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Re-evaluation of an immersive secondary school inquiry-based STEM program post pandemic: Understanding how to meet student needs after learning disruptions (Evaluation)

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Abstract

Senior secondary (grades 11 and 12) STEM education generally focuses on knowledge-based learning, yet this approach fails to reflect the dynamic application of STEM concepts in post-secondary and/or research environments. Consequently, many students graduate from secondary school with limited understanding of how STEM concepts are applied outside the classroom. To overcome this challenge, advocacy is high for student-centered learning that immerses students in realistic STEM environments through hands-on experience, self-motivated learning, and inquiry-based projects.

The *Discovery* Program was launched in 2016 with the dual objectives of providing (i) senior secondary school STEM students with immersive educational experiences and (ii) engineering graduate students with an opportunity to develop pedagogical skills. Each semester, senior biology, chemistry, and physics students from local secondary schools complete open-ended biomedical engineering-themed projects within post-secondary laboratories guided by instructional support from graduate student volunteer mentors and their classroom teachers. The program framework provides students with an opportunity to explore STEM interests by engaging in realistic, open-ended problem solving using state-of-the-art research tools and equipment not typically available in the secondary school environment.

Previous studies of pre-pandemic *Discovery* Program outcomes revealed multiple positive outcomes for participants. However, due to the COVID-19 pandemic and associated disruptions to teaching and learning, there have been a number of changes to educational practices, and new challenges to student engagement and learning have emerged. Current study goals therefore investigate whether the *Discovery* Program has retained positive impact on students and whether the current framework should be adapted for immersion within the post-pandemic secondary learning environment.

To investigate current program impact and changes since the previous studies, structured interviews of participating secondary school teachers were performed following Spring and Fall 2024 programming. Interviews focused on discerning how teachers currently integrate *Discovery* programming into their existing curricula, as well as teacher perceptions of differences in student engagement and learning during program participation compared to normal in-class instruction. Thematic analysis techniques applied to interview transcripts identified three main themes within collective teacher responses: (i) both teachers and students are navigating a myriad of new or intensifying challenges centered around student disengagement, knowledge/skill loss, and student persistence as the transition back to in-person teaching and learning continues; (ii) students are excited and more engaged when participating in *Discovery* Program projects compared to classwork; and (iii) the experience within *Discovery* helps promote a more effective long-term student learning mindset. Although the interconnecting themes suggest there are indeed new challenges that continue to obstruct student learning, teacher perceptions reveal that the *Discovery* model remains effective at increasing student participation and engagement in STEM. Furthermore, teacher perceptions indicated belief that *Discovery* project experience helped overcome some of the challenges educators increasingly face within their classrooms, suggesting that programs such as *Discovery* are increasingly relevant in post-pandemic education. Results of these analyses provide important and relevant information regarding how supporting STEM programs should be designed and adapted to ensure continued benefits to student learning through immersive experiences.

1. Introduction

The COVID-19 pandemic triggered a global disruption in education, fundamentally reshaping teaching and learning. With lockdowns and social distancing measures in place, schools, colleges, and universities transitioned abruptly from in-person instruction to online and distance learning [1], [2], [3]. This shift was particularly challenging for fields such as STEM (science, technology, engineering, and mathematics) which rely heavily on hands-on experiences such as laboratory experiments, collaborative projects, and practical applications to help students develop knowledge [4].

Despite now being five years post-pandemic, students continue to struggle with the lingering effects of these disruptions, which have significantly impacted their learning experiences and skill development. The sudden shift to remote learning meant that hands-on experiences (e.g., laboratory experiments) were either reduced or eliminated, leaving students with an incomplete grasp of key concepts and limited exposure to the iterative processes that define STEM education [5], [6]. Due to the lack of such opportunities at earlier grade levels, many current senior secondary students face gaps in foundational knowledge and theory [5], [7].

In addition to academic challenges, the loss of collaborative, in-person learning environments has hindered the development of vital complementary skills (e.g., communication) [6], [7], [8]. Group project dynamics, lab partnerships, and classroom discussions are essential for cultivating teamwork, communication, and problem-solving abilities. Virtual learning environments are challenged to offer the dynamic, interactive nature of face-to-face collaboration, and have left many students underprepared for real-world scenarios where these skills are indispensable. Moreover, prolonged isolation and the shift to independent, screen-based learning may have contributed to reduced confidence and adaptability, further affecting students' readiness for future academic and professional pursuits [5], [6], [7], [8].

The implementation of student-centered problem- or inquiry-based learning (IBL) exercises may serve as a method to address the learning challenges faced by students and educators in a post-pandemic landscape. When used effectively, IBL enables students to engage in active hands-on learning, develop critical thinking skills, and collaborate with peers or teammates [9], [10], [11]. Moreover, IBL enhances student motivation through investment in the learning process and relevancy to real-world problems, and fosters the development of transferable competencies (e.g., critical thinking and communication) across various contexts [10], [11]. In STEM education, student ratings of IBL significantly predicted their interest in a future career in STEM as well as their intrinsic motivation to study science [9]. A review covering 36 peer-reviewed articles on the implementation of IBL showed that this method improved knowledge retention, problem-solving abilities, and students' attitudes toward learning physics [11].

The *Discovery* program, launched in 2016, aims to enhance the educational experiences of secondary school science students while providing University of Toronto graduate students with valuable opportunities to develop independent teaching and mentoring skills [12], [13]. Rooted in an IBL framework, the program enables students in biology, chemistry, and physics courses to engage in biomedical engineering-themed semester-long open-ended projects within post-secondary laboratory settings. The projects are designed to foster critical thinking and prepare students for post-secondary STEM studies through immersion in authentic, hands-on laboratory experiences. Throughout the semester, students design and conduct experiments in university laboratories under the guidance of both their teachers and graduate student mentors. Pre-pandemic research of program outcomes highlighted numerous benefits, including significant improvement in student performance on *Discovery* deliverables compared to regular coursework, with nearly half of participants scoring at least 15% higher on *Discovery* projects than their final course grades. Furthermore, students expressed a strong interest in further STEM exploration, with 72% indicating a greater likelihood of pursuing STEM courses or degrees [12].

While the benefits of IBL and programs such as *Discovery* have been demonstrated pervasively in the literature and have gained popularity in STEM education, several factors can limit the effectiveness of IBL in learning environments [11], [14]. Specifically, effective IBL requires significant guidance of students from course facilitators and is thus time-consuming and demanding for both students and educators [11], [14]. Furthermore, implementation of IBL may also not be effective when students lack the necessary background knowledge and/or skills required for proper engagement in an IBL environment [11]. As pandemic-induced learning disruptions amplified challenges experienced by students regarding classroom engagement, learning loss, and motivation [5], [8], it is unclear how current students will engage with and benefit from IBL and programs such as *Discovery*.

