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Engineering Students' Perceptions of Learning Effectiveness: Implications from the Lived Experiences Amidst a Mixture of In-Person and Online Instruction

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Abstract

Grounded in the existing literature on learning effectiveness in postsecondary education, this study aimed to develop better understandings of learning effectiveness in the context of increased digital teaching and learning in the post-pandemic era. We applied interpretative phenomenological analysis to focus group data collected from undergraduate engineering students at a comprehensive Canadian university during summer 2022. The findings of this study confirm students' interpretation of learning effectiveness in terms of both learning outcomes and processes. The learning process perspective was related to the affective, cognitive, and behavioural domains of student engagement. Efficiency in learning and ease of access to learning resources were also identified as indicators of learning effectiveness. In particular, under the mixed in-person and online instruction modes, engineering students interpreted their learning effectiveness as a result of individual-contextual interactions. Students developed their own perspectives on the advantages and disadvantages of in-person and online instruction based on their experiences during the pandemic. For some engineering students, their discipline-based understandings of learning contexts in various courses shaped their perceptions of learning effectiveness, which suggests the role of engineering and personal epistemologies in perceived learning effectiveness. This can be an area of future research on learning effectiveness. Scholarly and practical implications from these findings are discussed.

Keywords: perceptions of learning effectiveness, online instruction, individual factors, contextual factors, personal epistemologies

Introduction

The context for this research paper was the changes in course delivery modes that arose from the academic disruptions of the COVID-19 pandemic. From spring 2020 to spring 2022, teaching and learning at most Canadian engineering schools experienced a shift due to the pandemic, from predominantly in-person course delivery to a mixture of in-person and online instruction, albeit with institutional variations. In the face of these changes, engineering students had to learn effectively in an educational environment that mixed in-person and online instruction in different ways. The resulting increasingly digital educational environment may turn out to be a lasting legacy of the pandemic. Therefore, it is important to study learning effectiveness in the evolving context of in-person and online learning in engineering education.

Research on learning effectiveness is not only critical to student learning but also significant to overall educational quality. Learning effectiveness is recognized as being indicative of the quality of instruction provided. For example, learning effectiveness constitutes one of the five pillars of a quality framework [1], along with cost effectiveness and institutional commitment, student satisfaction, faculty satisfaction, and access.

This paper was grounded in the existing literature on learning effectiveness in postsecondary education. We drew upon five student focus groups and some of the qualitative survey data about learning experiences that we collected from undergraduate engineering students at a comprehensive Canadian university during the Winter Term of 2022 (i.e., January to April). Our analysis aimed to address the following research questions:

- How did engineering students interpret learning effectiveness?
- What factors influenced engineering students' perceptions of learning effectiveness?
- How did in-person versus online course delivery modes affect engineering students' perceptions of learning effectiveness?

By addressing these questions, we sought to expand the existing understandings of what accounts for learning effectiveness, particularly for engineering students in a post-pandemic educational environment that characterizes more digital and flexible learning. This information will offer insights to help both engineering students and educators design their learning and teaching plans.

Literature Review

Definitions and Measures of Learning Effectiveness

The notion of learning effectiveness appears to have been often used but rarely defined. One definition goes as: "Learning Effectiveness refers to the learner's learning results in formative and summative evaluations" (p. 577) [2]. This definition places emphasis on the outcomes of student learning. Learning outcomes are found to be the most widely used measure of learning effectiveness [3], and can be represented by students' level of academic achievement (measured by test scores, e.g., [4, 5]) and skill development [6]. These measures can be actual or perceived learning outcomes (e.g., [7]). The outcomes-based interpretation of effectiveness can also be seen in the definition of "effective learning experiences" in the context of engineering education—"those that support the development of deep understanding organized around key concepts and general principles, the development of skills, both technical and professional, and the application of knowledge and skills to problems that are representative of those faced by practicing engineers" (p. 124) [8]. As such, learning effectiveness is first and foremost understood as relating to certain outcomes.

However, measures of learning effectiveness go well beyond learning outcomes. Other measures can be attitudes such as motivation [9, 10], satisfaction [9, 11], and initiative [7]. Some studies measured learning effectiveness based on resources, teaching activities, and services provided [12], or instruction, curriculum management, and technological media [2]. As these measures better reflect aspects of teaching practices, they may better represent teaching effectiveness than learning effectiveness. Notably, learning effectiveness is used as one of the measures to evaluate instruction quality [2]. In addition, learning effectiveness measures can also include an efficiency

measure (i.e., time on task) [4, 10], which became an additional concept we explored in our study.

Influencing Factors of Learning Effectiveness in Online Settings

Literature shows that learning effectiveness has been studied in three contexts: (a) when new teaching methods were introduced [6]; (b) when online or blended teaching was employed [7]; and (c) when comparing different learning modes [4, 5]. The first two contexts suggest that using alternative course delivery modes can provoke thinking and prompt studies on learning effectiveness in different instructional settings. The instructional changes during the COVID-19 pandemic, which this paper focuses on, is one of these circumstances.

A literature review paper [3] identifies three major factors that influence students' perceptions of learning effectiveness in e-learning: (a) the context for the e-learning solution (including support and resources); (b) the e-learning approach itself (including learning activities, cognitive load, communication, and technological constraints); and (c) the characteristics of the learners (including motivation, and prior experience and interaction with the e-learning settings). Similarly, a study on blended learning effectiveness found that some of student characteristics/backgrounds and design features were significant predictors for student learning outcomes [9]. Along the same line, the literature review in another study [2] reports that the contextual factors can include physical and social environment, and interpersonal supports, in addition to curriculum design and instruction; and individual factors can include demographics such as gender, age, education background and seniority, as well as attitudes such as motivation, expectations, and views on learning subjects and materials. These papers have informed us of using individual and contextual factors as two broad categories to understand various influences on learning effectiveness.

