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Exploring Self-directed Learning Among Engineering Undergraduates in the Extensive Online Instruction Environment During the COVID-19 Pandemic

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Abstract

The COVID-19 pandemic brought about unprecedented academic disruptions to postsecondary education, including engineering education. A considerable decrease in student motivation became a major issue for online learning during the pandemic. This paper attempts to address these questions: How did the online instruction environment affect engineering students' motivation and self-directed learning? How did these changes, in turn, affect their learning outcomes? We used survey data collected from a large Canadian engineering school and conceptualized self-directed learning from a social cognitive perspective to address these questions. Our findings revealed that students' self-directed learning capabilities mediated the effects of learning environment factors on estimated grades and perceived gains in competency development; and student motivation had both direct and indirect effects on these learning outcomes. In their comments, students ascribed lack of motivation to multiple aspects of the online learning environment and felt that decreased motivation affected their learning. Our analysis demonstrated the significant role of student motivation in an online environment and suggested that the decrease in motivation became a major affective barrier to learning. Thus, the extensive online instruction during the pandemic offered both challenges and opportunities for producing self-directed learners. We recommend that engineering schools implement more interventions to help engineering students enhance their self-directed learning capabilities.

Keywords: online, self-directed learning, motivation, social cognitive perspective, pandemic

Introduction

The current COVID-19 pandemic has brought about unprecedented academic disruptions to postsecondary education, alongside tremendous social and economic impacts to almost all sectors. In Canada, over 90% of postsecondary campuses moved some or all their courses online in response to the pandemic, according to a Statistics Canada survey report in May 2020 [1]. After a summer of intense planning, the "makeshift experience" [2] resulting from the transition to emergency remote teaching and learning in the spring of 2020 was transformed into a new norm of online course delivery for almost all Canadian postsecondary institutions by the fall semester. New approaches ranged from an entirely online mode to a hybrid-flexible mode, with variations based on institutional and disciplinary needs. The impact of this change was significant for postsecondary students on many levels.

Surveys conducted in the spring of 2020 at postsecondary institutions in North America, including engineering schools, revealed that students generally experienced a decrease in motivation after the transition to remote learning [3-6]. Findings also revealed that the capacity for self-directed learning became particularly important to academic success; those students who were better at self-directing their learning tended to better cope with challenges [6]. As academic disruptions during the global pandemic imposed a mode of system-wide online instruction on postsecondary education, we asked these research questions: How did this online instruction environment affect engineering

students' motivation and self-directed learning? How did these changes, in turn, affect their learning outcomes?

To address these questions, we used survey data collected from a large Canadian engineering school in December 2020 and conceptualized self-directed learning from the social cognitive perspective. The findings from our analysis shed light on the understandings of engineering students' self-directed learning capabilities when learning online during the pandemic and their association with two learning outcomes—academic performance and perceived gains in competency development.

Literature Review

Self-directed learning is a concept that is grounded in Knowles's work in 1975 [7], in which self-directed learning readiness refers to "a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes." In more recent literature, self-directed learning is manifested in the abilities to take responsibility for one's own educational experiences by monitoring their own progress and making adjustments to benefit the final outcome [8, 9]. Self-directed learning is closely linked to lifelong learning as it prepares individuals for becoming lifelong learners, thus constituting a dimension of, or a basis for, lifelong learning [10, 11]. Similar to self-directed learning is the concept of self-regulated learning. Bracey's literature review [12] concludes that self-regulated learning and self-directed learning basically have the same meaning and are often used interchangeably. One definition of *self-regulated learning* is "students' control of their thoughts, motivation, and learning behaviors in order to accomplish their learning goals" and includes the aspects of intrinsic orientation, self-management, metacognitive awareness and performance orientation [13]. Hence, in this paper we conceive of self-regulated learning as being an integral part of self-directed learning and draw upon literature on self-regulated learning to understand self-directed learning.

Literature shows that both self-directed and self-regulated learning are important to individual success in the 21st century [14], particularly in the digital society [15]. In an online environment, learners are entirely in control of when and how they engage in and carry out learning tasks independently, and thus need to be self-motivated and self-directed in order to succeed [16-18]. The ability to self-direct learning was found to be a predictor for adult learners' MOOC completion rate [9]. Aspects of self-regulated learning also affected students' online learning attitudes [13]. Those students who better self-regulate their studies by managing their time properly, being conscious of their learning and social behavior, being critical in examining course content, and persevering in understanding the learning material are most likely to better perform online [19]. On the other hand, research reveals that an online environment presents multiple barriers to self-directed learning. The instruction and peer interactions available in a traditional classroom setting are limited, thus leading to non-engagement of learners [20]. A qualitative study on online experiences of graduate medical science students [21] reported three types of barriers to self-directed learning: cognitive barriers (information overload and lack of focus on learning or mind wondering); communication barriers (inadequate coping skills and writing skills); and educational and environmental barriers (heavy workload and role ambiguity). All this suggests that learning online simultaneously requires and

challenges students' self-directed learning capabilities. The extensive online instruction environment during the pandemic thus offered an opportunity to better understand how these demands and challenges play out. These understandings will provide practical implications for online teaching and learning practices and help inform future possibly hybrid modes of engineering education during the post-pandemic era.

