Computers and Education Open 6 (2024) 100168

Contents lists available at ScienceDirect

Computers and Education Open

journal homepage: www.sciencedirect.com/journal/computers-and-education-open

Computer science and engineering students' self-directed learning strategies and satisfaction with online learning

Meina Zhu [a,*], Sarah Berri [a], Yaoxian Huang [b], Sara Masoud [c]

[a] Learning Design and Technology, Wayne State University, Detroit, MI, USA
[b] Department of Civil and Environmental Engineering, Wayne State University, Detriot, MI, USA
[c] Department of Industrial and Systems Engineering, Wayne State University, Detriot, MI, USA

ARTICLE INFO

Keywords:
Computer science and engineering education
Self-directed learning
Self-management
Self-monitoring
Motivation, Online learning

ABSTRACT

There is an increasing need for computer science and engineering (CSE) online education. This study examined CSE online learners' perceptions of self-directed learning (SDL) readiness, strategies, and satisfaction. The researchers surveyed 225 students and conducted semi-structured interviews with 15 online CSE students. The quantitative survey data and the qualitative interview data were analyzed using descriptive statistics and thematic analysis, respectively. The findings were as follows: (1) Both extrinsic motivation strategies (e.g., future career development, building a learning routine) and intrinsic motivation strategies (e.g., interest in learning) were utilized; (2) Diverse metacognition strategies (e.g., assignments, quizzes, and tests, discussing with peers, tracking progress, staying in touch with professors and teaching assistants) and cognitive strategies (e.g., watching recorded lectures, taking notes, reading books, seeking out information) were used to monitor learning; (3) Time-management (e.g., priority, checklist, fixed schedule, time-block for study) and resource management strategies (e.g., focused on lectures, textbook reading) were leveraged; (4) Specific designs or instruction promoted students' SDL skills, such as access to documented learning materials, reminders sent from instructors, availability of the instructor, group interaction, and flexibility, and (5) Student satisfaction depended on the design of the course. The advantages and disadvantages of online learning were identified. The findings indicated that the instruction strategies and online course design are critical for CSE students' SDL.

1. Introduction

Computer science and engineering (CSE) jobs are some of the fastest-growing careers and will continue to grow at least through 2030. Thus, the need for qualified workers in CS is increasing [1]. Employment of computer and information research scientists is predicted to increase by 13 % from 2020 to 2030, which is much faster than other occupations, on average [1]. This growth is expected to add approximately 667,600 new CS jobs, indicating that skilled CS professionals will be in high demand. In addition, most other STEM occupations also require computing knowledge and skills. Since about 98 % of computer and information technology majors are in CS [1], providing effective CSE education is critical to prepare students for the increased demand for CSE-related jobs.

The COVID-19 pandemic accelerated the shift from a traditional face-to-face format to an online format [2,3]. More universities, such as Purdue University, provide online CS degrees and courses [4]. Besides an effective course design, the success of CS online courses is also contingent on learners' participation, readiness, engagement, and motivation [5]. Since online courses generally have a flexible structure, learners decide when and how to engage with the content [6] and control their learning [7]. Self-directed learning (SDL) skills can positively impact online learning [8–11]. Self-directed learners are more likely to benefit from available online learning resources [12] by managing their time, tasks, resources, and learning activities [13,14]. SDL is considered a necessary 21st-century skill that plays a principal role in the success of learning acquisition and in predicting learners' readiness for online learning [15–17].

Given the increasing demands of the CSE-related workforce, online CSE education is crucial in meeting job market requirements. Teaching the CSE discipline online poses distinct challenges due to its hands-on activities and the necessity for complex mathematical applications [18,19]. The SDL skills and experience of online CSE students are essential in tackling the challenges of online learning. Gaining insights

* Corresponding author at: Learning Design and Technology, Wayne State University, 365 Education Building, 5425 Gullen Mall, Detroit, MI, 48202, USA.
E-mail address: meinazhu@wayne.edu (M. Zhu).

https://doi.org/10.1016/j.caeo.2024.100168
Received 6 March 2023; Received in revised form 3 February 2024; Accepted 29 February 2024
Available online 1 March 2024

into the SDL strategies and needs of online CSE learners aids researchers and educators in providing a gratifying learning experience. Thus, this study explored CSE online learners' perceptions of SDL readiness, strategies, and satisfaction to provide insights for educators to facilitate learners' SDL strategies and increase learners' satisfaction with online learning in higher education. Five research questions guided this inquiry:

1. How do CSE students self-monitor their online learning in higher education?
2. How do CSE students self-manage their online learning in higher education?
3. How do CSE students stay motivated in online learning in higher education?
4. What elements in online courses support CSE students' SDL?
5. What are CSE students' perceptions in terms of satisfaction and the advantages and disadvantages of online learning?

2. Literature review

2.1. Computer science and engineering education and online education

The need for CSE education has led to an increase in yearly enrolment, especially in mechanical engineering, computer science, and electrical engineering, with 31,936, 19,082, and 13,767 enrolled students in each degree, respectively, in the U.S. [20]. Traditionally, CSE education is predominantly offered in in-person settings, although advancements in technology have enabled institutions to increasingly offer online courses [21]. A typical CSE curriculum includes introductory courses to obtain basic knowledge, laboratory courses to acquire practical skills, project-based learning to develop problem-solving skills, and upper-division courses to obtain specialized knowledge and skills [22]. CSE education could be categorized into domain-general and domain-specific skills [23], as well as general soft skills that can be applied in various fields [24]. Soft skills in CSE education include communication [25], problem-solving [26], leadership [27], and creativity [28]. Field-specific skills that have increased the demand for computing experts in computer science (CS) programs include "programming, algorithms and complexity, systems, software engineering, and information management" ([29], p. 2). In contrast, field-specific skills acquired in engineering programs are "implementation, application, operation, design, development and management of projects and processes" ([30], p. 65–66).

The COVID-19 pandemic and the sudden closure of campuses hindered the traditional application of in-person courses, specifically, the hands-on experience [31]. CSE is grounded in hands-on science and complex mathematics applications, making it a challenging discipline to teach online [18,19]. The success of online courses requires special and intricate planning [32,33].

2.2. Self-directed learning skills in online learning

The success of online learning depends on learners' awareness of their learning needs and their ability to direct their own learning [34]. SDL is a process of learners taking the initiative in their own learning by planning, implementing, and evaluating their learning with or without outside aid [35]. SDL, which sees learners as the primary agent in their learning, is drawn from Bandura's [36] social cognitive theory (SCT). The theory emphasizes the internal and external social influences that affect people and describes factors, such as personal, environmental, behavioral, and cognitive factors as the driving forces behind their actions [37,38]. SDL is considered a necessary 21st-century skill that plays a principal role in the success of learning acquisition as well as in predicting learners' readiness for online learning [15–17]. Learners who are not capable of organizing their own learning cannot advance in the fast-evolving and technologically heavy distance learning [39,40]. Self-directed learners are more likely to benefit from available online learning resources [12] by managing their time, tasks, resources, and learning activities [13,14].