This paper focuses on the evolving role of the *Discovery* Program in senior secondary school science classrooms post-pandemic. Due to the myriad of COVID-19 pandemic-related disruptions to learning and the associated lingering impacts on students, we hypothesized that the impact of the *Discovery* teaching and learning framework had shifted in the post-pandemic senior secondary school science environment. This study investigated potential shifts by analyzing data from structured interviews with participating teachers following Spring and Fall 2024 programming. The interviews were designed to assess teacher integration of *Discovery* into their curricula, changes in student engagement, and the perceived effectiveness of the program compared to traditional instruction. Importantly, teachers were asked to reflect on how these dynamics have evolved post-pandemic. By analyzing these insights, this study aims to inform how *Discovery* and similar IBL-rooted STEM programs can adapt to ensure continued relevance and benefit, ultimately strengthening the educational landscape for secondary students navigating STEM pathways in a post-pandemic world.

2. Methods

2.1 *Discovery* Program overview

The general *Discovery* Program structure and timeline are outlined in Figure 1. Briefly, the program begins with a Skill Lab session held at Teaching Laboratories at the University of Toronto, where students are exposed to foundational skills relevant for their term projects. Each group of 3-4 students is provided with a subject-specific Request for Proposal (RFP) document, designed by graduate student mentors, outlining a real-world problem related to the chosen focus topic for the given semester. Using the RFP as a guide, students develop a research proposal that includes a clear rationale, defined goals, and an assessment protocol designed to yield a final recommendation or solution relevant to the problem.

Following proposal development, students execute their experiments during two on-campus laboratory visits. During the first visit, they implement their proposed plan, collect initial data, and identify areas for further optimization. Between visits, students participate in a virtual client consultation with graduate student mentors, where they receive feedback and propose modifications to their experimental approach. In the second on-campus visit, students refine and execute their updated plan, collect additional data and analyze results to formulate evidence-based recommendations. With support from classroom teachers and iterative feedback from graduate student mentors, students compile their findings in a summative scientific poster representing the final deliverable graded by their teacher. The program concludes with a symposium held on campus, where students present their work to university student judges, engage with undergraduate student panels, and attend university-level classes, providing them with a comprehensive and immersive STEM experience. Program structure and sample projects have been previously described to great depth [12], [13], [15].

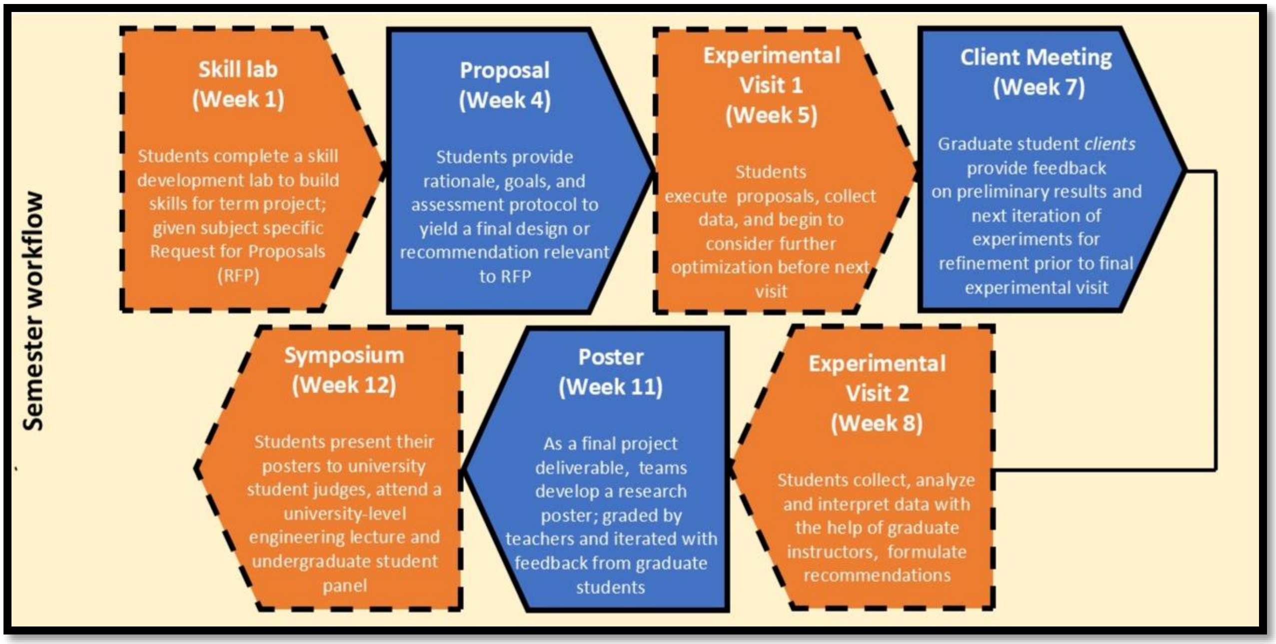

Figure 1. Overview of one semester of the *Discovery* Program. Orange chevrons with dashed outlines represent full-day student workdays in university teaching facilities; blue chevrons with solid outlines represent key project deliverables throughout the project.

2.2 Study participants

Eight secondary school STEM teachers, representing three schools currently partnered with the program, were interviewed for this study. All teachers had participated in at least one semester of *Discovery* programming with their classes. The schools rank variably on the Toronto District School Board Learning Opportunities Index (LOI), which is a numerical index reflecting the external challenges affecting student success based on the socioeconomic status of residents within the school's neighborhood [16]. In 2023, *Discovery* schools were within the second, third, and fifth quintiles of LOI rankings; higher rankings on the LOI indicate schools exhibiting greater resource constraints. Table 1 shares teacher aliases as well as their years of experience, their respective *Discovery* subjects, and associated school. Interview protocols were approved by the University of Toronto Research Ethics Board (protocol #00047071); each teacher provided written informed consent prior to participation.

2.3 Teacher interviews

All interviews followed a prescribed list of questions that were organized sequentially into the following sections: (i) student engagement in both regular classroom and *Discovery* activities; (ii) relative student performance in *Discovery*-deliverables versus other coursework; (iii) influence of *Discovery* participation on student attitudes and interest in future pursuit of STEM; (iv) integration of *Discovery* projects into course curricula; and (v) changes in student engagement and performance since pandemic learning disruptions. In certain instances, *ad hoc* follow-up or clarification questions were asked, as appropriate.