Conceptual Framework

The social cognitive perspective of self-regulated learning has informed the conceptual framework of this study. The social cognitive perspective contributes to understandings of self-regulated learning in two ways. On one hand, self-regulation is viewed as an agentic capability as individuals exercise their agency through self-regulated capabilities. On the other hand, self-regulation is conceived as a result of the reciprocal interaction of personal, behavioural and environmental triadic processes [22-24]. In other words, self-regulated learning both involves a mental model (i.e., cognitive) and depends on interacting with others (i.e., social). Self-directed learning can be conceptualized in the same way.

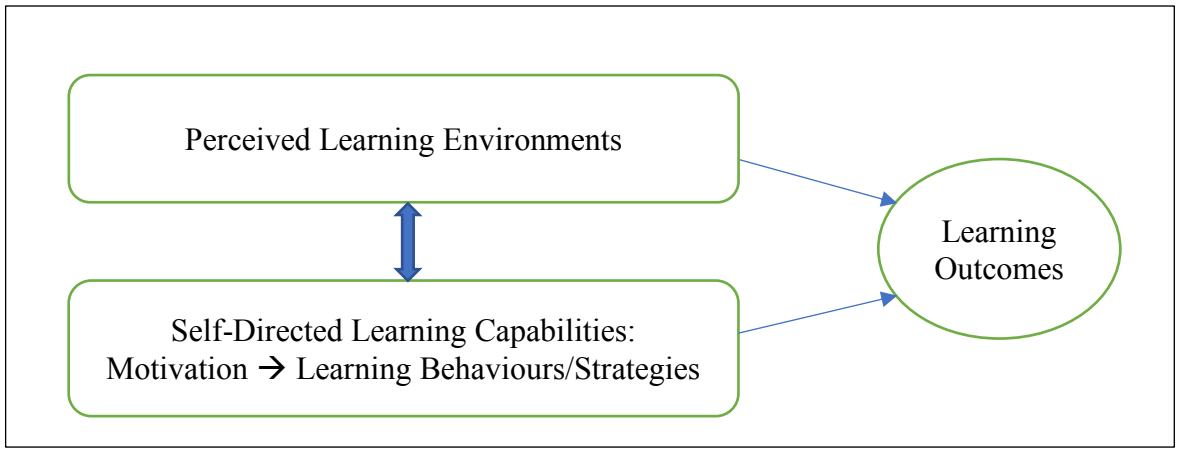
At the centre of the cognitive view of self-regulated and self-directed learning is learners' motivation. Self-motivation is a characteristic of self-directed and self-regulated learners [10, 13]. Motivation is often an integral part of self-directed learning instruments (see examples in [8, 25]). Learners' motivation helps sustain their self-directed learning, which, in turn, is associated with positive learning outcomes [26]. Motivation is linked to both cognition and volition [27]. Motivation-related theories, as reviewed by Eccles and Wigfield [27], contend that motivation should be conceived in cognitive processing terms; and motivation and cognition interact to influence self-regulated learning. Different motivational constructs, either interdependent and multidimensional [28], lend support to the relationship between motivation and cognition. In particular, a Self-Regulation of Motivation model [17, 29] differentiates two types of student motivation: goal-defined motivation and experience-defined motivation. The model posits that the more students value a particular goal and expect to achieve it, the more motivated they will be to make efforts to attain the goal (i.e., goal-defined); and that students' motivation is also defined by whether their learning experience is interesting and engaging. This model informed the design of the motivation questions in the present study. Furthermore, motivation is also linked to volition, which refers to both the strength of will required to complete a task and the diligence of pursuit [27]. While motivation guides decisions to engage in particular activities, volition guides the behaviours taken to attain the goal. Volitional strategies help with persistence in the face of distractions.

The social view of self-directed learning lies in the relationship between the individual and the environmental. Social cognitive theory rejects a dualistic perspective on personal agency and social environments for the effectiveness of human activities [22]. A general assumption behind self-regulated learning is that self-regulatory activities mediate between personal and contextual characteristics on one hand and actual achievement or performance on the other. That is, it is not just individuals' demographic, cultural or personality characteristics that influence their achievement directly, or just the contextual characteristics of the classroom environment that shape student learning; rather, the individuals' self-regulation of their cognition, motivation and behaviour serve as the mediator between the person, the environment and eventual achievement [30]. Social cognitive theories also point out that the exercise of personal agency varies depending on the nature of the

environment. The operative environment can be imposed (i.e., the physical and sociocultural environment that impinges on people whether they like it or not), selected (i.e., the environment that only comes into being when people select and activate it by taking appropriate action) and created (i.e., the environment in which people create the nature of their situations to serve their purposes) [22]. While research has yet to examine the impact of these types of educational environments can have on student learning, empirical studies have corroborated that students tend to adjust their learning strategies on the basis of their perceptions of their learning environments [11, 31].

Placing these elements together, Figure 1 illustrates the general conceptual framework for this study. Engineering students enter an online learning environment with their self-directed learning capabilities, which are mainly reflected in their motivation for learning and the concomitant learning behaviours or use of learning strategies. The self-directed learning capabilities interact with the physical and sociocultural aspects of the learning environment. These interactions could be manifested in that students' perception of the nature of the learning environment may affect their motivation and learning strategies; and their agentic capabilities may enable them to make the best of the learning environment or their existing self-directed capabilities may dysfunction in an inadequate environment. As a result of these interactions, particular learning outcomes eventually transpire.

