post-secondary STEM pursuits, indicated to be normal practice within the School A cohort, perhaps due to such pursuits being common practice amongst their families and/or role models. As such, we expect that *Discovery* functioned as a preview of potential careers for School A students, rather than broadening of perspectives to a path that was not previously considered (School B). While the opportunity to participate in *Discovery* was generally viewed positively, student surveys and department head interviews suggest that students of School A held a different perspective of beneficial program outcomes than did those of School B. If *Discovery* was not perceived as a means to improve one’s course grade, and the path to post-secondary education seemed relatively attainable, the opportunity to improve intrinsic and non-quantifiable skills such as “critical thinking” may not have been especially appealing to students.

Interviewed educators also articulated the importance of the physical environment and introduction of instructors in creating a constructive PBL atmosphere, wherein the learning style would be different from the regular classroom. Therein, student enthusiasm was a factor of available resources and autonomy in practice; educators believe this was reinforced by the *Discovery* environment. For example, one educator identified during their interview that the immediate requirement of students to don lab coats was a powerful cue to being in a different environment, with different norms, but coincidently being treated seriously with expectations for tangible outcomes. Similarly, the availability (and perceived abundance) of fully functional
equipment that the students could use under supervision may have further contributed to perceptions of autonomy.

It was reported that School A students may have viewed and treated university instructors as peers rather than as mentors, perhaps due to relatability in future vision of STEM pursuits. In this case, personalized mentor attention and goodwill may therefore have been less influential to School A students than those of School B, who may have viewed the instructors’ station as relatively unattainable. Here, educators also remarked that diversity of mentor role models (i.e., race, gender) was a source of positive motivation for many students. Although we do not specifically report on the demographics of marginalized groups in the two cohorts, this may have importance in observed outcomes and warrant further investigation in the context of Discovery as a model for equitable STEM education.

Each of these personalized impacts on learning contribute to, and are amplified by, cohort effects and intra-group interactions. Therefore, interviews attempted to elucidate positive or negative feedback loops in the perceived value of Discovery among students. Educators suggested that, not only did inter-student dynamics impact perceptions of Discovery, but also student effort in project completion. Interestingly, reflection on group dynamics highlighted this impact: School A indicated that the prevailing attitude was apprehensive due to potential for group work to negatively impact final course grade, given weight placed on Discovery deliverables. In contrast, School B students viewed these same deliverables as an opportunity to improve their course grade, which fostered higher accountability to colleagues (and corresponding effort) toward a common goal. Unlike the classroom, a cooperative environment encourages lower academically-performing students to actively contribute to projects. This is directly related to confidence built through positive feedback to completed work. Importantly, this feedback held greater significance for School B, given that it came from both their classroom educators and members of the university (a group they initially perceived as intimidating and unfamiliar).

Considering the longitudinal involvement of students at School B, experienced students (i.e., participants from Grade 12) were explicitly noted as being encouraging of first-time students. This allowed peers and students to better ease concerns and anxieties of first-time participants given that they have concrete experiences from which to draw from when explaining the program, its expectations, and deliverables. This would be further amplified by knowledge of the program structure as a standard piece of School B’s STEM curriculum, perhaps fostering an openness to inquiry-based learning approaches. Importantly, School A has not yet developed such mentorship through longitudinal involvement, and therefore may see similar benefit over time with increased student and educator familiarity with the Discovery model. School A, by educator admission, predominantly represents a competitive environment favouring failure-avoidance [2]. Students from School A “wanted to be right or wrong, and then know what they needed to do to make it right”. As School A completes more terms, some of the noted differences in program impact between cohorts may narrow or disappear entirely if the culture of learning adapts towards excelling in a PBL setting. Nevertheless, the School A educators, both formally and informally, expressed concern that high academic performance in many of their students may be “intellectually subsidized” at the cost of decreased student performance during post-secondary education, where students are not equipped with the critical thinking and grit required to excel in an open-ended and largely self-directed STEM environment. Therein, we
highlight the importance in differential consideration of student backgrounds. Our preliminary findings suggest that students of School B, contrary to traditional considerations, have been more fit to persevere in ambiguous or open-ended PBL programming. This is reflected in discussion with School B about post-secondary pursuits, where the educators were confident that their students had the emotional skills needed to adapt to an academic environment that was less like the knowledge-based secondary-level STEM classroom, but instead articulated concerns about financial feasibility. This highlights the multifaceted considerations around building meaningful strategies to transition from secondary to post-secondary learning.