Table 1. Teacher participant aliases, school affiliations, and years of experience teaching and participating in the *Discovery* program. LOI quintiles were ordered from to lowest highest external challenge to learning (i.e., within our sample, school A experiences the lowest external challenge to learning while school C experiences the highest).

Teacher alias	Years of teaching experience	Years of *Discovery* participation	*Discovery* subject(s)	School alias	School LOI quintile
Linda	25	6	Biology and chemistry	A	5th
Jeff	7	3	Physics		
Casey	14	3	Biology		
Greg	3	1	Biology	B	3rd
Oliver	5	2	Physics		
Karl	15	1	Physics		
Larry	16	1	Physics	C	2nd
Susan	23	8	Physics		

Interviews were conducted by 4 members of the research team. Interviewer and interviewee pairs were constructed such that the interviewer had never worked directly with the interviewee during delivery of the program. Interviews took place virtually using video conferencing software and audio was recorded, transcribed, and anonymized prior to analysis.

2.4 Data analysis

Three authors not involved in the interview process independently completed multiple readings of each transcript and independently identified key themes evident across teacher responses. Initial themes were developed without considering or interpreting the relationship between themes. Excerpts from transcripts were categorized into the theme and sub-themes identified by each reader. These three authors then compared and consolidated themes and developed an interpretation connecting the aggregate themes and sub-themes. The two lead authors subsequently reviewed the excerpts and re-categorized them into the finalized theme and sub-theme categories. The direct quotations presented herein include excerpts that retain the wording of the participants but have been edited for readability as necessary.

3. Results and discussion

The themes and sub-themes extracted from the interviews are identified in Table 2. The right-most column of the table summarizes key points expressed by the teachers for each sub-theme. Each theme and emerging connections between themes are discussed in detail in subsequent subsections.

Table 2. Summary of main themes, sub-themes, and key points emerging from the thematic analysis.

Theme	Sub-themes	Key points
Emergent challenges in secondary science learning	Accrued post-pandemic foundational knowledge gaps of students	• Virtual learning yielded reduced student learning • Loss of learning persisted post-pandemic due to lack of foundational understanding of prerequisite concepts • Students internalized relaxed expectations and requirements present during virtual instruction • De-streaming of junior (Grades 9 & 10) classes made transition into senior (Grades 11 & 12) science classes more difficult
	Reduced student engagement in academic activities	• Subset of students aimed for bare minimum required to achieve passing grade • Increased student absenteeism • Increased cell phone usage and distraction
	Decreased perseverance and STEM-specific problem-solving skills	• Reduced problem-solving skills • Increased student disengagement when faced with complex tasks • Increased reliance on artificial intelligence (AI) tools
	Diminished collaboration and communication skills	• Reduced socialization immediately post-pandemic • Worsened written and oral communication skills
	Approaches taken to address learning gaps and the reduced complexity of learning material	• More class time devoted to reviewing foundational concepts from previous grades • Additional scaffolding introduced to assessments
Enhanced engagement through the *Discovery* learning platform	Fostered engagement via hands-on, interactive experiences within university lab spaces	• Novel, exciting environment • Emphasis on hands-on, interactive activity • Deeper engagement via active learning
	Leveraged access to advanced university resources	• Access to equipment not available in schools • Opportunity to work with, and learn from, graduate student mentors
	Linked STEM learning to student Funds of Knowledge	• Alternate avenues to demonstrate knowledge and understanding • Flexibility to connect projects to other interests and strengths
Sustained long-term development beyond *Discovery*	Curricular content connections to practical, motivating contexts	• Tangible context and motivation for curricular learning objectives • Expansion of inquiry-based instruction
	Identification and bridging of gaps in STEM knowledge and skills	• Exposure to, and development of, required scientific inquiry skills • Development of growth mindset
	Nurtured STEM confidence and post-secondary aspirations	• Familiarization with post-secondary environment • Development of belonging • Excitement for post-secondary opportunities

3.1 Emergent challenges in secondary science learning

3.1.1 Accrued post-pandemic foundational knowledge gaps of students

The abrupt transition to virtual learning during the COVID-19 pandemic necessitated changes to instruction, including virtual lessons and modifications to student assessment. Teachers reported that changes negatively impacted student learning, both directly in the quality of learning during virtual instruction and indirectly in the expectations retained by students in the transition back to in-person instruction:

> *The effectiveness of virtual [instruction proved] to be very below average. [During online teaching, students] understand what they need to do. They need to log in to get marked present. [...] After that? They may not pay as much attention. Sometimes, something happens in the [lesson], and [they] don't register it because [they] don't pay attention. [Students were] missing some parts [of lessons] that [they] would probably not miss if [they were] in the room, but [they] had to do it from home, and the quality definitely dropped during COVID virtual [classes]. (Karl)*

> *A lot of evaluations [went from] pencil and paper […] to some form of multiple choice or fill in the blank. […] It's very, very formulaic. So, students are now getting the worst of online education where they think they don't need to go to class, and as long as they can fill in the right number in the blank or they have the answers, they don't really have to sit and think about things. (Larry)*

The observed loss of student engagement and attention during virtual classes was not unique to our interviewed teachers or their students. Indeed, the near-instantaneous transition to virtual learning created an environment where both teachers and students lacked the skills, resources, and understanding to replicate in-person teaching outcomes [17]. However, it appears that transitioning back to in-person learning has presented its own challenges. As outlined by Larry above, some students internalized the reduced expectations of engagement and assessment that were common, but intended to be temporary, during virtual learning.

A significant consequence of the diminished learning environment during virtual instruction was students missing foundational knowledge that should be learned in earlier grade levels, which posed a challenge during the transition back to in-person learning:

> *It was very hard to teach during COVID-19 - no one's going to dispute that. What it left was […] a lot of gaps in knowledge for the students. They find it a lot harder to grasp what I'm teaching because science as a course is usually taught based on concepts that were learned in the course prior. [...] What that has left us is a difficult situation where the students find the subject harder, which also means that they are less interested in pursuing the subject in the future. (Greg)*

While learning loss of students during the pandemic and virtual education has been widely documented [18], the interviewed teachers highlighted other recent policy and resource-based changes that have compounded the challenge of re-engaging students. Prior to the pandemic, secondary school students in Ontario were placed into separate academic and applied streams beginning in Grade 9 based on previous academic achievement. Academic stream courses were intended to prepare students for university, while applied streams were intended to prepare students for vocational careers [19]. Significant curricular differences between the streams raised concerns about the quality of education provided to students in applied programs. Additionally, curricular differences between the two streams meant that applied stream students often had learning gaps that prevented them from transferring into academic streams [19]. Because universities in Ontario require students to have taken academic classes, many students' ability to attend university was dictated by the stream to which they were assigned during their first years of secondary school. Further investigation into the practice of streaming revealed that low-income [19] and Black [20] students were disproportionately channeled into the applied stream. This raised concerns about systemic discrimination limiting educational opportunities for already-marginalized students.