2.3. Self-management, self-monitoring, and motivation and satisfaction

Garrison [41] proposed a self-directed model that includes three essential constructs that work together: self-management, self--monitoring, and motivation (see Fig. 1). The model explains that learners must be motivated and embody self-management and self-monitoring skills to self-direct their learning [42]. Through self-management, learners can control their learning based on their learning goals [43]. Through self-monitoring, they can assess the gap between where they are in the learning process with where they should be [44]. Self-monitoring and self-management allow learners to adjust their learning strategies to the changing needs of their end-goal(s) [45]. Motivation plays a crucial role in how the learners self-monitor and self-manage their learning, which can also affect their SDL skills [46,47]. Motivation, whether intrinsic or extrinsic, is required for heightened self-monitoring skills and can help maintain learners' independence throughout the learning process [48,49]. Motivation and self-monitoring are also required to increase learners' engagement and satisfaction in online learning environments [50], which is crucial due to the physical distance between learners and instructors [51–53]. Learners' engagement and satisfaction are interrelated [54] and can determine the learning outcome of online learners [55,56]. Research that utilizes Garrison's SDL framework to investigate learners' SDL strategies has been carried out in the context of massive open online courses [57–59]. Nevertheless, limited studies have applied Garrison's framework, especially within CSE online learning. Consequently, this study employs Garrison's model as a guiding structure for both the data collection instrument and the subsequent data analysis.

Course satisfaction is considered pivotal to academic achievement [60]. Learners with higher satisfaction levels experienced increased learning success [60–62], persisted in the course, and thus decreased the drop-out rate [63,64]. Some researchers have also examined factors influencing students' satisfaction with online courses (i.e., [65]). Learners' online learning satisfaction involves multiple factors, such as the course composition, activities, and resources, as well as instructor knowledge, engagement, and involvement [66,67]. Other factors that can also affect learners' satisfaction level with online learning include learners' perceptions of online learning [68], learning readiness [69,70], and comfort with online tools [71]. Lack of engagement and learning satisfaction can hinder learning acquisition and is associated with a higher dropout rate [72,73].

Although numerous studies have focused on online learning, further studies on satisfaction [74] and self-directness [75] in online learning are needed, especially in CSE education. Thus, this study explored CSE online learners' perceptions of SDL readiness, strategies, and satisfaction to provide insights for educators to facilitate learners' SDL strategies and increase learners' satisfaction with online learning in higher education.

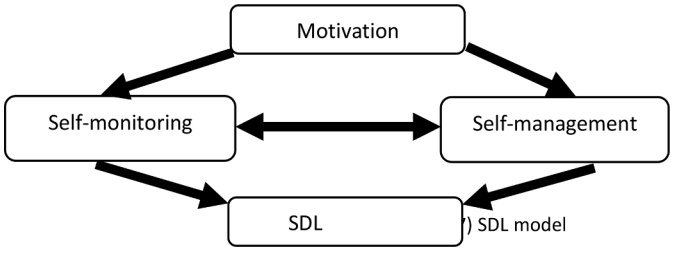

Fig. 1. Garrison's [41] SDL model.

3. Method

This study utilized a sequential explanatory mixed methods design [76,77], which includes quantitative data collection and analysis followed by qualitative data collection and analysis [76]. First, the authors developed an online survey through Qualtrics and sent it to CSE undergraduate and graduate students at a Midwest university in the U.S. in April 2021.

The survey remained open for three weeks to allow students to respond. Among 989 survey recipients, 225 completed responses were received, with a 23 % response rate. The survey includes 27 Likert-type questions that covered motivation (9 items), self-monitoring (9 items), and self-management (9 items). The scale questions within the questionnaire were assessed on a 5-point Likert scale, spanning from 1 (strongly disagree) to 5 (strongly agree). Second, based on the survey response results, the authors selected 15 student volunteers representing as many majors and education levels as possible in May 2021. The interview protocol was revised based on the survey results. According to Guest et al. [78], saturation was observed within the initial twelve interviews in non-probabilistic sampling. In the present study, saturation was noted after completing 15 interviews. Consequently,15 participants are adequate for the scope of this study. A semi-structured, in-depth interview was conducted via Zoom with 15 student volunteers in summer 2021 (see Table 1). By the summer of 2021, all students had experienced remote or online teaching in various formats due to the COVID-19 pandemic that occurred in March 2020. Each interview was audio-recorded and auto-transcribed via Zoom. The auto-verbatim transcripts were manually checked and sent to each interviewee for a first-level member check to ensure the trustworthiness of the study. The use of these different data sources enabled the researchers to triangulate the data [79]. The qualitative data is the primary data source with supplemental survey data. The survey provides a general picture of CSE online learners' SDL status, and the in-depth interviews offer detailed information about learners' SDL strategies. For instance, if students rate themselves highly in a survey concerning their ability to independently locate information related to course content while participating in online courses, the in-depth interview prompts them to elucidate the significance of this self-assessment and elaborate on the strategies employed to achieve it. This approach provides a more nuanced understanding of students' perceptions of online SDL than solely relying on one data source, which helps other researchers who are interested in using similar research approaches in similar educational settings.

The quantitative data was analysed using R. The mean and standard deviation (SD) were calculated. Moreover, boxplots were used to represent the interquartile range (IQR). The semi-structured interviews were analyzed by two researchers using thematic analysis [80,81], which includes six steps: (1) becoming familiar with the data; (2) inductive open coding; (3) identification of themes; (4) review of themes; (5) refining and defining themes; and (6) report writing. The data analysis was guided by Garrison's SDL framework. The final themes included five categories (i.e., motivation, self-management, self--monitoring, the designs that support SDL, and satisfaction) with 13 subcategories (see Table 2). The detailed explanations are described in the findings section.

Table 1
Interviewees' background.

Pseudo Name	Gender	Major	Level
Samia	F	Information Technology	Undergraduate
Adib	M	Computer Science	Undergraduate
Adam	M	Civil and Environmental Engineering	Undergraduate
James	M	Material Science and Engineering	Graduate
Dana	F	Electrical Engineering	Undergraduate
Ali	M	Electrical Engineering	Undergraduate
Yan	F	Social and Environmental Engineering	Graduate
Rania	M	Biomedical Engineering	Graduate
Omar	M	Biomedical Engineering	Undergraduate
Sophia	F	Chemical Engineering	Undergraduate
Maria	F	Electrical Engineering	Undergraduate
Tamar	F	Computer Science	Undergraduate
Mike	M	Mechanical Engineering	Undergraduate
Viraj	M	Computer Science	Graduate
Miral	F	Industrial Engineering	Graduate

4. Findings

4.1. Research question 1 (RQ #1): how do CSE students self-monitor their online learning in higher education?

Based on the survey results, the CSE students' self-monitoring levels were above average (see Table 3). Please see the detailed boxplots in Fig. 2. The specific strategies included cognitive learning strategies and metacognitive learning strategies. Students reported that their cognitive learning strategies depended on the nature of the courses in which they were enrolled and the instructors' strategies. For example, Adam, an undergraduate student in civil and environmental engineering, explained, "If the instructor seems to be focused heavily on lecture video recordings, then I would start there." The common cognitive strategies included watching and re-watching recorded lectures, taking notes,

Table 2
Data analysis themes.