Learning Effectiveness during the COVID-19 Pandemic

Online teaching during the COVID-19 pandemic was considered as emergency remote education [13, 14]. Initially, instructors and students were forced to try online delivery with little preparation; this disruption made teaching and learning practices during that time the least effective. A global report that drew upon experiences in some countries across the world [14] shows that for students, setting up routines and seeking help became more important than usual to learning effectiveness; and digital literacies and self-directed learning abilities became essential to student success at the time of crisis. Digital divide due to unequal access to internet connections was another prominent factor that affected learning effectiveness [14]. However, studies that focused on experiences in a later stage reported mixed results, with variations by country and disciplinary contexts. For example, a study that was conducted in a Hong Kong university on the learning experiences of dental students in 2021 found that most students indicated better effectiveness of online than in-person learning [15]. Another study that focused on students pursuing different degrees of Islamic Religious Education reported that online learning during the pandemic, perhaps in 2021, was effective, with the highest effectiveness perceived by doctoral students [16].

Engineering education literature also reports mixed results on learning effectiveness during the pandemic. A study conducted in Taiwan showed that use of the flipped classroom approach remained effective for electrical engineering students' learning fully online during the pandemic [17]. Another study situated in a dynamics course reported that most students found online learning comparable to in-person learning for a course in spring 2020, notably taught by an instructor who had prior experience in online teaching [18]. However, another study conducted in a project-based learning setting found that Grade 12 students' performance while studying electronics deteriorated as instruction shifted from in-person to online during the pandemic [19].

Individual factors that influenced students' learning effectiveness during the pandemic included their digital literacies, learning habits and behaviours, including self-directed learning capabilities [14, 20]. Contextual influencing factors comprised teaching methods [17], student–student and instructor-student interactions, course design [7, 21], and unequal online access in less well-off regions [14]. These factors could also have affected the perceptions of learning effectiveness of engineering students in the context of our study.

Data Sources and Methodology

Our study was conducted during summer 2022 at a comprehensive Canadian university. A notable local context was that all courses in the engineering school were offered online from January to mid-February 2022 and then switched to in-person instruction for the rest of the academic term (i.e., from mid-February to April). As a result of this unusual arrangement, students were exposed to both online and in-person instruction during the same academic term. Prior to this academic term, all courses had returned to in-person instruction during the Fall Term of 2021 (i.e., September to December 2022), after over a year of exclusively online instruction that began in spring 2020; however, the Winter Term had to end online due to the worsening pandemic situation. As such, by summer 2022, all students had experienced both in-person and online instruction, with various mixes in numerous courses, and presumably had developed personal views and observations about both instructional modes.

The primary data source for this paper was five 1.5-hour-long focus groups with a total of 15 undergraduate engineering students. These participants were from seven distinct engineering programs and years of study. This data collection was part of a larger research project that had obtained ethics clearance from the Canadian university, the site of the study. We began these focus group sessions by asking students to describe a course experience where they felt they learned effectively and explain how they knew they were learning effectively. When we completed the fifth focus group, we found that there was much repetition from the first four interviews, which suggested a point of data saturation. During the interview, the researchers intentionally recapped some of what they had heard in their own words and checked with the participants about these interpretations. A major limitation in our data collection process was that we did not explicitly ask if the focus group participants felt that any of their experiences might be specific to any gender or racialized group; therefore, our findings will not reveal whether or how engineering students' perceptions of learning effectiveness may have been influenced by their socio-demographic background.

We applied interpretative phenomenological analysis (IPA) to the focus group data. IPA emerged as a qualitative research methodology in health psychology in the 1990s [22] and has been used in engineering education research (e.g., [23, 24]). IPA investigates individuals' lived experiences and involves an interpretative endeavour [22]. This endeavour can be on two levels—the researcher's level and the research participants' level; that is, the researcher makes sense of how the research participants made sense of their lived experience [25]. Our study focused on engineering students' lived experience during the latter stage of the pandemic when they were exposed to a mixture of in-person and online modes. We aimed to better understand how these students made sense of effectiveness of their learning after being exposed to different instruction modes.

We adopted the IPA procedures outlined by Spiers and Smith [22] and performed the following steps:

1. We took descriptive and linguistic notes (particularly the wording indicating how students perceived learning effectiveness and the causality of their accounts of individual experiences) and made a conceptual level of interpretation in terms of individual and contextual factors.
2. We constructed a table of these descriptive, linguistic, and conceptual notes for all five focus groups, and identified commonalities or divergences across individual participants and the five focus groups.
3. We turned the descriptive, linguistic, and conceptual notes into emergent themes.

When we completed the analysis of the focus group data, we applied the generated themes to the qualitative survey data collected from an open-ended question in a questionnaire administered in May to June 2022: "What online or in-person teaching practices over the last two years most helped you learn effectively? Explain why these practices helped." This data source contained a total of 113 comments entered by individual engineering undergraduate students. The purpose of our analysis of these data was two-fold: (a) to validate the themes and sub-themes that had been generated from the focus group data; and (b) to identify more teaching practice that facilitated students' effectiveness in learning. We have included illustrating quotes from these survey data to complement the findings from the focus group data in the Findings section.

Findings

We have synthesized the subthemes from our analysis into three emergent themes to address each of our three research questions. In the following section, we have provided examples that speak to each question. Student names have been replaced with a numbering system (e.g., ST1) for ethical/privacy reasons. Please note that while participants mostly shared their experiences with engineering-related courses, some of them alluded to their learning in elective courses outside the engineering discipline.