Because of these criticisms, the Government of Ontario began de-streaming Grade 9 classes in the 2020-2021 school year. The Toronto District School Board elected to de-stream both Grade 9 and Grade 10 [21]. While teachers supported the decision to remove the streams, they felt that the transition has not been seamless. Casey highlighted that while the curriculum of junior science classes has changed to accommodate a wider range of students, the senior science curriculum has not been adjusted accordingly. Because of this, she observed that more students have struggled with the difficulty level of their senior science classes. These curricular changes, in conjunction with pandemic learning loss, larger class sizes, and a more diverse range of student needs, have made it challenging for teachers to support students:

> *I like to say that the streaming was like a band-aid over a gunshot wound of inequity. And then [the government was] like, well, "this band-aid isn't working." And they just took it off. And didn't fix the wound. And so now we have academic classes that are like 30 kids in grade 9, where we would have had applied classes of like 20 [...] It means the kids that need more support can't necessarily get it because they're in bigger classes. And it also means that they've changed the curriculum and the curriculum in grade 9 and 10 has certainly gotten easier. There's not as much content. And so, the jump from grade 10 to 11 university-prep is huge and the expectations get much higher. […] I think that's been a huge change that teachers are trying to figure out how to deal with: how to bridge the gap from [grades] 10 to 11 [and] still get them to a place where they can go off to university.*

Greg further expressed that de-streaming may have altered the overall interest and motivation of students within junior science classes, necessitating further teaching adjustments from teachers:

> *About half of our [grade 10 science] class would be […] prospective university students who want to [proceed to] university-prep classes. And the other half of the class don't even want to be in science at all. So, I feel like that also has a huge impact on learning.*

While it is important to note that similar de-streaming initiatives have taken place within other jurisdictions and have not resulted in significant negative learning outcomes [19], [20], teachers in this study expressed that it has been difficult to implement a de-streamed curriculum while simultaneously managing the lingering effects of the COVID-19 pandemic on student learning and engagement. Consequently, the perception of the interviewed teachers was that, compared to pre-pandemic cohorts, students were lacking the knowledge and skills needed for success in senior science courses.

3.1.2 Reduced student engagement, perseverance, and socialization

In addition to the weaker foundational skills of students within their senior science courses, teachers indicated that general student engagement in academic activities has declined since the pandemic. As a primary indicator of lower engagement, teachers reported increased student absenteeism, aligning with the increase in chronic absenteeism observed within several jurisdictions post-pandemic [22]. Beyond attendance, however, the teachers have observed that an increasing subset of students appear to be simply aiming to fulfill the minimum requirements needed to proceed to the next grade level:

> *I feel like very few of them are interested in learning. Just generally, a lot of them are trying to meet minimum requirements. High school is something that they have to do and they [only] need a particular average. So, what they're trying to do is do the minimum possible in order to get that. (Larry)*

The teachers theorized that part of this reduction in student engagement could be attributed to declining student perseverance and problem-solving skills. As observed above, teachers felt that student expectations of learning and assessment shifted during virtual learning, where assessments were often formulaic and straightforward. As a result, their students did not develop robust problem-solving skills and often disengaged entirely when presented with more complex tasks:

> *Their interest level and their attention span for problem solving, in my experience, has been very much reduced. Students will openly revolt if a question has three or four parts to it, [for example, if asked to] draw diagrams [...] or explain something where there's not just one answer that we're looking for [...] they're just not interested at all because up until now, it's been [questions like] "fill in the blank [with] one word." And that's the educational model that they're in. (Larry)*

> *I think through COVID-19 and through online learning, […] it was hard to really emphasize the process. Students started to develop an expectation that they were just handed everything, or [they] could hand in anything regardless of the quality and it would have the same value or same outcome for them. And as we started to transition back into school when there was less online knowledge-sharing, they didn't necessarily have strong problem-solving skills or the ability to persevere through challenging tasks because they didn't have to [during online learning]. There was no need for them to*

> *develop that. So, in terms of engagement, they would really disengage if things were hard. (Linda)*

Teachers further indicated that this decline in perseverance may have been accelerated by increasing use of generative artificial intelligence (AI) tools and mobile applications to complete assignments. Teachers believed that this, in conjunction with years of virtual learning, had blunted opportunities for students to strengthen their understanding of curricular concepts:

> *I think there's been a real reliance on technology, whether that's AI or apps that just take a photo of math and solve the questions for you. There's really been a reliance on that where the students [ask], "Why do we have to learn how to do this when I can just click a couple of buttons and get the answer?" […] With COVID-19, I think that just exacerbated everything because they were left on their own. They could just turn on a Zoom call and then [use] one of these [apps or] Google the answers. (Oliver)*

Furthermore, the teachers felt that increasing distractions of cell phones post-pandemic have impeded student ability to critically engage with materials in class. While distractions these were an issue in the classroom prior to the pandemic [23], the interviewees expressed belief that multiple semesters of virtual learning have exacerbated this issue:

> *Because of the years at home, the kids [became] addicted to so many things that they're looking at on their phones. Addicted to games, addicted to social media, and [now] coming back to school, back into the classrooms, they can't break that habit. They've had years at home enjoying their cell phones. They can't give it up now. Unfortunately, it's a hard battle that we're still struggling with every day. (Susan)*

Due to the variety and magnitude of changes experienced within education since the pandemic, it remains challenging to precisely identify the reasons for declining student engagement. Some researchers have posited that uncertainties and disruptions brought upon by the pandemic may have negatively affected adolescents' ability to engage in future-oriented thinking [24], the projection of oneself into hypothetical future scenarios to support goal setting [25]. Underdeveloped future-oriented thinking could be contributing to the reduction in student effort outlined by the teachers within our study. This unfortunately suggests that those who are not already interested in a STEM career may not perceive how the knowledge and skills taught in their science classes relate to their future goals and may therefore be less motivated to engage in STEM learning.