Figure 1. Conceptual framework of the study



Data Source

The data source for this study was an online learning survey that was administered to all undergraduate engineering students at a comprehensive Canadian university in December 2020 to January 2021, after an academic term of exclusively online instruction. The purpose of the survey was to better understand engineering students' perceptions of their online learning experiences during the pandemic. A total of 503 students completed the survey, with a response rate of 10%. The survey was home designed by incorporating input from instructors and students from the engineering Faculty of the university. The survey was part of a larger research project that received the approval of the research ethics board of the university.

We included four groups of variables for analysis in light of the conceptual framework for this study and used the general Input-Environment-Outcome framework to assess learning experience and outcomes in postsecondary education [32, 33]. The focus of interest for the study was self-directed

learning. We included five measures—motivation for learning, time management, self-regulation, persistence, and help-seeking—to serve as the self-directed learning (SDL) indicators as they represent the key characteristics of self-directed learners [10]. Questions from a validated learning strategy scale [34] were included with some adjustments to measure time management (3 items),[1] self-regulation (3 items),[2] persistence, and help-seeking. We included four question items[3] to probe the goal-defined and experience-defined aspects of motivation in light of Sansone and associates' Self-Regulation of Motivation model [17, 29], as outlined in the section of Conceptual Framework. The scales of time management, self-regulation and motivation had a relatively high internal consistency, with Cronbach's alphas of.77 and .67, and .70 respectively. We averaged the scores for each scale and created three composite scores to measure these three SDL indicators.

We also included the following seven questions to capture student perceptions of the learning environment:

- Increase in academic workload: "*My course-related workload was higher online than when I took classes in person*."
- Same quality of education provided by online instruction: "*Online instruction provided the same quality of education as in-person instruction*."
- Easiness in asking questions: "*It was easier and safer to ask questions in an online learning environment*."
- Peer support: "*My peers were supportive*."
- Instructor support: "*My instructors were supportive*."
- Valid assessment: "*Assessment methods used in most of my courses allowed me to demonstrate my learning*."
- Perceived Impact of online instruction to learning: "*Overall, I found that the online instruction this term was …*" (1=Very detrimental to my learning, 7=Very beneficial to my learning)

We used two indicators of student learning outcomes. One was students' estimated grades on a 9-point scale, which served as a proxy for students' academic performance. The other was a set of questions probing students' perceptions of their gains in 11 competencies.[4] Exploratory factor

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[1] The time management items were "I follow a defined timetable when I'm studying"; "I use the time that I have reserved for studying efficiently"; and "Even in a tough situation I stick to the schedule I have made for myself" on a 4-point scale from "Never" to "Very often."

[2] The self-regulation items were "I set learning goals to focus my studies"; "Before a study assignment, I review its different steps in my mind"; and "After a study assignment I think about how I did and how I could improve my performance" on a 4-point scale from "Never" to "Very often."

[3] The motivation items were "The courses I took this term were interesting" (measuring goal-oriented motivation); "Courses I took this term will be useful to my future studies or development" (measuring goal-oriented motivation); "I enjoyed online learning this term" (measuring experience-oriented motivation); and "I was less motivated to learn in an online environment that when I took courses in person" (the reversed scale was used in analysis) on a 4-point scale from "Strongly disagree" to "Strongly agree."

[4] The question asked "How much has your experience this term contributed to your knowledge, skills, and personal development in the following areas?", on a 4-point scale (Very little, Some, Quite a bit, and Very much). The question consisted 11 items: "Writing clearly and effectively"; "Speaking clearly and effectively"; "Thinking critically and analytically'; "Analyzing numerical and statistical information"; "Acquiring job- or work-related knowledge and skills"; "Working effectively with others"; "Developing or clarifying a personal code of values and ethics"; "Understanding people of other backgrounds (economic, racial/ethnic, political, religious, nationality, etc.)"; "Solving complex real-world

analysis showed that the responses to these 11 questions were loaded unto one factor, explaining 44.36% of the total variance. The responses to these questions demonstrated a high internal consistency (Cronbach's alpha = .90) so we created a composite score by averaging the responses to measure students' perceived gains in competency development. In addition, we included three pieces of student background information as the covariates—gender, residential status, and current year of study. Table 1 shows the descriptive statistics of the variables included for analysis.

Data Analysis

In our quantitative analysis, we first conducted correlation analyses of the components in the constructs of motivation and SDL to inspect how they internally related to each other. We examined the descriptive statistics for questions that probed the impact of the online instruction on students' self-directed learning capabilities. Then, we ran hierarchical linear regression on Estimated Grades and Perceived Gains in Competency Development by entering the three blocks of variables in the sequence of background information, SDL indicators and the Learning Environment indicators. Following that, to examine whether there were mediating effects of SDL on the perceptions of the learning environment, we conducted ordinal or binary logistic regression of the SDL Indicators on each of the Learning Environment indicators. Before running this mediation analysis, we recoded the 7-point scale for the variable Overall Perception of Online Instruction into a 3-point scale: Negative (1-3 in the original scale), Neutral (4 in the original scale) and Positive (5-7 in the original scale); and recoded the 4-point scale of other Learning Environment indicators into a 2-point scale: Disagree (1-2 in the original scale) and Agreed (3-4 in the original scale). The hierarchical regression and mediation analyses helped established the direct and indirect effects of SDL indicators on the two outcomes [33]—estimated grades and perceived gains in competency development.