Theme 1 – addressing Research Question 1 (How did engineering students interpret learning effectiveness?):
Engineering students interpreted learning effectiveness in terms of both learning processes and outcomes.

Sub-theme 1.1. Students used emotional, cognitive, and behavioural engagement to interpret their understandings of learning effectiveness.

Six participants in different focus groups shared that their experience of learning effectively involved feeling engaged; this engagement was emotional, cognitive, and behavioural. As illustrated in the quotes below, emotional engagement was reflected in students' level of interest in a course (ST3); cognitive engagement was reflected in mental efforts exerted for problem sets (ST6); and behavioural engagement was manifested in active class participation (ST4) and interpersonal interactions (ST1).

> *So in terms of effectiveness, I think it was just my level of interest that I'm measuring. To be honest, I've been successful in the larger lecture style courses, I think those fit my learning style well. But in terms of being effective, like learning effective, I think just being engaged through the entire semester, not getting tired of the course after a month and really just kind of directing my own learning, I guess I would say, it was a course that I was actively waiting for to come around each week. It wasn't something that I fell behind two weeks and I had to catch up the end of the semester trying to scramble up to catch up with all the content. I think it was something that was effective in motivating me to learn about the content of the course*. (ST3: using levels of interest to gauge learning effectiveness)

> *I know the course that he's talking about. There's also another thing I want to add is that you learn really effective when you practice the content, so since the support structure is very rigid, it forces you to attend the tutorials and practice sessions, but every week you're not only engaged in the lecture material, but also in the actual problems that would prepare you for the final exam, so that was very helpful as well.* (ST6: using mental efforts for problem sets to gauge learning effectiveness)

> *personally for me, that was kind of my measure of effectiveness, my willingness to engage in the course. And even throughout the course experience for me, for that specific course, I felt myself a little different from other courses. I would find myself engaging with discussions, engaging with questions that I normally wouldn't be participating in.* (ST4: using active participation in class discussion to gauge learning effectiveness)

> *I feel like the interactions between students is really ... at least for me, has always been really critical for me to learn effectively and efficiently, because I've always been a very collaborative person working off of other people. And then online doesn't really offer that.* (ST1: using interpersonal interactions to gauge learning effectiveness)

Sub-theme 1.2. Some engineering students associated efficiency and easier access to course materials and instructors with their learning effectiveness.

Another aspect of the learning process is efficiency, which students understood as spending less time than usual learning something in the course materials. Three students interpreted learning effectiveness in terms of efficiency, as illustrated below. While ST1 and ST5 found that efficiency and effectiveness are related, ST2 differentiated between the two by pointing out that efficient learning may take less time, but not be as effective. A survey respondent (#2) identified Piazza, an online discussion forum too, as being effective in the sense that their questions could be answered more efficiently.

> [Question: How did you know that you learned effectively?] *Mainly because I knew it took me significantly less time to ... or I perceived that it took less time for me to understand concepts in that course or those courses when they employed these methods, as opposed to, if it was the cut and dry, "here's all the lecture slides."* (ST1)
>
> *So I thought that kept me really engaged in the class, I never fell asleep in that class. And then I realized that when I came to talk about efficiency in that particular class, because of how engaged I was during the lecture time, I did very little homework, but then I still did really well in the class when I came to final examinations.* (ST5)
>
> *I think of effectiveness as how much knowledge I can retain and apply after the course is done. Whereas, efficiency would be how much time I put into gaining that knowledge. And so I would think of effectiveness as a baseline and efficiency would be the time it takes to achieve that effectiveness.* [ST1 nodding] *... For me, I think some online experiences were more efficient, but they were not more effective than in person.* (ST2)
>
> *Professors or TAs being easily reachable via Piazza helped me learn effectively because I could get my questions answered within a few hours, rather than needing to wait for weekly office hours*. (Survey respondent #2)

Some students, particularly those in vulnerable situations such as having health concerns, also explained how easier access to online resources and activities allowed them to learn effectively. These resources included online discussion forums (Survey respondent #2), recorded lectures that were made available to student use (#123), and online office hours (#19).

> *Professors who made an effort to do a great job of fully recording their lectures (including the boards), and taking care to ensure the quality of the videos were actually good were invaluable. I struggle from health problems that were further exasperated by the pandemic, and it meant I was too sick or vulnerable to come to class sometimes, and certainly more often than many of my peers. Professors committed to making learning accessible allowed me to flourish, and it showed in the best marks I got this year. Conversely, courses I did worse in showed marginal or no care for accessibility in the time of a pandemic, so I had to try to fill in gaps on my own.* (Survey respondent #123)
>
> *Online office hours: much more accessible for commuter students like me than office hours late in the evening because otherwise I'd get home at 11pm at night.* (Survey respondent #19)

Sub-theme 1.3. Students perceived learning outcomes of conceptual understandings, self-efficacy in problem solving, academic performance, and knowledge retention as indicators of learning effectiveness.

Some students also used achieved outcomes to gauge their learning effectiveness. The outcomes identified by focus group participants included enhanced conceptual understanding (ST11), increased confidence in problem solving (ST9), better grades (ST11, ST12) and better knowledge retention (ST10), particularly after some time (ST12). The three student responses also illustrated the importance they placed on understanding the course structure (ST9) and the connections among topics (ST9, ST10).