Interview responses from the teachers identified reduced socialization within educational environments as another factor contributing to reduced capacity to engage. Current senior secondary students spent crucial formative years online and therefore did not experience a typical, more gradual, transition into middle or secondary school. Virtual learning thus deprived students of opportunities to develop typical classroom behaviors, social skills, and communication abilities:

Right at the moment when we were back into face-to-face classes, I was teaching grade 9 class. And it felt like they're seriously lacking communication skills, collaboration skills, general behavior in the classroom. […] Because [after] being in isolation for a year or two, … they missed the transition [...] to high school. (Karl)

There's a huge difficulty in communication, I would say especially written or oral. Their ability to take what they're thinking and communicate that to their teacher [...] is a huge problem. (Casey)

While many professional and social sectors have indeed progressed steadily toward pre-pandemic norms, these responses show some of the issues that have persisted in secondary school education. A key contributor to some of these challenges appears to be the lack of pre-pandemic experience that students had in these spaces prior to the shift to virtual learning. Indeed, the "return" to in-person instruction was a misnomer, as this presented another significant and abrupt change for students who had minimal experience within secondary learning environments and therefore lacked the requisite skills to succeed in these spaces.

3.1.3 Approaches taken to address learning gaps and the reduced complexity of learning material

To address the emergent post-pandemic learning challenges, teachers have responded by making multiple changes to their curriculum and practice. A common adjustment reported by several teachers was devoting more class time to review foundational concepts from prerequisite courses:

We spend a lot more time catching up these days. [For example, during] a grade 12 lesson, [I say] "this is what you should have learned in grade 11." And half of my classroom will say, "oh, we didn't get to that part last year." So, [...] we're going to go back. I'm going to reteach you this thing and then we'll get to today's lesson. That's how we end up getting through a lot of our classes these days. […] It's definitely a lot more crammed per lesson. (Greg)

All teachers expressed that gaps in learning introduced in earlier grades were, to some degree, impeding student ability to learn more advanced concepts, resulting in lost class time and perpetuating learning loss. However, contrasting responses from teachers at different schools suggested that teachers from school C (2nd quintile LOI, greater external challenges to learning) have, on average, needed to adapt to larger learning gaps and disengagement than teachers in schools with lower external challenges to learning:

For my senior grades, I've actually moved completely away from inquiry-based [learning], and now I'm just gap closing. So, I do a lot of remedial math, some remedial problem solving (two equations, two unknowns, review of BEDMAS, what geometry means) to try and give them an opportunity to, if they do go to post-secondary, have the foundational tools so that they could possibly be successful. […] At the senior level, *because they've missed out on [inquiry-based learning] for so long, it's now just like triage and trying to fill in as much gaps as possible before they end up in post-secondary. (Larry; School C, 2nd quintile LOI)*

I'd say the students I'm seeing now, no [the pandemic has not affected student engagement with STEM education], because it's been about three years since they've been back in the classroom, [...] they've had exposure to high school science. So, I don't think it's changed their engagement. (Jeff; School A, 5th quintile LOI)

The larger discrepancy seen in student learning outcomes at school C may be attributed in part to the reduced pool of resources available to students at this school. Other studies have observed that marginalized and lower socioeconomic status students accrued greater learning losses throughout pandemic-induced virtual learning [18]. Importantly, these disparate observations underscore that the mix of challenges associated with the transition back to in-person instruction have not impacted all students equally. Consequently, providing equitable transition support to students will likely require tailored responses to identify and address the most pressing challenges facing each individual student.

To overcome some of the observed challenges regarding student disengagement and perseverance, several teachers reported that they have relied upon increased scaffolding of their instructional materials to enable more students to participate:

I use a lot of [...] checklists and graphic organizers. So, it's not just like, "here's a piece of paper with your assignment." It's "here's how you're going to do the assignment step by step by step." Sometimes I'm like, "am I doing too much for them?" But also they don't know how to do things [without the guidance]. (Casey)

While scaffolding is indeed a beneficial pedagogical tool for teachers, the concern, as articulated by Casey above, amongst the teachers was whether they may be over-scaffolding materials for students and thereby reducing student opportunities to develop their own critical thinking and self-efficacy skills, which teachers have highlighted as critical to re-enable deeper engagement and learning.

3.2 Enhanced engagement through the *Discovery* learning platform

3.2.1 Fostered engagement via hands-on, interactive experiences within university lab spaces

In contrast to the engagement challenges discussed above, the teachers reported several positive differences in how students engaged in *Discovery* versus regular classroom activities. Many suggested that the experience of being placed in a different environment increased student interest and excitement:

It's novel, and that tends to hold their attention, or, you know, generate a little bit more excitement, which is nice, too, in terms of keeping them engaged. (Linda)

Casey further indicated that she believed increased engagement was not solely due to students being placed in a new environment, but also a recognition amongst students that working in a university space alongside graduate students warranted a higher standard of behavior:

> *I also think that there's something really valuable about expecting more out of them. I think there's sort of a maturity of walking into this lab space with these grad students. And an expectation of the way that we work and where our behavior is at.*

A common remark to explain the increased engagement was that students were drawn to the practical, hands-on, and collaborative aspects of *Discovery*, which are less prominent within their regular classroom activity:

> *The practical component, I think, is huge. Just being able to [...] make something and have that product, [...] they loved it. So, I think it's like you have this idea. And then it comes out, and you can physically now hold what you designed. That was [...] something that they took a lot out of. (Oliver)*

> *Honestly, the classroom environment, being in a class, it's very structured, and we have to adhere to certain rules, and there's less flexibility in terms of the amount of talking that a student can do, because we have to get lessons out, we have to teach, and we have to answer, A, B, and C's questions, and so we don't give the students a chance to mix and mingle. It's the complete opposite at Discovery. They're in their groups. They're socializing at the same time as working. They're always doing group work. They're not alone. They're not just sitting in front of a board. They're not at a desk by themselves. They're not just forced to work with a textbook or whatever they're doing. They are talking with other students. They're talking with [their Discovery mentors]. They're trying to figure things out on their own. So, [...] it allows them the freedom to socialize [and] think for themselves. (Susan)*

Encouragingly, the teachers also expressed that the increased engagement during *Discovery* was observed amongst students at all academic levels, ranging from top students to those chronically absent from class. Teachers from schools B and C (higher LOI; lower resource) shared examples where students who seldom attended class were motivated to attend *Discovery* Program days:

> *This student barely shows up [to class, but] sure enough, that student does show up [to Discovery] because, you know, the classroom is not necessarily for everybody. But getting to go [to the university is] kind of the novelty [...] that really draws more engagement out of them. (Oliver)*

> *But as for the students who are weak, [...] they're a bit more disengaged from the class. Some of them are skipping. But they will show up to the Discovery projects because they like the practical work and they like collaborating with the group members. (Greg)*

These anecdotes align with pre-pandemic evaluations of *Discovery* where the frequency of student absences was lower for *Discovery* program days than regular classes [12].