As student motivation emerged from our quantitative data analysis as a SDL indicator that appeared to have more impact on online learning experience and outcomes than others (to be shown in Tables 5-7 in the Findings section), we further conducted thematic analysis of the student comments related to motivation. We coded and analyzed 170 comments that responded to different open-ended questions in the survey but explicitly addressed motivation-related matters. We then interpreted the findings from both quantitative and qualitative analysis.

Table 1. Descriptive Statistics of Included Variables for Analysis

	Range	Mean	SD
Learning Outcome			
Estimated Grades	1 to 9	5.6	2.1
Perceived Gains in Competency Development*	1 to 4	2.3	.65
Self-Directed Learning Indicators			
Motivation Score*	1 to 4	2.6	.60
Time Management Score*	1 to 4	2.4	.69
Self-Regulation Score*	1 to 4	2.6	.70
Help Seeking*	1 to 4	2.9	.82
Persistence*	1 to 4	3.1	.79

problems"; "Being an informed and active citizen"; and "Applying appropriate techniques and tools to engineering practice." The first ten question items were used with permission from *The College Student Report*, National Survey of Student Engagement, Copyright 2001-19 The Trustees of Indiana University.

Learning Environment Indicators			
Increase in Academic Workload*	1 to 4	3.3	.75
Same Quality of Education in Online Instruction*	1 to 4	1.9	.89
Easiness in Asking Questions*	1 to 4	2.5	.96
Peer Support*	1 to 4	3.2	.65
Instructor Support*	1 to 4	3.0	.73
Valid Assessment*	1 to 4	2.6	.82
Impact of Online Instruction on Learning*	1 to 7	3.6	1.7
Background Information	Percentages		
Gender	Men: 43%; Women: 42%; Other identity/Missing/Unsure: 15%		
Residential status	Domestic: 70%; International: 18%; Missing/Unsure: 12%		
Current year of study	1st year: 33%; 2nd year: 27%; 3rd year: 20%; 4-5th year: 19%		

* We used medians to impute missing data in the variables with an asterisk. The imputed values mostly constituted 0-6% of the total 503 respondents, except the variables of "an increase in academic workload" (20%), "easiness in asking questions" (10%), and "peer support" (9%).
The sample size for all these variables was 503, except Estimated Grades (n=462).

Findings

To address the two research questions, we have organized the findings in four sections: (1) unpacking the construct of SDL; (2) perceived impact of online instruction on SDL; (3) associations between SDL and perceived learning outcomes; and (4) exploring lack of motivation for online learning in the context of extensive online instruction during the pandemic.

Unpacking the Construct of SDL

Two correlation analyses revealed the relationship between the components of self-directed learning (SDL). Table 2 shows that the motivation for online learning relative to in-person learning had a higher correlation with the enjoyment in learning experience (r_s = .57), or the experience-oriented aspect of motivation, than interest and usefulness of the courses (r_s = .21 and .16), or the goal-oriented aspects of motivation. This suggests that the reduced motivation for online learning appeared to have a stronger association with the experience-oriented dimension than the goal-oriented dimension.

Table 2. Correlation among question items on motivation

	Interest	Usefulness	Enjoyment
The courses I took this term were interesting [Interest].	1		
Courses I took this term will be useful to my future studies or development [Usefulness].	.58**	1	
I enjoyed online learning this term [Enjoyment].	.39**	.29**	1
I was less motivated to learn in an online environment that when I took courses in person [Motivation for Online Learning, the reversed scale used]	.21**	.16**	.57**

**p < .01. This table reports the Spearman's rho values.

Table 3 shows that there was a low correlation ($r < .3$) between Motivation and the four SDL behaviors—Time Management, Self-Regulation, Help Seeking, and Persistence; the highest correlation was between Self-Regulation and Time Management (a moderate correlation, $r = .44$); and persistence was moderately correlated to Time Management and Self-Regulation ($r = .33$).

Table 3. Correlation among Self-Directed Learning Indicators

	Motivation	Time Management	Self-Regulation	Help Seeking
Motivation	1			
Time Management	.23**	1		
Self-Regulation	.22**	.44**	1	
Help Seeking	.10*	.20**	.25**	1
Persistence	.11*	.33**	.33**	.29**

* $p < .05$; ** $p < .01$. The values in the table are Pearson correlation coefficients.

Perceived Impact of Online Instruction on SDL

Results from the quantitative analysis suggested that exclusively learning online considerably affected students' motivation for learning and self-directed learning capabilities. The vast majority of the respondents agreed (28%) or strongly agreed (51%) that they felt less motivated to learn online than when they took courses in person. Particularly, first-year students ($M \pm SD$, $2.4 \pm .56$) had a statistically lower score in motivation for learning than the second-year and senior students ($M_{second} = 2.68$, $SD_{second} = .57$; $M_{senior} = 2.66$, $SD_{senior} = .65$), $F(3, 499) = 5.1$, $p < .01$, $\eta^2 = .03$, while no significant group differences were found by gender or residential status.

In addition, Table 4 shows that a larger proportion of the respondents reported that learning online detracted from their abilities to manage time, set goals, seek help, and persevere. Further, changes in these abilities were moderately, positively correlated to the changes in motivation for learning, with Spearman correlation coefficients ranging from .32 to .42. For example, those students who agreed that their motivation for learning decreased were more likely to feel that their abilities for time management were negatively impacted by the online environment, $r_s = .42$. $p < .001$.