Themes	Sub-themes	Items
Self-monitoring strategies	Cognitive learning	Watching recorded lectures
		Taking notes
		Reading books
		Seeking out information
	Metacognition	Assignments, quizzes, and tests
		Discussing with peers Tracking progress through the Canvas calendar
		Staying in touch with professors and TAs
Self-management strategies	Time management	Priority
		Planner/Calendar/Checklist
		Fixed schedule
		Block out time for study
	Resource management	Focused on lectures
		Textbook reading varies
		Depends on the course and the instructor
Motivation	Extrinsic motivation	Goals (e.g., future career development, high grades) Building a learning routine
		Specific learning environment
		Social interaction
	Intrinsic motivation	Interest in education
Design that supports SDL		Access to structured learning materials
		Reminders sent from instructors
		Instructors' availability
		Group interaction Flexibility
Advantages		More free time
		Documented resources and structured
		Flexibility
		Use of technology for teaching
Disadvantages		Less effective (e.g., retain less information)
		Lack of hands-on experience
		Lack of interaction
		Lack of engagement
		Distraction
		Lockdown browsers bring stress
Satisfaction		Depending on course design and instructors

Table 3
Students' self-monitoring skill levels.

Items	Mean	SD
1. I am responsible for my own learning while taking online courses	4.23	0.78
2. I am in control of my learning while taking online courses	3.89	1.01
3. I have high learning standards while taking online courses	3.66	1.07
4. I prefer to set my own learning goals while taking online courses	3.57	1.04
5. I evaluate my own performance while taking online courses	3.77	0.94
6. I have high beliefs in my learning abilities while taking online courses	3.55	1.09
7. I can find information related to learning content for myself while taking online courses	3.92	0.91
8. I am able to focus on answering or solving a problem while taking online courses	3.48	1.13
9. I am aware of my own limitations while taking online courses	4.08	0.82

reading textbooks, and seeking out information. Twelve of the 15 interviewed participants expressed their appreciation for recorded lectures and having access to them whenever needed. For example, Maira, an electrical engineering undergraduate student, explained that if she did not understand the content, then she watched and re-watched the lectures. She said, "If you don't understand a topic, watching the lectures is like a must."

Aside from watching and re-watching lectures, 14 of the 15 interviewed participants mentioned that taking notes was the dominant cognitive strategy. For instance, Mike, a mechanical engineering undergraduate student, explained that he always took detailed notes of the learning materials. Likewise, Omar, a biomedical engineering undergraduate student, took handwritten notes. He explained: "I like to take handwritten notes. When I do lectures and stuff, I always try to write notes, like in a notebook, or do practice problems in that notebook."

When it comes to reading the textbooks, some students focused on the textbook, while others did not. For example, Maira, an electrical engineering undergraduate student, explained that reading the textbook was a must in her engineering courses, "Most of the time, my classes would be just like problem-based. I do have to refer to my textbook for the information. I'd be going for the textbook. And reading a textbook will be like a must." Similarly, Samia, an information technology undergraduate student, viewed the course textbooks as an important source of information, although some professors did not focus on the textbooks as much as they did on the lectures. She explained: "I like to start with reading the book because I feel like there are some good authors the professors choose, and the book breaks it down." On the other hand, Rania, a biomedical engineering graduate student, did not focus on the textbooks as much as she did on the lectures "because the video kind of repeats it anyway. So, I just read it and take out bullet points that are important and put [the notes] in a separate file."

Another strategy that most students employed was seeking information by searching for external resources to supplement their knowledge or reaching out to professors or teaching assistants (TAs). Twelve of the 15 interviewed participants explained that they searched for external resources to fill any gaps in their knowledge. Samia explained, "It's hard to teach yourself something very new. Luckily, YouTube has many supporting videos and information." Omar, a biomedical

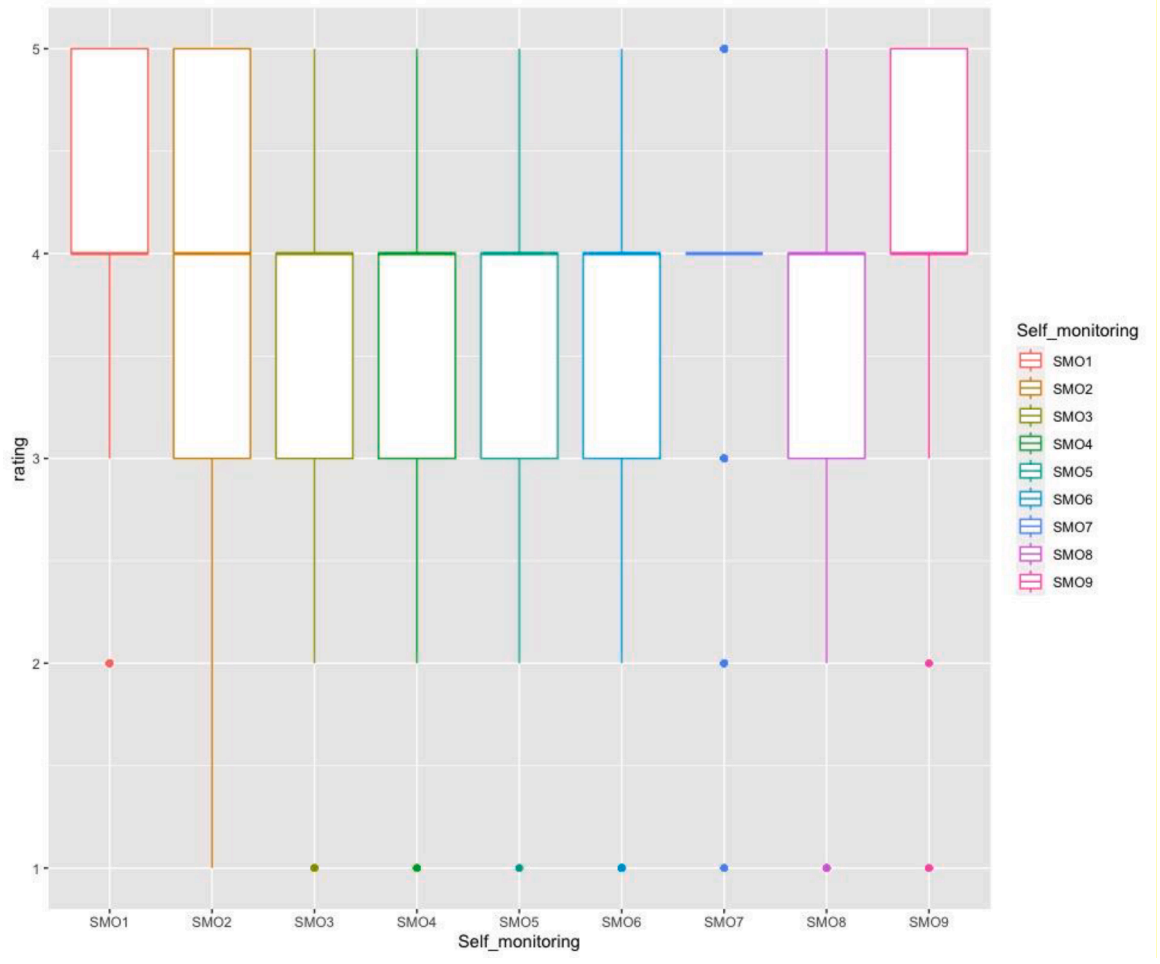

Fig. 2. The boxplot of the rating of self-monitoring from CSE participants' responses. Note: SMO refers to Self-monitoring. The SMO numbers in the figure correspond with the number sequences in Table 3.