This study further supports previous evidence that an experiential, open-ended STEM environment offering mastery-based learning can inspire latent talent in students, encourage critical thinking and scientific skill-building, and motivate students towards future STEM pursuits [14-15]. However, we observed a differential program impact between school cohorts with significantly different externally defined learning opportunity. Given the stability of the disproportionally high School B student performance specific to Discovery over time, we attribute differences in Discovery performance to the value that students ascribe to the program. Available evidence provided through student surveys and educator interviews suggests that the perceived availability of opportunities to learn new skills, the autonomy granted to students, whether students feel more valued or legitimized in the STEM environment, and the presence of role models, may all provide avenues to motivate student engagement. Additionally, intra-cohort interactions as groups self-reinforce opinions of the program may be positively or negatively impactful on program perception; School A was typified by their department head as “sometimes... reluctant in terms of participating because they felt that in a group, other kids might bring down their mark”, while those of School B were described as “[pulling] each other along and [helping] each other. They seem all very positive about it and how they interact”.

These findings appear to support previous research into influence of external challenges to learning on the response to open-ended curriculum, as well as how student familiarity with knowledge-based, avoidance-focused learning may conflict with mastery-based content. From these findings, we suggest a novel target to equity focused education, where those that have externally developed “grit” may serve as high-yield targets for enhancing STEM literacy and performance with PBL, and consequent recruitment for post-secondary education. However, further study is required to divorce these findings from the covariates of different levels of familiarity with the program, as well as cohort effects in the metrics assessed. Future work will identify long-term, multi-cohort trends of student engagement or performance in cohorts in continued Discovery offerings.

Acknowledgements

Equal contribution to this work was made by JC, HC, ILC, NI, NTN, and JR and these authors are listed alphabetically. Correspondence can be directed to LDH or DMK. The authors would like to acknowledge the support of the undergraduate, graduate, and postdoctoral volunteers of Discovery for countless hours of involvement in program planning and execution, and in particular the cohorts of the executive organizing team each year. We further acknowledge the science departments and administrations at our participating secondary schools for their continued support and vision, as well as the IBBME Director and Undergraduate Programs
Office for their support. This program is financially supported by the IBBME and the NSERC PromoScience program (PROSC 515876-2017).

References

Table 1. Perspectives on student engagement, performance, and impact between Schools A and B, summarized from interviews with the schools’ respective science department heads. Direct quotations are in italics, while remaining text is a summary of ideas expressed in the transcript.