> *It was also a math-based course, but the whole course was structured around problems. We started the class every day with a problem. We worked on it individually and then took it up as a class, and we did it all as a class. There was always a time to attempt it alone, but it was always brought up and finished as a class. Then theory and how those problems were advancing was talked about as well, but it was kind of mixed into a whole bunch of problems. After every concept we learned, we would do a problem to apply it. I think that really helped my understanding of the concepts. I definitely did better in that class, overall, than most of my other classes that are just lecture based.* (ST11: using enhanced conceptual understandings and better grades to gauge learning effectiveness)

> … *as the semester kind of progressed and the project kind of progressed, I found myself wanting to go to the tutorial or the lecture more so even though none of those were mandatory, right? And when I went there, I came out with information that was relevant to my project that I was working on and I would come out of the lecture hall or the tutorial hall knowing that, "Okay. Now I know how to solve this problem. Now I know what to work on next."* (ST9: using interest in the course and increased confidence in problem solving to gauge learning effectiveness)

> *University's more like it just continuously builds on top of each other and how I found I was learning effectively, in this class, was I would always remember what the professor had taught in their previous lecture when we were going to the next one, because of the structure that he had. Whereas I would find that some professors don't clearly state the topic that we're doing right away, or they talk about it after, and that sometimes makes me a bit confused or I can't remember fully what we learned.* (ST10: using knowledge retention to gauge learning effectiveness)

> *this professor used to put those kinds of very difficult problems in our weekly problem sets, and that was useful because when the exam came, no surprises. … because it took so much time for so little reward for the problem sets. I learned a lot from it. I still remember what I learned from that course today. I don't always remember what I learned from courses. Sometimes if the course just goes by, I forget what I learned from it. This course has stuck with me. It was one of my highest marks.* (ST12: using knowledge retention after some time, and better grades to gauge learning effectiveness)

Theme 2 – addressing Research Question 2 (What factors influenced engineering students' perceptions of learning effectiveness?):
Individual and contextual factors influenced students' perceived learning effectiveness.

Sub-theme 2.1: Individual factors included students' interest, motivation and learning strategies.

While our focus group data did not capture any association between students' demographic background and their perceptions of learning effectiveness, our data demonstrated other individual factors (e.g., interest and motivation) which helped enhance their perceived learning effectiveness.

> [Question: What made your learning effective?] *… I would say the thing that helped me learn was just sheer interest. A lot of the things were just things that I was always interested in, that I was curious about, and it didn't really take me much to motivate me to go and seek out that extra knowledge, whether it be online or through industry resources that we had. And that's it.* (ST7: interest as an influencing factor for learning effectiveness)

> *Being able to go to class and see people that I know is nice. It makes me want to attend class more. Then, also, working together, studying together, it's all much more motivating and I think that I learn much better this way. Whether it's motivation or whether it's my understanding, I'm not sure, but I think my motivation is helping my understanding of concepts.* (ST11: motivation as an influencing factor for learning effectiveness)

In addition, our data also suggested that individual students developed distinct learning strategies when learning in different courses, thus requiring different forms of instructor support. For example, the following quotes of two students' comments illustrated that they took very different approaches to learning in math- and design-based courses. While ST12 was an independent learner in a math course but required interpersonal interactions in a design course, ST11 used quite different learning strategies; as a result, tutorials of a design course were more important to ST12 than tutorials of a math course whereas ST11 found tutorials of a math course to be more effective to learning. Presumably, these personalized learning strategies can affect their perceptions of learning effectiveness when certain resources they would need for implementing a certain learning strategy were available or absent.

> *for a math course, I'd welcome the two or three hours of lectures, but then I don't need another three hours of tutorials and practicals. I'm just going to be home working it out. For me, that's how I work it out. I don't need someone else there to teach me what I just learned in the lecture again. So I'll work it out and then submit my work and see what I did wrong and fix it. So that's how I do math, but for, say, a design course, I would love the three hours of practicals if I got to do that. Got to spend time with a professor because the way I learn design is different. I need to talk to someone continuously for design, check if I'm on the right path, if I'm thinking the right way for this problem.* (ST12)

> [In response to ST12] *I would say I'm actually the opposite for that. For me, I definitely struggle more with those math and physics courses. I'm also a very visual learner, so I like going to the tutorials because I feel like that's often the main times that I get to see problems being done by someone else and kind of how to set it up and what kind of structure to follow and kind of the steps of how to do it and that normally helps me figure out how I can do it as well and how I can recognize the problem and lay out the structure. So I find that those ones are often very helpful for me, whereas in a design course, I'm definitely more independent. I like to kind of go off on my own and think about it. I would normally still go to the tutorials and stuff, but I definitely would say that in a course that's more math or physics based, the tutorials are often more useful than in a course that's more design based. But, again, that's my experience*. (ST11)

Sub-theme 2.2: Contextual factors were exhibited through various teaching practices, including good theory/practice balance, cohesive course structure, and pedagogical methods.

The data revealed teaching practices that students found effective for their learning. These practices were independent of learners' preference and out of their control, thus constituting the contextual factors that influenced students' perceived learning effectiveness. Several students expressed their appreciation of teaching practice that facilitated a good balance of theory and practice. For example, one student shared their experience in a math course offered online as follows.

> *So this was a math course that I took online during the pandemic, and I think what made this course effective was this instructor had a way of teaching that I had never seen before. They used*

> *worksheets. Basically they would give us a worksheet every lecture, and on the worksheet, there would be like a set of learning outcomes at the top of the worksheet or what to learn in that, what was going to be taught in that lecture that day. Then they would go through the concept at hand, more like the theory behind it and then they would show example problems after that. … I prefer to see like the structure of "This is what we're learning today. Here's the theory behind it.", and then "Here's an example right away.", because then I'm able to more solidify what the professor has been teaching.* (ST10)

Other effective practices that students shared included cohesive course materials and course structure (ST7) and alternation between lecture and active learning activities (ST5).