engineering undergraduate student, searched for external resources "all the time" for extra help. He found it difficult to communicate with the professors via email and easier to find the answers on his own. Similarly, Viraj, a computer science graduate student, resorted to external links and outside resources before emailing the professors with questions. He explained, "First, I try to understand the content from the external sources. If I can't, then I send emails to the professor, and I also talk with the professor." Another strategy that was mentioned by some of the participants is meeting with tutors. Samia explained, "Meeting with tutors really helps."

The metacognitive strategies used by interviewees included (1) using assignments, quizzes, or tests to monitor learning progress, (2) discussing with peers, (3) tracking learning progress, and (4) communicating with the instructor and teaching assistants (TAs). The majority of the students monitored their learning through formative and summative assessments, such as assignments, quizzes, and test grades. For instance, Rania, a biomedical engineering graduate student, explained, "Of course, tests and quizzes are the best indicators of whether or not you're on the right track for now." Similarly, Mike, a mechanical engineering undergraduate student, monitored his learning through assignments and stated, "The short-term assignment is how I keep myself in check. Analyzing which questions I'm struggling with on homework assignments or quizzes is very useful for gauging my learning."

In addition, some students reported using the calendar view on Canvas to track progress. Adib, a computer science undergraduate student, explained, "When it comes to learning, I just use Canvas the calendar view, and that's my main way to keep track of everything."

Another strategy students used to monitor their learning was discussing the content and progress with peers. For instance, Viraj, a computer science graduate student, monitored his learning by discussing the content with his classmates. This not only helped him monitor his learning but also helped him make sure that he understood it correctly. He explained, "Because sometimes, actually, from my previous experience, I understood something from the lecture, but it was not correct. When I talked with my friends or classmates then, they told me that 'you are not correct.'"

Some students stayed in touch with professors and TAs as a way to monitor their learning. For instance, Adam, a civil and environmental engineering undergraduate student, monitored his learning by emailing and staying in touch with his professors. He said, "I try to stay in touch with the instructor. At least right before our Zoom meeting, I email the instructor to check whether I am on the right track." Another participant, Miral, an industrial engineering graduate student, discussed her progress with the TA, especially since she could not compare her performance with other students. She explained, "Because we couldn't communicate with other students to see their performance and compare my performance, I tried to ask the TA. Most of the time, in her office hours, I asked, 'Do you think my assignment is good?'"

4.2. RQ #2: how do CSE students self-manage their online learning in higher education?

The self-management skills of CSE students were relatively high (see Table 4). Fig. 3 details the data distribution. Students' self-management skills were divided into two categories: time-management and resource management strategies.

4.2.1. Time management

The participants used different strategies to manage their time while enrolled in online courses. Strategies included prioritizing time for studying, using a planner, emphasis on using a calendar or checklist, having a routine, and blocking time slots for studying.

With the flexibility of online learning, managing their time is important for success in the courses. The participants used different strategies to manage their time depending on what worked best with their schedules and other daily activities. Some preferred not to follow a specific plan, while some functioned better with a more explicit and rigid timeline. For instance, Maria, an undergraduate electrical engineering student, prioritized her time by putting more time and effort into the hard courses and working on the assignments and quizzes based on their due dates. She explained,

> After taking a couple of classes, I tried to see which classes were harder. So, based on that, I'm trying to put more time into that. When it comes to submitting some assignments or exams or tests and quizzes, I would also like to prioritize my time—like tomorrow, this is due, so I have to complete this first and then go to something else.

Most participants had fixed daily schedules, and some used planners or checklists to stay on track. Dana, an electrical engineering undergraduate student, had a planned schedule to help her tackle her online courses, "I had written a schedule of all of my courses and then had set like some time for studying or for doing homework." Similarly, Samia, an undergraduate information technology student, also explained that she functions best when she uses a planner and a checklist. She stated, "I feel like, for me, having a planner is the best strategy. Having a planner and a checklist, especially a checklist, gives you a rewarding feeling that you're checking off your list so you can go on about your day."

Another strategy is to have a fixed schedule. Adam, a civil and environmental engineering undergraduate student, stated that managing his time was crucial for progress in online learning environments. He reported, "I usually block off the morning for study."

4.2.2. Resource management

Besides managing their time and planning their study schedules, the participants used different strategies to manage the available learning resources. Most of the participants' strategies varied by course and professor, so their strategies changed from one course to the other. For example, some participants focused on the lectures when they felt that the lectures covered what was important in the course and did not focus entirely on the lectures when they felt that the lectures did not align with the assignments or tests. Some read the textbooks entirely when they felt that the course relied on the textbooks, and others reported skipping the textbooks because the instructor did not place much emphasis on them. For example, Omar, a biomedical engineering undergraduate student, explained how the nature of the course dictated how he managed the learning resources. He explained, "Every class is different; some classes are more focused on textbooks, or some are more focused on lectures. So, I find out what type of class it is first, and then go to whichever one is more important usually." James, a material science and engineering graduate student, also chose his learning strategy based on the course and the instructor. He stated, "That's highly dependent on the class and the professor."

Table 4
Student self-management skill levels.