<table>
<thead>
<tr>
<th>Aspect of engagement</th>
<th>School A educator perspective</th>
<th>School B educator perspective</th>
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| Behaviour and outward signs of engagement in | “I would say that the behaviors in the classroom are very similar to what I am seeing [in  | “In the classroom, the kids are … not all participating. But you can actually see the participation at the [Discovery] program.”
<p>| Discovery vs. the classroom                  | Discovery].”                                                                                  |                                                                                               |
|                                              | • There was little difference between external behaviours in the classroom and Discovery lab  | • Students demonstrated a higher level of participation in Discovery than in the classroom |
|                                              | settings                                                                                      | • This participation manifested in greater discipline and focus to take advantage of opportunity |
|                                              |                                                                                               |                                                                                               |
| Interaction with instructors                 | “... I think they treat [the student mentors] more like they treat their peers than they do as an additional teacher.” | “[During the] very first encounter they're a little hesitant to interact with the grad students ... [they say] ‘Well I don’t want to ask a question because then they're going think I'm not smart.’” |
|                                              | • Students viewed mentors as peer, rather than as instructors or authority                      | • Many students initially viewed the mentor as an intimidating authority or superior, who was potentially passing judgement over them. This may represent general initial discomfort in the environment |
|                                              | • Many students appeared to carry a presumption of belonging in the environment, or perceived the inevitability of being in similar roles in the future | • Students demonstrated a greater feeling of accomplishment and the valuation of their work after being given positive feedback from graduate students or professors that are not viewed as peers |
| Interactions between students in Discovery vs.| “Sometimes they were reluctant in terms of participating because they felt that in a group, other kids might bring down their mark” | “Discovery provides students an opportunity to work together that don’t exist within the classroom |
| the classroom                                | • The level of collaboration observed in Discovery was student-dependent                        | • Students engaged with other students beyond their own “friend circles”                       |
|                                              | • Students who collaborated well in the classroom remained good collaborators in Discovery     | • Students perceived an opportunity to work together to improve their grades                 |
| Academic performance in Discovery vs. the   | • Appreciated opportunity to learn outside the classroom as it provided                        | • Students view Discovery as an opportunity in which to succeed and improve their class grades |
| classroom                                     |                                                                                               |                                                                                               |</p>
<table>
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<tr>
<th>Academic performance: Factors influencing underperformers</th>
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<tbody>
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<td>“They couldn't really wrap their head around [the open-endedness of the project]. They either wanted to be right, or wrong and then know what they needed to do to make it right.”</td>
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<tr>
<td>Most students expressed some form of discomfort with mastery- or project-based knowledge demonstration</td>
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<td>Students were generally avoidance-focused with respect to “being wrong”</td>
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<td>Underperformers were students who were disengaged from the onset of the course</td>
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<td>For ESL students, the communication and writing portions of the experience could be a barrier to success</td>
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<thead>
<tr>
<th>Academic performance: Completion rate and quality of assignments in Discovery vs. the classroom</th>
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<td>Students showed higher completion rates of Discovery materials than classroom assignments</td>
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<td>Student work did not often show a significant increase in quality, other than assignments were complete rather than partially complete</td>
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<td>Some students exceeded their regular classroom work quality in Discovery assignments</td>
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<td>Group dynamics spurred some students with low submission rates to “pitch in”</td>
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<tr>
<td>For some students, positive reinforcement of Discovery success builds confidence</td>
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<td>In general, a higher relative assignment completion rate was observed in Discovery than in class</td>
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<th>Academic performance: Impact on student understanding of curriculum</th>
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<tr>
<td>Students showed a noticeable improvement in lab skills at school and openness to inquiry-based work.</td>
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<td>Students gained problem-solving skills that extends past classroom curriculum</td>
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<th>Academic performance: Change in intrinsic academic behaviours</th>
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<td>Student personal growth was observed, as a result of exposure to different techniques, equipment, approaches</td>
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<td>“[The experience] makes them more aware … of what they want and what they don’t want. Therefore, they’ll work a little harder now that they’re more interested in biology now than engineering, so they put more effort into biology. And that’s probably where the kids are finding out what they really do like and don’t like in science.”</td>
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| Ownership and appreciation of *Discovery* work | • Most students displayed ownership over their project, but for many this didn’t manifest until receiving external validation during the symposium  
• Delayed or absent ownership over project could be due to lack of familiarity with the program and prioritization of failure avoidance | “In class, if I’m doing a lesson or a chapter, they kind of expect me to teach them the chapter. Well, [in *Discovery*], they do it all themselves.”  
• Students displayed significant ownership over their projects, often reflecting on the impetus created by having to present and display their work to the public  
• Students were visibly excited by the opportunity to work on a different or unique project  
• Value was observed in flipping initiative from educator to student to conduct knowledge information acquisition |
| Students understand purpose of *Discovery* as part of curriculum | • Students expressed an understanding of the purpose of *Discovery*, but could be hesitant to participate due concerns of group performance impacting personal grades | • Students recognized an opportunity to practice and develop skills essential to all branches of STEM (e.g. lab skills, data analysis, iterative discovery, communication of results)  
• Student understanding was furthered after learning that “Scientific Investigation Skills” was a required component of all STEM classes |
| Students feeling valued during *Discovery* | • Feeling of being valued was variable between students  
• Students who sought support and help felt valued  
• Others who did not seek help did not feel valued  
• Many students may have felt they should be catered to, rather than taking initiative to seize opportunity | • Students almost universally felt valued in the *Discovery* environment  
• Students were aware of being given access to environments and tools that are typically unavailable  
• Students appreciated autonomy to execute their own procedures and protocols  
• Students recognized that availability of certain resources, including instructor-student ratio, were not common |
| Relative value of interacting with *Discovery* instructors as role models | • Interaction with mentors allowed students to build better understandings of what roles they might have in the future  
• *Discovery* connected classroom knowledge to realistic projects  
• Projects represented a ‘bonus’ opportunity that gave students an advantage over their peers in future endeavours | “[Mentors are] opening up the kids’ eyes to say, ‘This is what is possible.’”  
• Students interacted with mentors and role models that represent their demographics that do not exist within the classroom  
• Students were exposed to career paths and lifestyles that they were not previously aware of |
|---|---|---|
| Student perception of *Discovery* as a unique program | • Students perceived a unique program, but within a context of other STEM programs that exist and are equally accessible | • Students perceived a unique program  
• Being designated the first group to have access to the program was a source of pride for students |
| Impact of attitudes towards STEM | “I think there's a group of students that ... didn't have confidence before in pursuing any inquiry ... based work or exploring open ended questions”  
• Many students seemed to maintain a specific attitude towards STEM  
• Some students gained positive or negative motivation towards continuing in a STEM field | • Greater number of students were observed taking university-preparatory STEM courses  
• More students applied to STEM university programs  
• Participation instilled confidence in students that they could succeed in STEM fields  
• Some students’ participation made them recognize that STEM is not their career interest |
| Students reinforce each other’s attitudes towards *Discovery* | • Attitude reinforcement was observed in both positive and negative forms  
• For those interested in STEM, displayed enthusiasm leading to better project outcomes  
• For students negative about involvement, they were “unsure of the quantity of work and whether it was worth it” and often distracted other students or discouraged effort | • Mostly positive attitude reinforcement was observed between peers  
• Older students with previous experience eased new student concerns regarding program difficulty  
• The ability to choose groupmates reinforced positive group dynamics, accountability to each other, confidence, and effort levels |