> *There was a civil engineering structures course that I had to take in my first year. And I felt like the course was particularly effective, especially when you consider the difficulty of the material relative to some of the other courses,… And what I found the instructors did really well was that, and this was all in-person by the way, just normal lecture, they had content that was really engaging and they found a really good mix between providing lecture-based learning materials, as well as textbook use and quizzes, problem sets, that kind of stuff. … Whereas in this course, a lot of the information that was provided was already condensed in that relevant, small packet of information. … I feel like they did a good job of integrating all those ways of learning into a cohesive unit.* (ST7)

> *I had this one course in my winter semester where I felt the lecture style was very unique, but also effective. So instead of it being kind of like a blackboard and chalk, the professor talks at you for an hour. It was more like we had five minutes of lecture time where the professor would talk about new content. And then he'd give us like five minutes of group work where we would sit in a table of like four or five and work on a problem. And then we'd have five minutes of takeoff and review, and just like have the professor solve the problem for us. So I thought that kept me really engaged in the class, I never fell asleep in that class.* (ST5)

Qualitative student survey data also reported a number of aspects of teaching practices that engineering students found effective. For example, instructor availability, easy access to course materials, well-presented lectures, and take-home assessments were mentioned in the following comments in the student survey.

> [In response to the question on teaching practices that helped them learn effectively.] *Instructor making themselves available after lecture for Q&A: served similar function to office hours, but easier to access and accessible right after covering material so material was still fresh when discussed. Lectures providing clear, complete explanations of course content, including background theory, application, real-life uses, and ties to other subjects. Take-home assessments that challenged us to use technical course concepts in creative ways, rather than regurgitating information/processes*. (Survey respondent #26)

Sub-theme 2.3. Engineering students' discipline-based understandings of the learning context affected their perceptions of learning effectiveness.

Another contextual factor that affected students' ways of gauging learning effectiveness was the discipline-based learning context. As shown in the following quote, a senior student who started with a broad science curriculum in the first two years and then pursued biomedical engineering

in the upper years explained how their interpretation of learning effectiveness shifted across courses in different disciplines—from better conceptual understandings in math-heavy courses to memory facilitation in biology-focused courses, and to enriching class discussions in humanities courses. As the student was exposed to courses in different disciplines and appreciated the different foci of expected learning in these courses, they seem to have developed different criteria for evaluating effectiveness in learning: conceptual understandings (alearning outcome indicator (sub-theme 1.3) for math-based courses, being interesting (an emotional engagement indicator, sub-theme 1.1) for biology-focused courses, and interpersonal interactions (a behavioural engagement indicator, sub-theme 1.1) for humanities courses. .

> *I think there's kind of like a split in my university experience one from very ... so the first two years of engineering science are very, I think, math based. And then I kind of feel like I restarted everything in third year when I went into biomed because there's a lot of different ... like everything is different. It's very, I guess, memory focused, biology focused. … I think my idea of learning effectiveness was probably changed as well. I think one went from how effective professors were able to explain concepts, a lot of like difficult concepts, making them straightforward and easy to learn. So whether that was in linear algebra or calculus or physics, I think it was how effectively I was able to understand the concepts in a quick manner. And I think in biology, it was more making the courses engaging and I guess not boring because it can get pretty monotonous if you're just trying to learn and memorize things for an entire semester. … I did take humanities courses as part of the electives you're afforded. And I enjoyed those courses quite a bit. One, I kind of think it was just like a change of scenery and change of style. Two, I think there was a lot more discussion between classmates, which was great. I think having interactions with classmates is something that can really help people's learning if that's something they like to do. I know people have different preferences.* (ST3)

Theme 3 – addressing Research Question 3 (How did in-person versus online course delivery modes affect engineering students' perceptions of learning effectiveness?):
Individual and contextual factors interacted to shape engineering students' perceptions of learning effectiveness under in-person versus online instruction modes.

These individual-contextual interactions were exhibited in two sub-themes.

Sub-theme 3.1. Engineering students developed their own perspectives on in-person versus online instruction modes based on their experiences during the pandemic.

Students observed different aspects of in-person and online course delivery that facilitated their learning effectiveness. During the pandemic, online course delivery was disadvantaged in fostering social learning in comparison to in-person course delivery (Sweeney et al., 2021) but allowed easier access to course materials (Liu & Evans, 2021). It appeared that after two years of remote learning, many students developed their views on the pros and cons of different delivery modes. As two students (ST8 and ST9) observed, students associated the in-person instruction environment with a higher motivation for learning and better interpersonal interactions, and the online teaching with easier access to course materials.

> *I've heard different things among my peers. Some people would prefer online, some people would prefer in-person. I think most common argument I've heard for in-person learning is that they feel more motivated, for sure, to go to in-person classes, and that helps them learn more effectively, I*

guess. And again, most people, who enjoy the online classes, would say that because material is more accessible, they can go back to it more easily, and that way it's easier to review and to really make your learning more effective if that makes sense. Whereas in-person, professors get a little stingy with recording sometimes and maybe the content isn't as accessible sometimes. So I mean, there are arguments for both sides, but I think it really depends on person. (ST8)

Personally, if I'm comparing, going back to the design courses, I found it more effective to kind of work in a team in-person rather than working online because working in-person allowed us to kind of learn from each other and also answer each other's questions as we kind of went through the design process. While doing it online, we were more so on our own rather than... And we would only meet when we're doing a team update or something like that. So in terms of that, I definitely preferred in-person. And then I think there was a question about office hours and accessibility for professors. Personally, I found it less intimidating to go to a Zoom office hour or an online office hour compared to an in-person one, especially if it was something that was a smaller class. … Sometimes office hours may not be close enough to your next lecture, so you might be a little bit short on time, whereas with Zoom, you can join from anywhere. (ST9)