Items	Mean	SD
1. I prefer to schedule my own learning plan while taking online courses	3.76	1.14
2. I am self-disciplined about completing the required work while taking online courses	3.89	0.99
3. I have good management skills (e.g., time, learning resources, etc.) while taking online courses	3.78	1.04
4. I set specific times to study while taking online courses (e.g., 9:00 a.m. or 10:00 a.m.)	3.16	1.25
5. I set strict time frames for learning while taking online courses (e.g., 1 hour, 2 h, etc.)	3.22	1.17
6. I am able to keep my learning routine in online courses separate from my other commitments	3.56	1.19
7. I can apply a variety of learning strategies while taking online courses	3.76	0.96
8. I am disorganized while learning in online courses	2.80	1.15
9. I am confident in my ability to search for information related to learning content in online courses	3.99	0.80

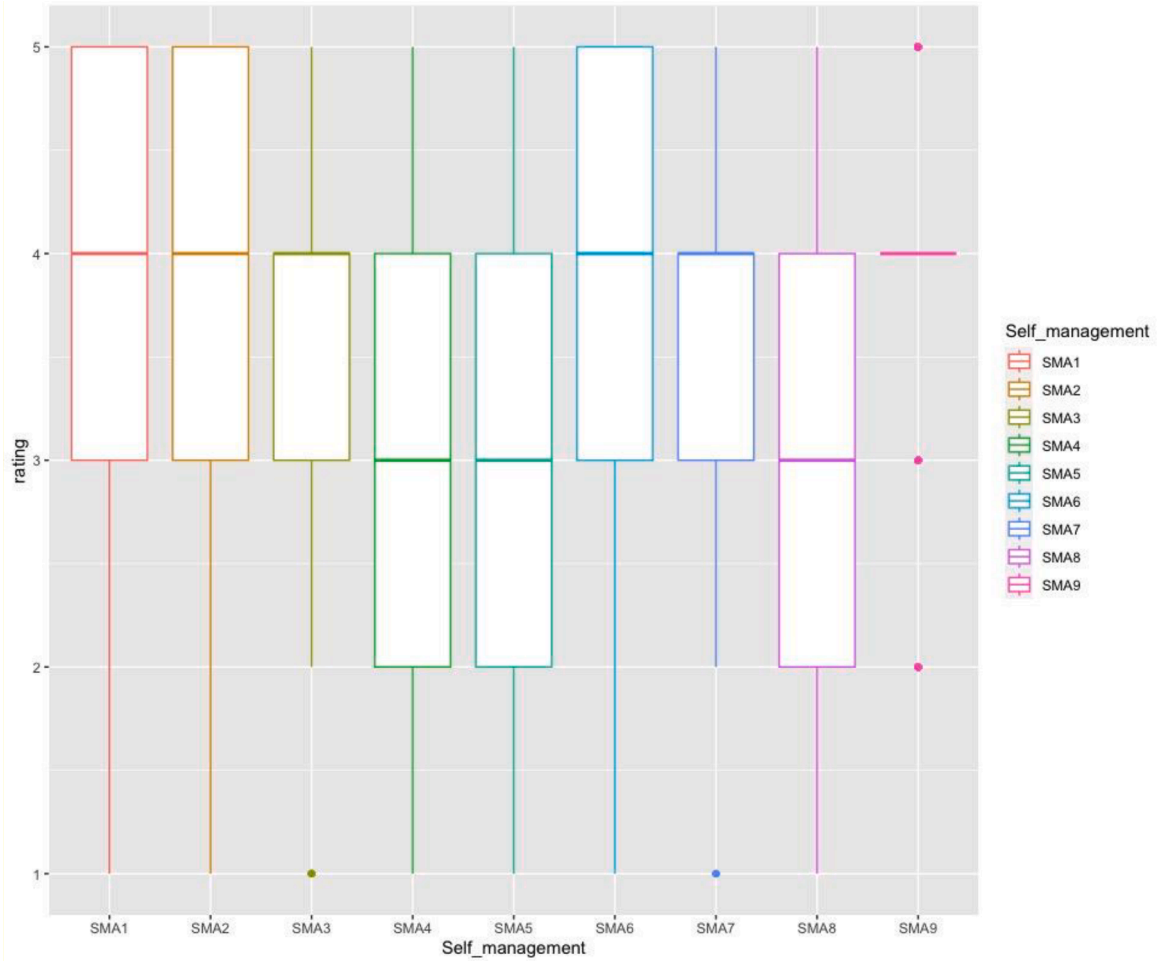

Fig. 3. The boxplot of the rating of self-management from CSE participants' responses. Note: SMA refers to Self-management. The SMA numbers in the figure correspond with number sequences in Table 4.

Mike, a mechanical engineering undergraduate student, used a different strategy. Instead of trying to figure out what the course instructors' emphasis was, he always focused on the lectures. He explained, "Well, I always focus on the lectures. These I find most important. You get the professor's insights along with the material. You get an emphasis on the material that's gonna be covered in exams and homework assignments." Similarly, Miral, an industrial engineering graduate student, focused mostly on the lectures, specifically to avoid confusion. She explained, " I mostly focus on the lecture part."

In addition, students had different strategies regarding textbook reading. Some relied on textbooks, while others seldom read textbooks and focused on notes from the instructor. James, a material science and engineering graduate student, realized that focusing on textbooks, in general, is helpful because textbooks are the original source. He explained,

Generally, textbooks are what help. I found (this) because that's what the professor is going off of, instead of trying to understand something from them [the instructors], which, you know, honestly is not always super clear. I just go to the source.

Although textbooks are assigned in most courses, some participants did not focus on them. Adib, a computer science undergraduate student, did not fully read the textbooks and resorted to summaries instead. He stated: "I try to read summaries. I don't actually read the book. So when it comes to it, I'll go to spark notes to find summaries of those things and learn that way."

4.3. RQ #3: how do CSE students stay motivated in online learning in higher education?

CSE students' motivation levels were slightly above medium, in general (see Table 5), but staying motivated in online courses was a challenge for most participants. Fig. 4 boxplots indicate students' response distribution. CSE students' online learning motivation can be categorized into extrinsic motivation and intrinsic motivation. Regarding intrinsic motivation, some participants were interested in the

Table 5
Students' motivation levels.

Items	Mean	SD
1. I want to learn new information through online courses pertaining to my major	3.72	1.14
2. I enjoy learning new information while taking online courses	3.76	1.12
3. I enjoy the challenges that may occur while taking online courses (e.g., analysis/application of concepts)	3.11	1.29
4. I do not enjoy studying for online courses	3.28	1.33
5. I critically evaluate information that I received while taking online courses	3.73	0.93
6. I would like to know the deep reasons behind the facts while taking online courses	3.62	1.01
7. I learn from the feedback provided by my peers while taking online courses	3.41	1.16
8. I learn from the feedback provided by my instructor while taking online courses	3.86	1.03
9. When presented with a problem I cannot resolve, I ask for assistance through different means while taking online courses	3.84	0.96