Beyond attendance, the teachers highlighted that the interactive nature and length of the *Discovery* projects created a more enriching learning opportunity:

> *They were making decisions. And those decisions actually resulted in a change to their experiment. And so, I think it was nice that they actually had an active role in their learning. (Oliver)*
>
> *A regular class is only 75 minutes whereas when they're at [Discovery], they're there for six, seven hours and so I think the depth of the engagement is much stronger at [Discovery] because they have a chance to work with each other for so much time on one specific topic. Whereas when they're with me in a classroom, it might be 15 minutes, half an hour, maybe up to the 75 minutes, but then we're on to the next thing and because the Discovery program problem extends over an entire day, over a couple of months, they have a chance to really think deeply about the problem and engage deeply with each other. (Jeff)*

The benefits of iterative learning in STEM have been previously reported elsewhere: students reported significantly higher self-efficacy when engaged in semester-long, challenging pre-engineering experiences over shorter STEM programs such as single-day workshops or field trips [26]. Similarly, students participating in *Discovery* continually work on their projects over a semester, providing them with the time and resources to internalize learned concepts.

3.2.2 Leveraged access to advanced university resources

When discussing the differences between classroom versus *Discovery* engagement, the teachers often referred to how they felt student learning opportunities were enriched by the use of university resources not typically available at their schools. Consistently, teachers indicated that access to more sophisticated laboratory equipment increased student interest and ability to critically engage with curriculum content:

> *It's very challenging to do labs that are relevant to the kind of work that they'd be doing in university because technology is so expensive and inaccessible. (Casey)*
>
> *[Students] get [access] to equipment that helps support their understanding of that topic. For example, when we use force plates [in Discovery] it's great because we learn forces theoretically, we draw the free body diagrams, but we don't have anything besides our little dinky Newton's spring scales to measure forces. So, when they actually get to use force plates, it's better [because] they can measure something that weighs more than 10 grams or [what the limit of the spring scale is]. [With force plates] they can understand how forces come into play when they're doing [familiar body] movements. (Susan)*

This commentary from the teachers was unsurprising as hands-on experimental work is critical to effective STEM learning [4], [5]. By situating students within university laboratories with modern equipment and experienced practitioners, participants have access to resources to meaningfully explore and experiment with STEM concepts with minimal constraints.

Beyond the availability of lab equipment, teachers indicated the positive value provided by having students interact with and learn from the *Discovery* mentors:

> *It seemed like a fantastic opportunity for the students [...] to have a chance to interact with somebody other than myself, to learn physics and the scientific method and the engineering design process. (Jeff)*

These insights from teachers indicated that a key element of *Discovery* retaining a positive impact on student learning and engagement post-pandemic was access to university resources not typically available within secondary schools.

3.2.3 Linked STEM learning to student Funds of Knowledge

Funds of Knowledge is an educational concept that refers to the individual and collective skills, knowledge, and resources that students can draw on to support their learning [27]. Giving students opportunities to access their funds of knowledge is particularly important for students who may otherwise experience barriers to success [27]. Teachers' reflections showed that the open-ended, inquiry-based *Discovery* environment provided an accessible platform for students, especially those who typically struggled in science, to demonstrate their learning in ways that aligned with their personal skills and interests and draw on their funds of knowledge:

> *[For] some students who are less academically inclined, less successful on standard tests or quizzes, they have better opportunities to demonstrate their understanding and talents through Discovery. Some of that has to do with the length of the [Discovery project], it gives them time [...] for thinking and processing to catch up if they're not understanding something and to collaborate [with peers]. So, they're able to use the collective strength of the different people that they're working with to develop a better understanding and better outcomes. And it's not a timed task. I mean, there are obviously timelines. But it's not like, you know, "get this done in 60 min." (Linda)*

Susan specifically recalled a student who had weak math skills but excelled at communicating his group's projects at the symposium:

> *He was able to [...] speak with confidence [to] whoever came to visit [his group's] poster and handle all of the questions that were thrown at him. He did an amazing job. Because he was at a weaker level, he had to figure out and understand what the other group members had done [and] put it in terms that he understood [to explain] the physics.*

In addition to varied learning outcome assessments, students enjoyed the freedom to personalize their projects and draw upon their other interests. Casey and Karl both highlighted the diversity of experiments and designs that different student groups proposed. Oliver shared an example of how one group drew upon their woodworking skills to complete their project:

> *When they brought [their prototype] back to the classroom they were finding time outside of school hours to add to the project. I know last year there's some students that went to the woodshop [...] in our school and they were working with their old woodshop teacher*

> *to create new things for their [prototype]. It was something they really took ownership of. And so, they did spend that time outside of Discovery to really kind of make it their own.*

The themes discussed by teachers within this section aligned with our prior pre-pandemic analyses of the *Discovery* Program [12], [15]. Specifically, the responses from the teachers indicated that the active, inquiry-based learning *Discovery* model continued to be an enticing opportunity that draws greater and deeper engagement from students of all levels. Beyond the scope of the *Discovery* Program, the results also appeared to affirm the wider benefits of inquiry-based learning [9].

3.3 Sustained long-term student learning beyond *Discovery* participation

In addition to providing a platform for increased engagement during *Discovery* campus visits, the teachers expressed that the *Discovery* Program experience promoted a sustained growth and learning mindset within students that helped combat some of the within-classroom learning and engagement challenges.

3.3.1 Curricular content connections to practical, motivating contexts

A repeated theme within teacher responses was that the *Discovery* projects provided a tangible and motivating context for their curricula:

> *Looking at developing a solution to a problem that they're given that has a very tangible application and outcome. I think those things suit post-secondary preparation well but also provide purpose to what students are doing in school. (Linda)*

This feedback aligns with observations from previous analyses of *Discovery* benefits: by grounding curricular theory to tangible project applications, the teachers felt that students better understood the relevance and utility of the concepts and theory introduced within the classroom [28]. Indeed, further validating the positive value provided by the *Discovery* model within the current secondary science education environment, several teachers indicated desire to more expressly integrate the *Discovery* project into their curriculum or apply the *Discovery* project model to their other courses:

> *I would want to integrate [the Discovery project] a lot more and almost treat it as like a case study that we return to throughout the entire semester. (Oliver)*

> *What I've started to look at is how can we leverage the Discovery model into other courses [...] I've been looking at a grade 10 course and I think, for me, Discovery has inspired me to look [at] "how can you bring these engineering design processes into other courses and how can you make that a culminating project?" [...] Looking at the idea of Discovery and maybe having [...] a lighter version of what happens in the grade 11/12 levels [...] into grade 9 and 10. (Jeff)*