Further, students developed their learning strategies to cope with what in-person and online instructions afforded them. Students like ST2 took advantage of the benefits of in-person and online components of courses using the flipped classroom approach to learn effectively. Notably, students like ST4 considered online learning to be more suitable for a one-way knowledge transfer in lectures. However, students like ST5 still preferred to attend in-person lectures while agreeing with the knowledge transfer pattern.

for me personally, I felt that it was most efficient and effective to learn basically doing flipped classroom. So the bulk of the contents could be delivered online so you can go at your own pace as long as the application section of the course, such as tutorials or practicals are done in person. So practicals and tutorials that were online, I felt like were not engaging and often not a great use of time. So yeah. I like content to be delivered online, but practical stuff in person. (ST2)

If your activity really doesn't involve anything other than knowledge transfer, "This is A, B, C content, I just want you to know what these are. Just absorb it as a sponge." If that's the primary goal, I think online is completely fine just doing it on your own kind of synchronously. For stuff that requires some amount of back and forth, I think in-person is definitely much stronger at that than online is. … (ST4)

I like what ST4 said when he said, when you record the lectures, you can have something back to refer back to, or especially just the knowledge transfer, then you don't need to go to a classroom where you're sitting with peers and professors, where you can just do that by yourself. But I think I want to offer a little bit of a different perspective. Even if I had the choice between watching an online video or going to the lecture in-person, I would still pick the in-person lecture just because when I'm surrounded by peers who are also watching the professor, I'm less tempted to turn off the video and go play on my phone or something. So even though it could be about knowledge transfer, I think just being in that in-person room helps you to stay focused. (ST5)

Sub-theme 3.2. Engineering students' perceptions of learning effectiveness under in-person versus online instruction modes interacted with their discipline-based understandings of the learning context.

Students in three out of the five focus groups shared their experiences in elective courses in humanities and social sciences. Engineering students observed different teaching strategies in these courses, as shared by ST1. Some students shared how their perceptions of learning effectiveness differed when taking courses in different disciplines. One student (ST12) found that engineering courses were taught in different ways than philosophy and leadership electives in terms of the nature of the knowledge (practical versus theoretical) and how the knowledge was conveyed to students (through demonstrations versus case studies and discussions); and these understandings affected their preference for in-person versus online instruction in these courses. Students believe that in-person instruction mode benefits learning effectiveness when they feel they need instructor guidance (ST12) and hands-on activities (ST13). It should be noted that students' understandings of the focus of expected learning can be biased and may not align with the instructors' perspectives. Similarly, within engineering courses, students' perceptions on different course delivery modes also appeared to interact with their understandings about the, often, discipline-based focus of expected learning (learning from content-heavy lectures versus from interpersonal interactions), as shown in the quote from ST13.

> *I only realized how different learning styles can be when I started taking classes outside of engineering and in humanities where the teaching style is just very different because it's a lot more discussion based because you can't really discuss how right or wrong the slope of a line is, or the equation for the slope of the line is, it just is. So you can't really get that in engineering. You can in some courses, but not all of them versus humanities like that's the thing.* (ST1)

> *In my experience* [in humanities courses], *we had discussions, over Zoom, but they're mostly verbal. I didn't have to explain an idea through the discussion. It was more like this, like how we're doing right now* [in this interview]. *We're answering questions, answering prompts. We're not explaining concepts to each other. We're not trying to teach each other. Like in engineering, you do a lot of teaching to each other. One person understands the concept better than you, you want them to teach that to you. I feel that the teaching aspect is a lot better in person. In those courses, no one really taught me stuff when we had discussions, it was just us answering questions and tackling questions so that worked out for me. I know not all humanities courses are like that so it has to go by the content, I guess. … For engineering lectures, it's nice to be in person because just the demonstrations the prof can do, and you can ask the prof on the thing. While he's doing it or she's doing it, you can ask some questions. For my electives, I liked them online because they didn't need to convey the ideas the same way that they did. A lot of it was just theoretical. My electives were mostly based around philosophy or leadership. Leadership usually is around events or situations and you can't demonstrate that, live anyway. They give you a case study and for philosophy, again, it's like ideas in the mind. It doesn't really matter whether it's in person or online, and those ones I preferred online because the quality was the same as I would expect in person*. (ST12)

> *If it's just a course where you sit down and take notes on probably some math heavy subject or something like ECE* [Electrical and Computer Engineering] *or physics related, it's probably okay because you're pretty much just translating the lecture into just video format. But if it's a course like Praxis* [a design course] *that we took in EngSci* [Engineering Science] *that has a lot more student engagement, it's going to be very difficult to substitute that student engagement or the hands-on activities that you do into online form.* (ST13)

Scholarly and Practical Implications

A Framework on Perceptions of Learning Effectiveness

The themes and sub-themes that emerged from our analysis can inform a framework on perceptions of learning effectiveness, which is represented in Figure 1. Engineering students interpreted their learning effectiveness in terms of process and outcomes. The process indicators include cognitive, affective, and behavioural engagement, and the efficiency and accessibility in the learning process; the outcome indicators are represented by better grades, and higher levels of conceptual understandings and knowledge retention, and stronger self-efficacy in problem solving. Both individual and contextual factors influence student perceptions of learning effectiveness. The individual factors include interest, motivation, and personalized learning strategies. The contextual factors comprise of students' perceptions of teaching practice and their discipline-based understandings of the expected learning in specific courses. As part of the teaching practice, in-person / online course delivery modes make a difference to students' perceptions of learning effectiveness through the interactions between individual perspective and contextual settings in play as a result of the learning experiences during the COVID-19 pandemic.