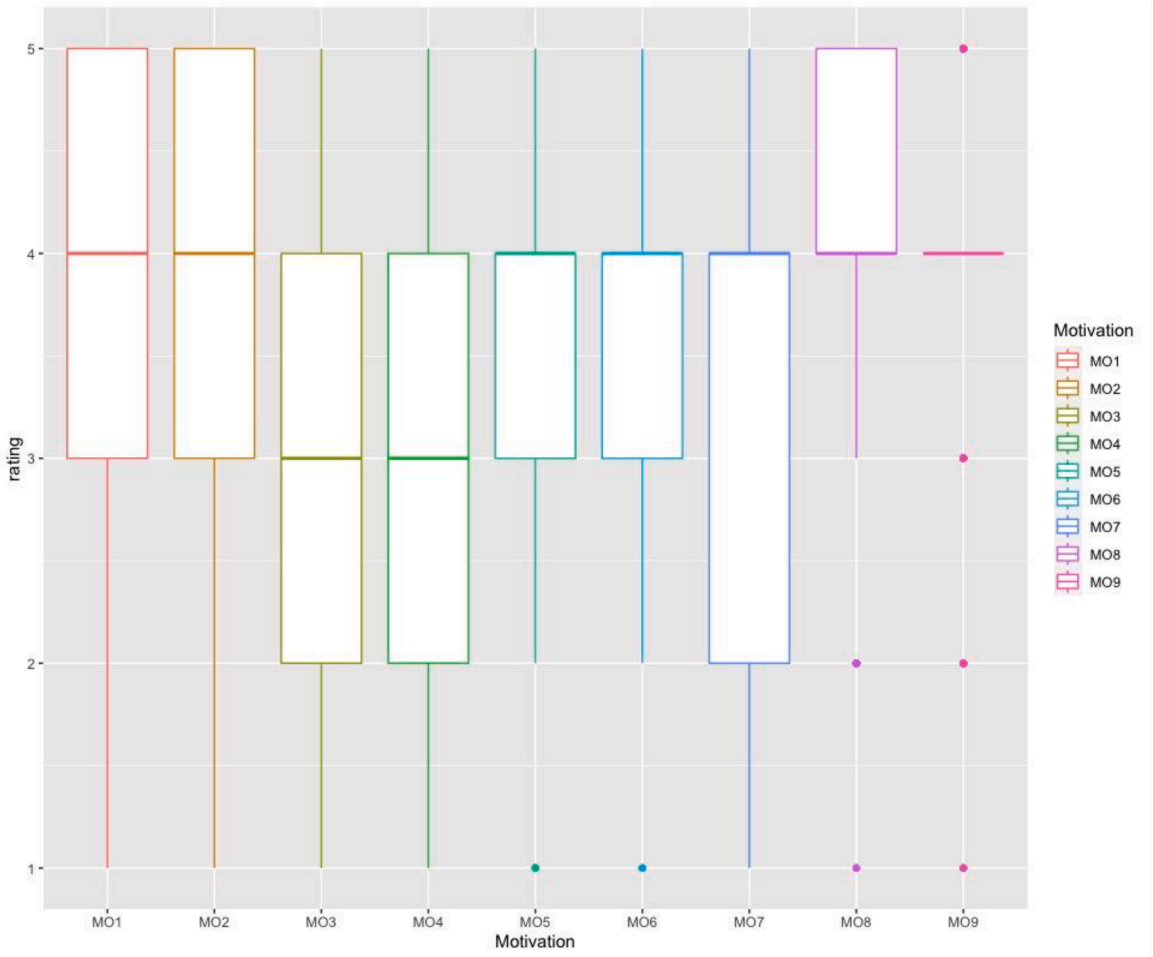

Fig. 4. The boxplot of the rating of motivation from CSE participants' responses. Note: MO refers to Motivation. MO numbers in the figure correspond with number sequences in Table 5.

courses or learning by nature. For example, Adam, a civil and environmental engineering undergraduate student, reported that intrinsic motivation was his main motive. He stated, "I think a lot of it has to come from within for the motivation, at least for me, given my position, right now, where I'm married, I have a house." James, a material science and engineering graduate student, considered motivation as more of a habit that occurs naturally. He said: "I've never really thought about it. It's just kind of one of those things where once you get into the habit of doing it, it's almost hard to stop."

The extrinsic motivations that kept participants motivated included setting goals (e.g., future education and career, high grades), building a learning routine, setting up a specific learning environment, and social interaction. Most participants discussed the importance of having learning goals, such as long-term goals for their future education and career and short-term goals for each day. Thinking of their current online courses as part of the big picture kept them going. They understood that succeeding in each course in the program was necessary for them to graduate and continue their education or start their careers. For example, Rania, a biomedical engineering graduate student, said that motivation was hard to maintain, but thinking about the end result helped her stay on track:

I look at the final product. Like, I want to get an A in this class, so I need to do this and this. I don't have time to slack. Also, because I've been doing a Ph.D. right now, I know what I need to do.

Similarly, Samia's future career was what drove her to keep going and not give up. She explained:

Knowing that this is what's going to shape my future, I've come to plan my education, where the classes I take are the things I'm going to be doing in the future, like programming and stuff. I have to be prepared for my job and future.

Short learning goals also play an important role in keeping students motivated. Mike, a mechanical engineering undergraduate student, admitted that staying motivated was challenging but found that creating small daily goals and achieving them gave him a sense of accomplishment. He said, "It's difficult, but identifying small goals to achieve throughout the week, whether it's completing a couple of assignments early…I really focus on one thing at a time."

Dana, an electrical engineering undergraduate student, created a routine and was dedicated to studying in a specific location to help avoid distractions. She stayed focused by establishing a study room that she only used for work. She also dedicated a specific time only for studying. She said, "I tried to keep it in my study room, so I only do school stuff in here. I do want to further my education, possibly getting a Master's and a Ph.D. degree to teach eventually."

Being connected with peers is another approach for students to stay motivated. Sophia, an undergraduate chemical engineering student, preferred to study with other students, and she did not allow the nature of online learning or the pandemic to stop her. She created a routine as part of a virtual study group on Zoom. The sense of belonging to a group kept her motivated and accountable. She explained,

> For me, it was still like a lot of collaboration. I had four or five other friends with that; we did everything together. If it was any assignment, homework, studying, like all of my schoolwork was done on Zoom with them. Even if it was something that we had to

independently write a separate paper, we would still just be on Zoom to motivate each other.

Miral, an industrial engineering graduate student, and Maira, an electrical engineering undergraduate student, also reported that staying connected with peers and friends helped them stay motivated. Although Miral did not form a study group like Sophia, she connected with others through discussion boards, texts, and phone calls. Elham also explained: "Actually, I try to be connected with students, for example, in Canvas we created a discussion group and also met through a WhatsApp group."

4.4. RQ #4: what elements in online courses support CSE students' SDL?

The nature of online learning sharpened the participants' critical learning skills, problem-solving, and adaptability. The specific design or instruction that the participants reported facilitated their SDL skills included (1) access to structured learning materials, (2) reminders sent from instructors, (3) instructors' availability, (4) group interaction, and (5) flexibility. For instance, Dana, an undergraduate electrical engineering student, said, "Professors posting lecture material ahead of time definitely helped because we were able to preview it—see what it was before coming to class. I think that was probably the biggest thing that helped." Similarly, Viraj and Rania, both computer science graduate students, explained that the prerecorded lectures made it possible for them to watch the lectures whenever they wanted and as many times as they needed until they grasped the content.

Along with accessible recorded lectures, the majority of the participants described the organization and structure of the LMS as being very beneficial in facilitating their SDL skills. Overall, the participants believed that the Winter 2021 semester was more structured than the previous semesters. Sophia thinks the professors were much more organized during online learning. They had everything posted online, followed a planned schedule, and had everything accessible. She liked how one of her asynchronous courses was very organized and had a weekly to-do list, and the discussion thread was helpful because it forced her to read the materials in order to write the discussion. Likewise, Omar, a biomedical engineering undergraduate student, expressed that the online courses had more structure and clear expectations compared to in-person courses. He explained, "every course I've taken has had modules. You knew exactly what we had to get done. And this is the timeline for when we have to get it done, which helped me stay focused."