3.3.2 Identification and bridging of gaps in STEM knowledge and skills

Further to linking course curricula to practical applications, teachers appreciated that *Discovery* offered detailed feedback highlighting discrepancies between students' current skill and knowledge levels and the competencies required for success in post-secondary STEM education or careers. Importantly, teachers noted that *Discovery* demonstrated the nature of realistic STEM work in contrast to the teacher-directed learning exercises common in secondary school curricula and provided an opportunity for the nascent development of iterative, scientific exploration:

> *We've realized that [students] need to leave high school knowing how – not facts and figures with science – but how to do science. And I think that's the power of what Discovery brings. (Jeff)*

> *I think it's important for them to see that [...] STEM [is] always about the process and finding new directions or persisting with the course that you are on, depending on the data you are gathering, and that not being seen as a failure [because] there is no right or wrong. It's very open ended. [...] There's a lot of development of skills that [...] we don't really have a lot of time to develop, day-to-day, but over a prolonged period of working through the [Discovery] program. You can see some of those skills being developed. (Linda)*

As expressed by teachers, the type of feedback that students receive within *Discovery* is distinct from the feedback that they receive within regular instruction. As students complete their projects, they are supported by graduate student mentors that help them bridge knowledge and skill gaps (e.g., laboratory equipment techniques, protocols, data interpretation). This implicitly provides students with the "where I am now" (i.e., understanding their own skills and limitations within the context of the project) and "where I need to go" (i.e., the skills of the graduate students) tenets of effective instructional feedback [29].

Perhaps most importantly for sustaining continued student growth, however, was the shift in some students' attitudes post-*Discovery* as described by Larry:

> *The Discovery project helped me understand that a lot of students are going through physics without ever really trying to understand what they're doing. And then when they went to Discovery, all those things that we had learned [in class], they were [trying to] apply them [in their project]. And if they didn't understand [the concepts], then they couldn't [apply them] because [they had] to communicate [their] understanding. [...] So, I think what ended up happening is they were realizing that they actually had to know what they were doing. So, I think I'll say that they all underperformed [based on my expectations]. But what surprised me was that they understood afterwards that they underperformed and acknowledged that they would have to approach things differently after [their Discovery experience]. So, the learning that they got that I thought was valuable was not necessarily about physics per se. But it was about how to go about learning something.*

Further to this observation, Oliver expressed that the project demonstrated the limitations of some of the habits and reliance developed by students around the use of generative AI:

> *And that's where I think Discovery is a great project, because it's not like they can just ask AI to develop a [physical prototype] for them, [...] and so getting that more hands-on practical experience where they can't just type [the problem] into a search bar and have the answer pop up has been really good.*

Again, these comments align with the known benefits of inquiry-based learning and reflect the power of the implicit feedback provided to students as they complete their projects. Particularly with the rise of generative AI, the project illustrates the limitations of relying solely on external tools without strong foundational skills. Students are required to take ownership because they cannot rely solely on apps or AI in this open-ended, hands-on learning scenario.

3.3.3 Nurtured STEM confidence and post-secondary aspirations

Further motivating these shifts in student attitude were increasing levels of self-confidence and aspirations around post-secondary STEM environments. Indeed, students' experiences on campus increased their familiarity with post-secondary environments. Moreover, conducting their experimental work alongside graduate students and presenting their work to members of the university community affirmed student belonging:

> *And they have said that they feel a lot more confident. You know like for a lot of them, university was this nebulous thing. [...] Now that they have had some time to go into university grounds and not just be on the outside of the building but be in the same learning space as people who have much more experience [...] than them and carrying out those same tasks. I feel like they're a lot more confident possibly going into university in the next year. (Greg)*
>
> *That confidence boost that the symposium gives them when they're able to speak in front of this whole group, in front of many students, in front of many professors [...] and to be approached, not as a [high school] student, but be approached almost in a collegial way. I think that they feel the respect that [mentors and symposium attendees] give them when [symposium attendees] approach them and ask them about their project as if they're [peers] who have just discovered something new. (Susan)*

The teachers even noted positive impacts among students whose post-secondary interests did not align with their *Discovery* projects:

> *The fact that they were [on campus] a few times, I think [it] became a habit for them. And they started to [think] "if I was going to the University of Toronto, this is how I would get here every day. [That perceived] barrier has been broken down and now it's not another foreign [location], it's a place that they know exists. Having conversations with students, they were like "yeah I think I could see myself there, maybe not with physics." So, just being [on campus] I think was valuable. (Larry)*

For the students with post-secondary STEM interests, their project work in the university teaching laboratories provided opportunities to further develop a better understanding of the disciplines that interest them and generate excitement for their future studies:

> *A lot of teens are really held back by the unknown and so by starting to eliminate some of that, I think it gives them a broader perspective [of whether] this could be a field for them. And then I think, when they actually start to see what somebody within the field may do [through the Discovery project], it helps them in a couple of ways. One, it may affirm for them that yes, this is an area where they want to focus, and they'll continue to pursue. Sometimes it's sort of an introduction like, oh, this looks really interesting. I might want to continue on with this, or it might be they kind of had an idea about a particular field, say, of engineering. But now they would consider another field of engineering instead. (Linda)*

> *I've had kids tell me [...] "I'm going to do biology in university now. And I was not, I was going to do chemistry or physics, but I want to do bio now because I understand what it is and I'm excited about it." I've had that multiple times. (Casey)*

Prior studies have similarly identified the exploration and confidence-building experience of on-university-campus activities can positively influence the career and post-secondary aspirations of secondary students [30], [31]. Based on this prior evidence and the attitudes expressed by the interviewed teachers, programs similar to *Discovery* may be increasingly relevant to combat the increasing student anxiety and career uncertainty observed since the pandemic [24], [32].

3.4 Connections between themes

Figure 2 presents a visual representation of the logical connections between the major themes identified within the teacher interviews. Our interviews revealed that teachers felt that relative to pre-pandemic levels, many more students are struggling to thrive within secondary STEM education. The themes expressed by these teachers (Theme 1: disengagement, reduced skills, lower perseverance, increased learning gaps and necessary curricular simplification; left side of Figure 2) are inter-related and reinforce each other, resulting in a self-sustaining negative learning environment for students. Specifically, knowledge and skill gaps increased the difficulty of learning exercises, which contributed to a reduction in student engagement and willingness to persevere through challenges. Consequently, teachers felt the need to adapt and lower the difficulty of learning materials and exercises. Some students became habituated to this simplification, which further hindered their skills and prompted further disengagement, perpetuating a negative feedback loop.