Table 4. Impact of the Online Instruction Environment on Learning Behaviours

	Somewhat or Significantly Negatively Affected	Not affected	Somewhat or Significantly Positively Affected
Time management	56%	11%	34%
Goal setting	37%	39%	24%
Help seeking	45%	21%	34%
Ability to persevere	48%	24%	29%

Associations between SDL and Perceived Learning Outcomes

When three blocks of variables were regressed on Estimated Grades, the results indicated that the model was statistically significant, $F(19, 442) = 8.6$, $p < .001$, adjusted $R^2 = .24$. The first block—

the three student background information variables—explained 10% of the total variance; the variance explained increased by 11% when the SDL indicators were added; and the variance explained further increased by 3% when the Learning Environment indicators were included. As shown in Table 5, in Model 2, four SDL indicators—Motivation Score, Time Management Score, Persistence and Help Seeking—were significant predictors of Estimated Grades, with Beta values of .20, .14, .15 and .09 when student background information was controlled for. However, in Model 3, the Motivation Score became insignificant and its variable inflation factor, an indicator of multicollinearity, was inflated from 1.1 to 2.5 when the block of Learning Environment Indicators was included. This suggests that certain Learning Environment indicators may have stronger associations with Estimated Grades than the Motivation Score and that the Motivation Score could be significantly correlated to some of the Learning Environment Indicators. These possibilities justified a further analysis to explore whether there was any mediating effect of the Motivation Score on the Learning Environment Indicators.

The linear regression analysis also showed that when the Learning Environment Indicators were entered (Model 3), the variable Perceived Impact of Online Instruction to Learning stood out as the only significant predictor for Estimated Grades, with a Beta value of .18, when other variables were controlled for. This means that when students had a positive perception of online instruction, they tended to perform better academically. Furthermore, across the three models, women students and first-year students, on average, believed that they performed less well academically, with lower estimated grades than their comparable groups—men and third-year students, with Beta values of -.21 and -.20 respectively in Model 3.

Table 6 shows that the linear regression model of the three blocks of variables on Perceived Gains in Competency Development was statistically significant, $F(19, 483) = 22$, $p < .001$. Three blocks of variables explained 44% of the total variance of Perceived Gains in Competency Development, almost twice as much as the variance explained in Estimated Grades (i.e., 24%). The block of background information variables only explained 5% of the total variance (Model 1). Model 2, which included the block of SDL Indicators, explained an additional 31% of the total variance. When the block of the Learning Environment indicators was also included in Model 3, the model explained 8% more of the total variance.

Similar to the linear regression results for Estimated Grades, the Motivation Score had the largest standardized coefficient among the SDL indicators, with the Beta value being .47 in Model 2 and .20 in Model 3 (Table 6). However, while Time Management was a significant predictor for Estimated Grades, Self-Regulation stood out as a significant predictor for Perceived Gains in Competency Development, Beta = . 13 in both Models 2 and 3, when other variables were controlled for. Further, Increase in Academic Workload (Beta = .10), Peer Support (Beta = .10) and Instructor Support (Beta = .09) in addition to Perceived Impact of Online Instruction to Learning (Beta = .23) were found to be statistically significant to Perceived Gains in Competency Development. In terms of student background, international students, on average, reported larger perceived gains in competency development than domestic students; and first-year students reported larger perceived gains and senior students reported smaller perceived gains in competency development than third-year students, when SDL indicators and Learning Environment indicators were controlled for.

In the mediation analysis, results from the ordinal logistic regression indicated that the Motivation Score was a positive and significant predictor of the probability of perceiving benefit of online instruction to learning, $X^2(12) = 288$, $p < .001$, when controlling for other SDL indicators and the three covariates of gender, residential status and year of study. The odds ratio of the Motivation Score, as shown in Table 7, indicated that for every one-unit increase in the Motivation Score, the odds of perceived benefit of online instruction to student learning increased by a factor of 23, $p < .001$. Similarly, the binary logistic regression showed a positive association between motivation and the positive perceptions of the learning environment; that is, when students felt better motivation for learning, they were also more likely to perceive that online instruction provided the same quality as in-person learning, that there was no increase in academic workload, that it was easier to ask questions, that peers and instructors were supportive, and that assessment methods used in most courses allowed students to demonstrate their learning. These results revealed that students' level of motivation for learning was a significant mediator for their positive perceptions of their learning environment in all areas being examined, whereas the mediation effects of other SDL indicators were much weaker and less consistent.

Table 5. Results from Hierarchical Linear Regression on Estimated Grades

	Model 1			Model 2			Model 3		
Variables	B	SE B	Beta	B	SE B	Beta	B	SE B	Beta
(Constant)	6.2	.23		2.0	.57		3.5	.81	
Gender: Women	**-.89**	**.20**	**-.21*****	**-.83**	**.19**	**-.20*****	**-.89**	**.18**	**-.21*****
Gender: Other/Unknown	.27	.49	.04	.21	.46	.04	.25	.46	.04
Residential status: International	.04	.25	.01	-.01	.23	.00	.03	.23	.01
Residential status: Unknown	-.75	.53	-.11	-.62	.49	-.09	-.75	.49	-.11
Current year of study: 1st year	**-.89**	**.26**	**-.20****	**-.83**	**.25**	**-.19****	**-.89**	**.25**	**-.20*****
Current year of study: 2nd year	-.07	.27	-.01	-.25	.25	-.05	-.36	.25	-.08
Current year of study: 4-5th year	.54	.29	.10	.43	.28	.08	.29	.27	.05
Motivation Score				**.71**	**.15**	**.20*****	.11	.22	.03
Time Management Score				**.42**	**.14**	**.14****	.33	.14	.11*
Self-Regulation Score				-.15	.14	-.05	-.10	.14	-.03
Help Seeking				**.22**	**.11**	**.09***	.24	.11	.10*
Persistence				**.40**	**.12**	**.15****	**.48**	**.12**	**.18*****
Increase in academic workload							-.24	.13	-.09
Same quality of education in online instruction							.08	.14	.04
Easiness in asking questions							-.04	.10	-.02
Peer support							-.17	.15	-.05
Instructor support							-.06	.15	-.02
Valid assessment							.20	.13	.08
Impact of online instruction on learning							**.22**	**.09**	**.18****
Adjusted R^2		.10			.21			.24	
F for change in R^2		8.0***			15***			3.1**	