Along with the structured weekly modules, Rania, a computer science graduate student, felt that the announcements and deadline reminders from the professors on the course LMS helped her stay on track and not miss out on assignments. She said, "I like that a lot. It kind of keeps you on the right track. I didn't have an assignment that popped up out of nowhere."

Another design that facilitated the learners' SDL was group interaction, such as incorporating breakout rooms during synchronous lectures. The breakout rooms gave the learners a chance to work together and communicate during class, which mimicked in-person learning. James, a material science and engineering graduate student, said, "I only had one class where they actually did that. I enjoyed it. I thought it was useful." Similarly, Rania enjoyed the breakout rooms, and that was how she made friends online. She said,

> People I have never met, I made friends with. We text all the time, like, "Hey, let's take this class together." [We made friends] mostly through breakout rooms on Zoom because, especially, the professor is not there. It's not very awkward, just like talking.

The flexibility of online learning was also among the features that some participants believed helped them become better self-directed. Ali, an electrical engineering undergraduate student, explained that having the freedom to construct his own schedule and work at his own pace helped him be more self-directed. He said, " There wasn't a big emphasis on specific due dates for the assignments. I would say that the design of the course makes me self-instructed just because I have to manage all my own due dates."

Tamar, a computer science undergraduate student, described having a self-paced course with no specific due dates for assignments, quizzes, or exams as the strongest factor that facilitated her SDL. She explained,

> It's a self-paced online course. So, there are no due dates for any of the assignments, quizzes, or exams. So, that is highly dependent on whether you're watching the videos and if you're taking notes on the slides. I've already been able to complete most of the quizzes. I'd be done with this class sooner than I expected because it's going at my pace.

4.5. RQ #5: what are CSE students' perceptions in terms of satisfaction and the advantages and disadvantages of online learning?

The survey results showed that the average satisfaction was 3.25 out of 5. Survey participants' satisfaction levels regarding the contributions of the courses to educational development and professional development were 3.41 and 3.28, respectively. Satisfaction with interaction among peers and interaction between instructor and students were 2.74 and 3.20, respectively.

4.5.1. Disadvantages

The participants' satisfaction with online learning varied. Some participants described online learning as unsatisfactory, some were indifferent, and some had a positive experience. The unsatisfactory experience was mostly due to the disadvantages of online learning, such as less effective learning, lack of hands-on activities, interaction, and engagement, distracting environment, and stress with lockdown browsers in tests. Ten of the 15 interview participants voiced their concerns over the quality of education in online learning. They believed that they would have learned more if the courses were in person. For instance, Omar, a biomedical engineering undergraduate student, felt like he did not learn as much in online courses, especially due to the lack of group projects and interactions. "I felt like I didn't learn as much. [It's] one of the biggest things, especially because hands-on group projects, it's very hard to do online."

Besides the quality of learning, the participants expressed their concern over the lack of interaction and engagement in online courses. Sophia, a chemical engineering undergraduate student, explained that the lack of social interaction made it difficult for her to meet new students, get to know the professors and connect with them. Adam, a civil and environmental engineering undergraduate student, also discussed how online learning can be isolating. "Normally, when you're in class, it's easier to talk to other people. It can be about class, social, or something else. [Online] you truly do get somehow isolated, even though you're in a big group together." Mike, a mechanical engineering undergraduate, explained that the disconnect from his instructors and peers online had an effect on his knowledge retention. He said, "I just certainly don't absorb as much as in person. It is difficult to make a personal connection with the professors that I need to learn from. It's hard to make connections with other students."

Sophia touched on the question-asking aspect of synchronous lectures, and many more participants reported having a problem with asking a question during synchronous and asynchronous lectures. In general, the nature of asynchronous lectures made it challenging for the learners to ask immediate questions or to get immediate answers from the instructor. Mark, a mechanical engineering undergraduate student, explained, "Prerecorded lectures are a bit more difficult to learn from and understand. It's the lack of ability to ask questions when there's confusion." When it comes to synchronous lectures, especially in larger classes, the participants did not feel comfortable raising their hands or posting questions in the chatbox. Miral, an industrial engineering graduate student, explained, "Sometimes, professors couldn't see the chatbox, or sometimes, I couldn't turn on my videos, but it is hard for

professors to follow all the students online. I have experienced professors missing some questions."

Omar, Ali, Sophia, and Adib's dissatisfaction was mostly due to the distracting nature of online learning and lack of engagement. Omar, an undergraduate biomedical engineering student, perceived it as a lack of focus:

> It is very hard to focus. When you're in person, you have eye-to-eye contact. You can actually see the person. I feel like it forces you to pay attention when you're sitting in a classroom, right, whereas if you're at home, there are a lot of other distractions. And it's like, I'll be sitting in bed, and I would fall asleep during class on accident or something like that.

The majority of the participants reported having problems taking tests online. The problems emerged from the stress that lockdown browsers imposed and from the quality of the test questions. Dana, an electrical engineering undergraduate student, did not like the lockdown browser during quizzes and exams. It added stress and pressure to her learning experience. She preferred when the professors opened Zoom during their tests because it imitated the traditional setting more. She explained, "I actually was not a fan of lockdown browser quizzes and exams."

The majority of the participants believed that the Winter 2021 semester was better and more organized than the semesters before. The professors were much more organized, followed an organized set schedule, posted everything online, and had everything accessible to the students. Another important point that the participants mentioned is that during the winter semester, the professors were more aware of the students' capabilities online. For example, Sophia, a chemical engineering undergraduate, described a scenario where she felt that her online learning experience improved after Winter 2020. She attributed the positive change to the professors gaining more experience with online learning. Previously, the professors only used PowerPoint presentations and presented them so quickly that the students could not keep up with the pace. She said,

> This semester, like the past semester, was fantastic. All professors, you know, I think they got the hang of it. The semester before was hard in the sense that a lot of professors were never used to writing on an iPad, or they would just come with a PowerPoint presentation, and it's like a lot of professors expected more out of us online. They thought we had more time. But it was more effective this semester. One professor just went through and wrote the entire lecture, and we would keep up with her speed because she was writing (Sophia, chemical engineering, undergraduate).

4.5.2. Advantages

Even though the participants voiced concerns regarding online learning, they also recognized the numerous advantages. Advantages included having more free time without commutes, documented and structured resources, flexibility, and the use of technology for teaching. Most participants explained that the greatest advantage of online learning was more free time. Not having to get ready to attend in-person classes and/or commute saved them considerable time. Samia, an information technology undergraduate student, also said, "Time, more time. More time was an advantage, So I had more time to be at home and manage. Like, I had all day for school and work." Elham, an industrial engineering graduate student, explained, "…because before I had some issue getting to campus, find a parking lot, parking space; now I can attend the courses at home."