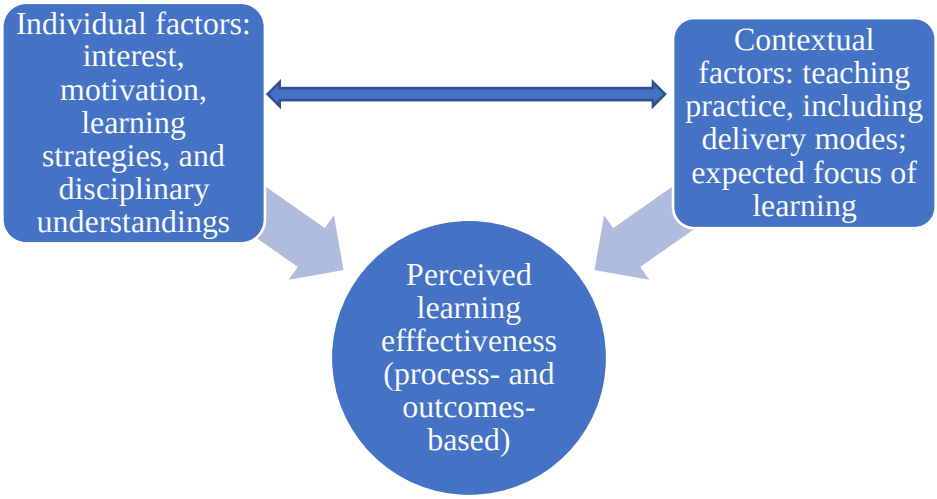

Figure 1. A framework on perceptions of learning effectiveness

Multiple Dimensions of Perceived Learning Effectiveness

This evidence-based framework corroborates the existing literature that perceptions of learning effectiveness are based on learning outcomes [4-7]) The relationship between learning outcomes and learning effectiveness has offered another application of learning outcomes in postsecondary education, in addition to instructional design [26, 27] and learning assessment [28, 29]. On the other hand, our findings also reveal various aspects of a learning process that engineering students use to interpret their learning effectiveness. In particular, these aspects of a learning process can be represented in terms of student engagement. In student development literature, student engagement means the time and energy students devote to educationally purposeful activities, and it is a key indicator of student success [30, 31]. Students' learning engagement involves multiple dimensions, including behavioural, emotional, and cognitive [32]. Our analysis

demonstrates that engineering students used their interest in courses, mental efforts for problem solving, and class participation and interpersonal interactions, which are indicators of learning engagement, to explain their learning effectiveness. This connectivity with student engagement adds another dimension to the existing understandings of learning effectiveness.

In addition, engineering students also illuminate that while learning effectiveness can mean taking less time to learn, that is, efficiency, which aligns with other studies [4, 10], it does not have the same connotations as learning efficiency; actually, students can sacrifice one for the other in certain situations. Furthermore, after an extensive exposure to remote and online learning during the pandemic, engineering students relate learning effectiveness to easier access to learning resources and opportunities, such as availability of lecture recordings, active online discussion forums, and online office hours. Easier access allows students to alleviate the stress of vulnerable situations such as health concerns and get questions answered in a timely manner, thus contributing to their perceptions of learning effectiveness. Adding ease of access as an indicator of learning effectiveness will create another condition for making the education environment more equitable than before. Instructors play a significant role in providing the ease of access to learning resources and opportunities.

Influencing Factors and Epistemologies

Our study revealed both individual and contextual factors that affect engineering students' perceptions of learning effectiveness in the educational environment in the post-pandemic era. In addition to affective elements such as interest and motivation in the existing literature [2, 3, 9], the individual influencing factors also include use of learning strategies—a behavioral element, and perspectives about pros and cons of in-person versus online instruction—a cognitive element.

On the other hand, learning effectiveness, a student-centered concept, closely relates to the contexts that facilitate the learning. These contextual factors include particular pedagogical approaches, such as the inverted classroom and problem-based methods, and general effective teaching practices, as exhibited in the widely used Seven Principles for Good Practice in Undergraduate Education [33]. For example, engineering students in our study described peer interactions, active learning, and receiving prompt feedback from the instructor as positive experiences that fostered the effectiveness of their learning.

Another contextual factor is the particular learning contexts specific to courses in different disciplines. Engineering students typically take math-heavy courses in their first year and usually have design-based courses in their curriculum in addition to courses specific to the engineering discipline of their choice. They also take humanities and social sciences courses as electives. When shifting between these courses with different disciplinary foci, they also shift across different learning contexts that are shaped by disciplinary knowledge and the expected learning outcomes set by instructors. Our data show that engineering students adapt their learning strategies to how they understand about the expectations in different course. Thus, a notable individual-contextual interaction lies in engineering students' discipline-based understandings of the learning contexts in these courses, particularly when comparing engineering and non-engineering courses. Quotes under sub-themes of 2.3 and 3.2 suggest that engineering students

may not understand the expected learning outcomes and the pedagogies used in humanities courses so well as those in engineering courses, which could affect their self-evaluation of learning effectiveness under different instructional modalities.