*$p < .05$; **$p < .01$; ***$p < .001$.

Table 6. Results from Hierarchical Linear Regression on Perceived Gains in Competency Development

	Model 1			Model 2			Model 3		
Variables	B	SE B	Beta	B	SE B	Beta	B	SE B	Beta
(Constant)	2.1	.07		.07	.16		-.44	.21	
Gender: Women	.04	.06	.03	.08	.05	.06	.05	.05	.04
Gender: Other/Unknown	-.09	.15	-.05	-.06	.12	-.03	-.15	.12	-.08
Residential status: International	.33	.08	**.19*** **	**.27*** **	.06	.16	.21	.06	**.12*** **
Residential status: Unknown	.21	.16	.11	.24	.13	.12	.20	.12	.10
Current year of study: 1st year	.13	.08	.10	.16	.07	**.12***	.17	.06	**.12****
Current year of study: 2nd year	.13	.08	.09	.03	.07	.02	-.04	.07	-.03
Current year of study: 4-5th year	-.11	.09	-.07	-.19	.08	**-.11***	-.20	.07	**-.12****
Motivation Score				.52	.04	**.47*** **	.22	.06	**.20*** **
Time Management Score				.05	.04	.05	.04	.04	.04
Self-Regulation Score				.12	.04	**.13****	.12	.04	**.13****
Help Seeking				.06	.03	**.08***	.04	.03	.05
Persistence				.04	.03	.05	.03	.03	.04
Increase in academic workload							.09	.03	**.10****
Same quality of education in online instruction							.05	.04	.07
Easiness in asking questions							.05	.03	.08
Peer support							.10	.04	**.10****
Instructor support							.08	.04	**.09***
Valid assessment							.01	.03	.01
Impact of online instruction on learning							.09	.02	**.23*** **
Adjusted R^2		.05			.36			.44	
F for change in R^2		5.1***			49***			10***	

*$p < .05$; **$p < .01$; ***$p < .001$.

Table 7. Odds Ratios of SDL Indicators for Positive Perceptions of Perceived Environment Indicators

	Positive perception of online instruction to learning	Not perceiving an increase in academic workload	Same quality of education in online instruction	Easiness in asking questions	Peer support	Instructor support	Valid assessment
Motivation	23***	3.7***	14.8***	2.8***	4.5***	7.5***	4.3***
Time Management	1.6*						
Self-Regulation		.51**					
Help Seeking							1.3*
Persistence						1.5*	.72*
Women (vs. men)	1.6*		1.9*				
International (vs. domestic) students				2.0**			
Year of Study (vs. 3rd-year students)				2nd-year: 1.8*			

*$p < .05$; **$p < .01$; *** $p < .001$.

Exploring Lack of Motivation for Online Learning

Aligning with the quantitative results reported earlier, the analysis of student comments showed that a lack of motivation for learning was prevalent among the respondents. These comments revealed two main themes. One theme was that students linked lack of motivation to multiple aspects of the online learning environment. These aspects included: being constrained at home, lack of social interactions, dissonance with an online learning environment, challenges in time management, the perceptions that certain aspects of course delivery were unhelpful to their learning. The following quotes illustrated these themes.

> *I drew inspiration as I kept talking to colleagues in university, but there was barely any interaction of me and my colleagues this semester that decreased my motivation*. (lack of social interactions).
>
> *Being at home and having your workspace in the same room as where you're sleeping makes it very difficult to stay motivated. On top of that it is difficult to not be around your peers who help motivate you (seeing other's do work makes me feel more motivated).* (lack of social interactions)
>
> *I just don't think online school is for me. My grades have dropped significantly and I find I don't have the motivation to try hard in any of my classes anymore*. (dissonance with online learning)
>
> *I would do much better in person than online for engineering. The physical environment of being with your peers really motivates you and helps you understand the material better instead of being stuck home alone all the time. Furthermore, there should be available resources for those who have learning styles that are not suitable for an online environment, as I can clearly say that I am not an online learner, and I haven't been able to show my skills and abilities which reflected my low exam scores*. (dissonance with online learning)
>
> *I felt that it was harder to manage time since there "seems" to be more free time and so I would spend longer on an assignment more than I needed to in order to "perfect" it. This would lead to delays in other subjects and thus impact my motivation and ability to persevere*. (challenge in time management)
>
> *I was drained mentally from the increase in assignments, the increase in video calls (for group projects and extracurriculars), and the increase in screen time in general, and so I sometimes had decreased motivation to deal with any of it*. (increased workload)
>
> *The pace of the plant design course is poorly designed and is very stressful to force oneself to be motivated to work on it*. (course delivery issues)
>
> *Lecture videos and reading instead of having a live class. I'm not motivated to watch and read them, and I don't think plainly reading and watching them helped my understanding*. (course delivery issues)

The other theme of student comments was that lack of motivation affected student learning in various ways. Students reported that lack of motivation had negatively affected their mental health, time management and goal setting skills, and academic performance, as shown in the following quotes. These findings echoed the results from quantitative analysis.