Nevertheless, teachers expressed that the *Discovery* Program provided an effective foil to the challenges currently identified within the classroom. *Discovery* provided a hands-on, open-ended, and multifaceted project within a novel setting (Theme 2; center arrow of Figure 2) that drove increased student enthusiasm and deeper engagement with course curricula. Critically, program participation provided a gateway for teachers and students to reach a more positive,

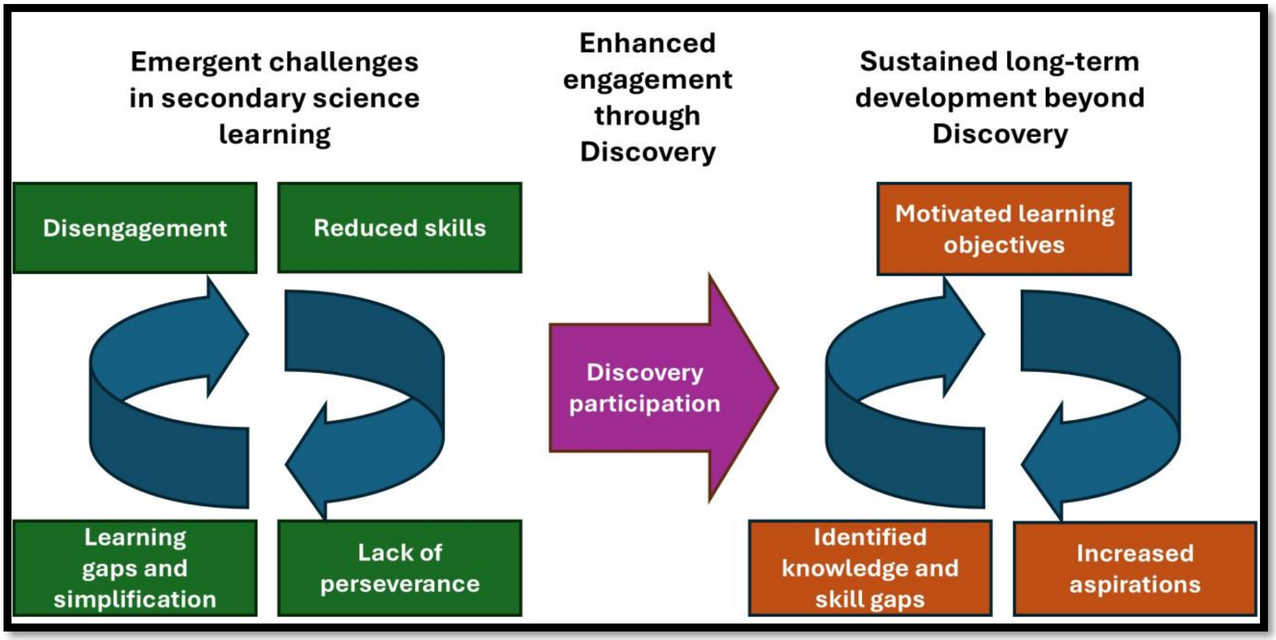

Figure 2. Visualization of inter-theme connections. The post-pandemic challenges expressed by teachers (green boxes on left) create a feedback loop thereby perpetuating negative learning environments and learning losses accrued throughout pandemic-induced virtual learning. Teachers expressed that participating in the *Discovery* Program (center arrow) provided a useful platform to break the self-sustaining cycle of challenges identified on the left and transition students to transition students to a cycle of positive learning attributes (orange boxes on right).

student-driven learning cycle (Theme 3: motivated learning objectives, increased aspirations, exemplified knowledge and skill gaps; right side of Figure 2). Similar to the loop shown on the left of the figure, these sub-themes are interconnected and represent a positive feedback loop. *Discovery* provided students with tangible contexts for the relevance and applications of curricular materials as well as an opportunity to experience the type of work that they could perform if they continued to pursue education within that field. Concurrently, the project experience demonstrated the skills and knowledge that students need to develop to be successful within these STEM fields. The increased interest and understanding of skill/knowledge gaps can motivate students to engage more deeply with course material and further their learning.

5. Conclusions and recommendations

Herein, we presented a thematic analysis of interviews from secondary school STEM teachers participating in the *Discovery* Program with the objective of evaluating how the role of the program has changed in the post-pandemic secondary science education environment. The analysis yielded three key themes: (i) teachers and students have been navigating a myriad of challenges centered around student disengagement, knowledge/skill loss, and student persistence; (ii) students were excited and more engaged when participating in *Discovery* educational programming compared to standard classroom curriculum; and (iii) the *Discovery* experience helped promote a more effective long-term student learning mindset.

The identified themes and connections between them suggest that *Discovery* has remained effective at fulfilling the original program objective of increasing student engagement in STEM learning. Indeed, at program conception, the primary challenge facing teachers was lack of student engagement within the classroom. However, based on the results presented from the current study, it is apparent that challenges within the secondary science classroom have grown and evolved, primarily due to pandemic-induced learning disruptions. Rather than diminishing the value of *Discovery*, however, the program benefits are enhanced within the post-pandemic landscape. The teachers interviewed in this analysis affirmed that the *Discovery* model was a useful tool in combating all emergent challenges. Furthermore, as teachers have gained experience with the program, they are learning how to better leverage the experience to improve the learning of students within the classroom.

Based on the analysis presented and our experience with the *Discovery* Program, we present the following recommendations for crafting effective inquiry-based STEM learning projects that can assist in combating post-pandemic learning challenges:

1. **Provide open-ended projects contextualized within real scientific or engineering challenges.** In this and prior work, we have repeatedly found that providing such projects provides motivation for course learning objectives and improves student understanding of realistic scientific inquiry.
2. **Give students freedom to develop solutions that align with, and allow students to explore, their own interests.** The flexibility of iterative and open-ended projects allows students to explore aspects of the projects that are of greatest interest to them and demonstrate their knowledge and learning in diverse ways.
3. **Immerse the project work within modern teaching laboratories and support students with both teachers and practicing scientists.** Executing the project within teaching facilities with modern equipment and tools drives student interest and engagement. Pairing students with experienced practitioners within these spaces provides important opportunities to learn and aggregate different perspectives and for students to understand the knowledge and skills that they will need to develop into competent practitioners.
4. **Promote collaboration between classroom teachers and project designers to ensure accessibility of learning materials to target students.** The pandemic has broadened the diversity and depth of learning gaps and student needs. Teachers have intimate knowledge of their students, their abilities, and the support that they may need to successfully complete such projects. By working closely with teachers, project designers can adapt experiences to ensure sufficient scaffolding exists to allow meaningful engagement of all students in the project.

Author contributions

NI and NTN contributed equally and share first authorship of this work. FA, RC, DL, FHM, and KMS all contributed equally, and these authors are listed alphabetically. Correspondence can be directed to DMK.

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