Although our study was not originally designed to study epistemologies, several pieces of evidence from our data have informed us of the relevance of engineering epistemologies and personal epistemologies to the interpretations of our findings. These pieces of evidence include:

- Value attached to self-efficacy in problem solving and knowledge application when interpreting learning effectiveness (ST1 and ST9, sub-theme 1.3). The importance of problem-solving and knowledge application relates to a belief that engineering students hold about engineering practice.
- A good theory-practice balance perceived as effective teaching practice (ST10, sub-theme 2.2). This perception embodies epistemic beliefs about what constitutes desirable engineering knowledge. In this regard, engineering students often appreciate the procedural knowledge that allows them to translate theory into practice.
- Using different learning strategies in different types of courses, for example design versus math courses (ST11 and ST12, in sub-theme 2.1). These personalized learning strategies reflect students' beliefs about how to acquire knowledge, and they apply these beliefs to learning different types of disciplinary knowledge.
- Discipline-based understandings of the learning contexts in different courses (ST3, ST12 and ST13, in sub-themes 2.3 and 3.2) affected their preference for instruction modes. At least some engineering students considered knowledge transfer in a lecture as learning and therefore attached greater importance to engineering courses than to humanities elective courses, which, in the student's mind, mainly involved discussions and opinions. This epistemological view suggests a positivist worldview that dominates engineering students' thinking and that constructivist learning is not the norm. Perry's (1998) scheme of dualism, multiplicity, and relativism can be used to characterize the possible gaps in intellectual development among undergraduate engineering students.

All of these suggest that personal epistemologies that consist of the nature of knowledge (simplicity and certainty of knowledge) and the processes of knowing (sources of knowledge and justification) [34, 35] underline engineering students' perceptions of learning effectiveness.

Learning Effectiveness in the Post-Pandemic Era

With all the academic changes as a result of the pandemic, engineering education will become more oriented to digital and flexible learning. Online course delivery will continue to complement the in-person instruction. The effective teaching practices associated with either and both of the in-person and online instruction modes, as important contextual factors, will continue to impact engineering students' perceived, and actual, learning effectiveness. With increased availability of digital learning resources and pedagogies (e.g., [36]), learning opportunities in various instruction modes will abound.

Although our study was conducted in an academic term of transitioning to in-person instruction in the later stage of the pandemic, its findings will exert lasting implications for the post-pandemic era. The epistemic beliefs that engineering students developed about the advantages and disadvantages of in-person versus online instruction will stay with them when they progress

in their undergraduate studies or pursue graduate studies. Our data show that these beliefs can be that in-person learning feels more motivating than online learning; and online learning involves a higher level of accessibility and efficiency. These beliefs will interact with students' personal epistemologies to influence their strategies and choices in future learning activities. Some of these beliefs, when entirely grounded in a positivist worldview, can be limited or biased, relative to what is expected of learning. Educators and learning strategists working with engineering students should facilitate effective discussions among students to mitigate biases and better utilize in-person and online resources to optimize learning opportunities. Further, our analysis suggests that learning effectiveness can be evaluated in multiple ways—in terms of learning processes and outcomes. Learners and educators should be mindful of this diversity when evaluating effectiveness in learning.

Practical Implications

This study suggests several practical implications for instructors, engineering students, and researchers. For engineering instructors, it is important to understand that their teaching practices, including the course structure, the organization of course materials, use of any pedagogical methods, and the choice of in-person or online instruction, will serve as contextual factors for students' learning that can significantly impact their learning effectiveness. For those instructors who teach courses outside the discipline of engineering in an engineering school, it is necessary to be aware that engineering students enter these courses, more often than not, with engineering epistemologies, which can considerably differ from the typical epistemological views embedded in these courses. Therefore, it becomes crucial to unpack the epistemological differences for engineering students and take some actions to clarify learning outcomes and help students adjust their expectations and learning strategies so that they can learn more effectively in these courses. Moreover, it may be helpful for instructors to know that students' perceptions of learning effectiveness can be idiosyncratic as they are shaped by individuals' distinctive ways of interpreting the surroundings. Hence, while students' perceptions of learning effectiveness offer one way to gauge student learning, instructors may want to cautiously use these perceptions to evaluate the quality of their instruction; collecting information from multiple sources can help address this limitation. Lastly, as students' perceptions of learning effectiveness appear to be shaped by their personal epistemologies in some ways, these perceptions may not align well with students' actual learning as measured by reliable assessment methods. Therefore, instructors can note a gap between how effectively students feel they are learning and how well they are performing academically.

On the part of engineering students, self-assessment of learning effectiveness is part of their reflective learning process; and strong perceptions of effectiveness in learning help boost their self-esteem and self-efficacy. Based on the findings in this study, strategies for enhancing learning effectiveness can include the following:

- Fostering interest in the course materials by connecting them to what they already know and they would like to achieve, to enhance emotional engagement in learning;
- Developing effective learning strategies for improving conceptual understanding and problem-solving capabilities, to enhance cognitive engagement in learning;
- Building a learning community with peers and actively participate in various learning activities, to enhance behavioral engagement in learning;

- Cultivating versatile study skills to learn effectively under in-person and online instruction modes;
- Fostering a growth mindset to appreciate different types of knowledge and different ways of knowing.

For researchers, the multiple dimensions of perceived learning effectiveness mean that it is not sufficient only to know what teaching practices students found effective to their learning. Our findings in this study suggest that caveats be placed for interpreting the responses to survey questions on learning effectiveness. Follow-up questions should be asked: What makes students feel that the teaching practice was effective to their learning? What epistemic beliefs underline the perceptions of learning effectiveness? And, are these beliefs grounded in certain discipline-based epistemologies? These questions will help unpack the patterns in students' perceptions on effective learning.

Given the limited scope of this study, the findings mainly drawn from five engineering student focus groups should be validated by future studies that involve a larger sample size and desirably are conducted in various disciplinary settings. We also acknowledge that this study did not probe learning assessment methods—an important teaching practice that could impact students' perceptions of learning effectiveness. This can also be an area of exploration for future research.

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