> *My confidence in myself has significantly decreased, I find myself depressed and not motivated anymore - I used to be able to have goals and motivate myself to study and have an action plan but now I don't even see the point, I feel like I'm not good enough, and that studying won't help*. (affecting mental health, with a spiral effect)
>
> *I feel that my time management and goal setting skills were negatively affected due to lack of motivation when studying online*. (affecting skills)
>
> *I have always had really good time management but with remote learning I lacked motivation and found I was easily distracted by other things since there is no set time for socializing with friends and parents are around to talk to, the internet is easily accessible while working online. The lack of motivation also impacted the desire to set goals and seek help*. (affecting skills)
>
> *It just wasn't the same as in real life. My motivation took a nosedive and I had a lot more trouble getting my assignments done*. (affecting academic performance)
>
> *I just don't think online school is for me. My grades have dropped significantly and I find I don't have the motivation to try hard in any of my classes anymore*. (affecting academic performance)

Discussion

This paper looks to apply a social cognitive perspective to examining self-directed learning (SDL) among engineering undergraduates in the extensive online instruction environment in response to the global pandemic. From a cognitive perspective, SDL involves a mental model that is comprised of motivation and volition. When we unpacked the mental model of SDL, we found that dimensions within the construct of motivation related differently to student motivation for online learning. The stronger association between the experience-oriented dimension of motivation and motivation for online learning than the goal-oriented dimension, suggests that a positive online learning experience may be more important to motivating students to learn during the pandemic than the alignment of goals and interest. The low association between the motivation measure and the four learning behavior measures suggests that the students' level of motivation did not necessarily translate into the same level of commitment to particular learning behaviours, such as time management, self-regulation, help seeking and perseverance. Some students, while highly motivated, may lack the skills to apply more effective learning strategies whereas other students, while less motivated to learn in the online environment, may still be able to persist in applying effective learning strategies to their coursework. This misalignment reflects a distinction between goal intentions and implementation intentions [35].

From a social perspective, our data showed that engineering students' SDL capabilities were not impervious to external influence; rather, they were significantly impacted by the imposed extensive online instruction environment during the COVID-19 pandemic. For a good proportion of students, their existing SDL capabilities were dysfunctional; and the strongest negative impact was found to be on their motivation for learning. Significant decreases in motivation and the ability to keep track of time were reported in other student surveys during the pandemic [3-6], thus representing common challenges for student learning during the pandemic. These challenges can be related to other changes, such as significant increases in school-related anxiety and non-productive attention-related behaviors during online learning (e.g., mindless technology use), as found in a recent study with a focus on psychology [5]. Arguably, the evident impact of the learning environment on SDL cannot be ascribed to extensive online instruction alone but was compounded by various challenges experienced by students during the pandemic.

In light of its conceptual framework, this study identified engineering students' perceptions of the learning environment and SDL capabilities as two types of contributing factors to learning outcomes of interest, i.e., estimated grades and perceived gains in competency development. However, these two contributors had different effects. The SDL indicators explained a larger proportion of the variance explained (i.e., 11% in estimated grades and 31% perceived gains in competency development) than students' perceptions of the learning environment (3% in estimated grades and 8% in perceived gains in competency development), when student background information was controlled for. This means that SDL capabilities carried a larger weight in predicting these learning outcomes than the perceived characteristics of the learning environment. This corroborates the importance of SDL to students' academic success in an online learning environment [18, 19, 36].

Our analysis also confirmed that students' SDL capabilities mediated the effects of learning environment factors. In particular, those students who had higher levels of motivation for learning were more likely to perceive aspects of the learning environment positively, with the strongest effect on the positive perceptions of online instruction, as shown earlier in Table 7. As these survey questions probed students' perceptions in relation to online instruction, their responses could reflect their self-evaluation of their learning experiences, their epistemic beliefs that are based on, or independent of, their personal experiences, or a mixture of both. As illustrated earlier in student comments, some students expressed their disinclination for online learning and other students' motivation for learning was negatively impacted by particular course delivery issues, such as extensive use of lecture videos, and the general lack of social interactions in the online learning environment. All these suggest that individual students' SDL capabilities, including motivation and learning behaviours, interact with the characteristics of the learning environment.

Furthermore, our analysis results unequivocally demonstrated the significant role of student motivation in online learning. Student motivation was found to have both direct and indirect effects on learning outcomes. Motivation was the strongest predictor for both students' perceived academic performance and gains in competency development among the five SDL indicators when students' background information was controlled for. It also mediated the perceptions of all the aspects of the learning environment examined in this study, with the strongest effect on the perception that had direct bearing on online instruction. The perceived impact of the learning environment on SDL

behaviours appeared to hinge upon the changes in motivation for learning. In addition, student motivation appeared to matter more to perceived gains in competency development than their academic performance, as shown in the results of Tables 5 and 6. This suggests that while many engineering students experienced a lack of motivation for learning during the pandemic, they may be able to achieve relatively good academic performance but felt inadequate in competency development.

On the other hand, our data showed a prevalence of reduced motivation for learning in the extensive online environment during the pandemic. Lack of motivation can also be a challenging aspect of SDL for engineering students studying in an in-person learning environment [37]; however, this challenge did not seem to stand out so strongly as in the extensive online learning environment during the pandemic. This may reflect many students' involuntary reactions to the only option of online instruction available to them. Furthermore, our analysis revealed that student motivation appeared to be more associated with their learning experience than their learning interest and goals. As such, the lack of motivation became a major affective barrier to online learning, thus adding another dimension to the cognitive, communication, and educational barriers identified in other research [21]. The reduced motivation for learning appeared to have become a severe issue at the time when student success in online learning significantly depended on their motivation for learning. This issue was most severe among first-year students, which was another finding of this study. The larger motivation problem among first-year students was highly concerning as this could exert a negative impact on the remainder of their engineering studies.

In addition to shedding light on motivation and SDL in the online environment, our quantitative analysis also demonstrated that perceived academic performance and gains in competency development are different learning outcomes and were influenced by different individual and environmental factors. Our statistical model, consisting of student background information, SDL indictors and learning environment indicators, performed much better for students' perceived gains in competency development than for their estimated grades. Among the SDL indicators, students' time management, help seeking and persistence mattered more to their anticipated grades whereas self-regulation abilities were more important to their perceived competency gains; however, motivation for learning remained a significant contributor to both learning outcomes. Among the learning environment indicators, while perceived impact of online instruction to learning contributed significantly to both learning outcomes, perceptions of an increase in academic workload and being supported by peers and instructors contributed to perceived gains in competency development alone. The different contributing factors of the two learning outcomes could reflect different learning approaches student used to meet their learning goals; and the lack of hands-on experiences in labs when students learned exclusively online could be another explanation for perceived inadequacy in competency development.

The SDL indicators included in this paper were part of a comprehensive questionnaire on engineering students' online learning experiences during the pandemic, they only represented some characteristics that reflected students' SDL capabilities. An in-depth examination of engineering students' SDL capabilities will require the use of validated instruments such as Self-directed Learning Readiness Scales (e.g., [25, 38]). In addition, our findings stemmed from the data collected from one engineering school and therefore were contextually situated in the particular culture of the school, including the features of its general teaching environment and the characteristics of its student

population. All these constrained the generalizability of this study. Future research could aim to overcome these limitations in study design and further explore how individual students exercise their agency to not only survive but thrive in challenging learning environments. This could extend the social cognitive perspectives of SDL to a deeper level.

Despite these limitations, our work has confirmed that social cognitive theories offer valuable perspectives for framing research on student learning in engineering education, particularly when it relates to motivation for learning. Social cognitive theories and the related perspectives [22, 24, 27, 30] help ground research on student learning in theoretical underpinnings that involve both individual and environment factors, thus enriching and deepening the data analysis and interpretation in engineering education research. Our paper contributes to applying these theoretical perspectives to engineering education research (e.g., [37]), particularly in the context of online learning. Further, due to the connectivity between self-directed learning and lifelong learning [10, 11, 39], this research illustrates how better understanding engineering students' self-directed learning capabilities and the influencing factors on their development can be a way of exploring how to attain the lifelong learning outcome, which is part of the accreditation standards set by organizations such as the U.S. Accreditation Board for Engineering and Technology and the Canadian Engineering Accreditation Board.

On a practical level, the findings in this paper provided strong evidence for the importance of enhancing engineering students' self-directed learning capabilities in order for them to better cope with future challenges in their academic studies and beyond. This aligns with and serves the ultimate goal of preparing engineering students for becoming lifelong learners. As the development of these competencies entail interactions between individual determination and effort, and a supporting learning environment, developmental strategies can be created from the individual and environmental perspectives as well. From the individual perspective, student-centred strategies can focus on students' choice, control, interest and engagement [40]. Volitional strategies, such as cognitive control, emotional control and motivational control [27]; and forethought, performance and self-reflection [41], can help students to persist when they are faced with challenges. Skill improvement in time management and goal setting can help students translate the decision to action into effective behaviours. The development of these strategies are particularly important for first-year students. The environment-centred strategies can include modifying online learning infrastructure and the learning-teaching process [42] so that the environment can facilitate motivated behaviours. Literature shows that self-regulated and self-directed learning models have been used in engineering education practice in a limited scope; these efforts include courses with a focus on self-regulated learning strategies [43, 44], programs based on self-regulated learning models [45]; and creating a self-regulated learning environment through use of technology in engineering courses [46]. However, efforts to promote engineering students' self-directed learning capabilities in an online environment are rarely seen partly because of the limited online delivery before the pandemic. A meta-analytic review of motivation interventions in education [47] provides a helpful resource and may inspire more ideas for engineering education practitioners. We recommend that engineering schools implement more interventions to help engineering students to enhance their self-directed learning capabilities.

The COVID-19 pandemic has disrupted numerous aspects of postsecondary education and exposed engineering education to online instruction in an unprecedented manner, and the impact of

these disruptions will be far-reaching. It is very likely that future engineering education practice will include increased online components and the use of technology for course delivery will continue to expand. The extensive online instruction during the pandemic offered both challenges and opportunities for producing self-directed learners. Future challenges will hopefully never surpass those encountered in the disrupted practices necessitated by the pandemic. Moving forward, engineering educators are presented with imminent tasks, involving changes and adjustments on multiple levels, to foster the increasingly important self-directed and lifelong learning capabilities of engineering students.

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