Besides saving time, another primary advantage is that structured learning materials make online learning more self-directed and flexible. James, a material science and engineering graduate student, explained, "For me, the big advantage is that everything is documented, and I can go back and look at it. It's 100 % my responsibility." Dana, an electrical engineering undergraduate student, explained that having recorded lectures was the greatest advantage of taking online courses. Rania, a biomedical engineering graduate student, stated that the greatest advantage of online learning was being independent and not having to rely on others to get things done. She said, "For me, the advantages are that I can self-plan, and I have a lot more control over what I do and how I can organize everything." Similarly, Maira, an electrical engineering undergraduate student, said that having everything structured and accessible was the greatest advantage of online classes, "Online classes record your lectures, so most of the time, when you're in person, you won't be having those recorded lectures. So that is another advantage."

Another advantage of online learning was utilizing technology to make the experience more efficient and meaningful. Despite the physical distance between the learners, instructors can utilize technology to create a more interactive outlet for the learners. Adam, a civil and environmental engineering undergraduate student, explained, "I had one class where we had a group project, and we worked on Zoom with the breakout rooms, and honestly, it was one of the best teams I have worked on in my life."

5. Discussion

This sequential mixed-methods study examined CSE students' SDL strategies and instructional design elements that enhance their SDL and satisfaction with online courses. For this purpose, the researchers surveyed 225 students and conducted 15 semi-structured interviews with students in higher education who enrolled in online courses after the COVID-19 pandemic disrupted traditional face-to-face courses. This study explored how CSE students self-managed their learning, self-monitored their learning, and maintained motivation. The study also examined what elements in online courses were viewed as supportive of the learners' SDL as well as their general perceptions of satisfaction with online learning.

The data in this study revealed that the participants employed strategies based on extrinsic motivation (e.g., future career) and intrinsic motivation (e.g., interest in learning) during their online learning. This study confirms previous studies on the importance of motivation and its effect on how learners self-monitor and self-manage their online learning [46,47,82]. Most participants reported employing extrinsic motivation strategies to help them remain on track, especially when their intrinsic motivation was low. Therefore, online instructors and instructional designers could leverage strategies to enhance students' extrinsic motivation for learning, such as gamification [46], interactive activities, multimedia learning materials [58], clear grades, and future career development resources. Moreover, academic advisors could guide students regarding the value of courses for their future careers and educational goals. This guidance could serve to further motivate learners while they engage in online courses.

Second, this study found that participants used various self-management strategies to manage their learning. The resources they used also varied, mostly based on the course design and instructor. Typically, participants' time-management strategies were consistent. They often used a planner, calendar, or checklist to manage their study time. The findings align with prior studies [57]. Time management is related to situations when learners schedule and manage their study time [83,84]. Time-management is important for SDL [85] since low time-management skills may cause students to procrastinate [11,86] and lower learning outcomes [87]. Thus, online instructors can support learners' self-management skills [88] by suggesting the estimated amount of time needed to complete certain learning activities [84] and encouraging learners to set up study schedules [8]. Moreover, from the university level, general courses or training on time management could be offered to students to support their online learning.

Third, the course content and instructor's teaching methodology also had a strong effect on how the learners monitored their learning. Hence, their cognitive strategies were not always consistent and changed from one course to the other. Our findings also align with previous studies

regarding the strong influence of the learning design and how it impacts how learners approach their courses [89,90]. Moreover, the interviewees' primary meta-cognitive strategy to monitor learning was primarily through assignments, quizzes, and interaction with peers, instructors, and teaching assistants. Therefore, the design and delivery of online courses play critical roles in online learning. For example, online instructors could create assignments that encourage learners to self-monitor their learning. Moreover, online instructors could intentionally design peer interaction activities, such as peer assessments, peer feedback, or group projects, to foster self-monitoring of learning while reviewing peers' work.

Although this study showed that the CSE online learners employed high levels of SDL and did not allow their motivation to interfere with their learning, the way courses were structured had a strong impact on their learning process. Having structured and organized courses and access to learning resources was essential to help learners self-manage and self-monitor their learning, which supports the findings of the Authors [57]. Most of the participants said they appreciated having access to recorded lectures and suggested that all professors continue this trend even after going back to in-person learning. Overall, the participants noticed that when instructors had more experience with online teaching, the online learning experience was better. In addition, the participants mentioned that during the Winter 2021 semester, the professors were more aware of the students' capabilities and prior knowledge regarding online learning. The study findings align with previous studies showing that quality instructions are especially important in online learning settings [32,33] and that online instructions, requirements, and expectations are different from in-person learning settings [32,33,91]. It is worth noting that at the beginning of the pandemic, all courses were abruptly transitioned to emergency remote teaching. Significantly, emergency remote teaching differs from traditional online teaching, as it was not originally designed for learners to study online [92]. Over the course of a year, instructors have intentionally redesigned courses for online delivery. Our study reveals that the quality of courses in Winter 2021 significantly improved compared to the previous year. In a systematic review by the Authors [59], encompassing 191 studies on research topics in online learning during COVID-19, "online course design and development" emerged as one of the more critical subjects. Therefore, university administrators should offer professional development opportunities, such as courses, workshops, and webinars, to instructors to enhance their knowledge of instructional and learning experience design for online education.

Another important finding is that synchronous lectures are not always preferred by online learners, even though they are considered to be highly comparable to in-person lectures. For synchronous lectures to be perceived as necessary and worthy of the learners' time, they need to include engagement with the instructor, peers, and the content [93]. In this study, the participants did not prefer synchronous lectures over asynchronous lectures when the engagement level was low. The participants reported that most synchronous lectures involved one-way information transmission where the instructor did most of the talking, and there were no live discussions. The participants also explained that most of the students turned their cameras off, which did not make them feel comfortable asking questions or engaging with others. Turning the cameras off has been a challenge in distance learning and is mostly due to the learners not feeling comfortable showing their surroundings [94]. As self-directed learners, the participants preferred asynchronous lectures where they could watch the recordings at their own time and pace instead of sitting through a timed synchronous lecture that was not engaging. These findings align with previous studies on how the full benefits of online lectures cannot be obtained unless the instructors engage the learners and tailor the instructions based on the learners' needs [95]. Numerous studies have found that learner engagement and satisfaction in online learning environments are necessary for a successful learning experience and can determine the learning outcomes of the learners [50–56,72,73]. On the contrary, other researchers found that online learning satisfaction was not correlated to learning outcomes during the COVID-19 pandemic [96]. Therefore, it is critical to further examine instructional strategies to enhance learning outcomes.

6. Limitations

This study has several limitations. Firstly, the primary data collection methods revolved around self-reported information, encompassing surveys and semi-structured interviews conducted with CSE students. It is important to acknowledge that self-reported data might introduce potential biases. To enhance the robustness of future investigations, the inclusion of longitudinal observational data for triangulation purposes could prove beneficial. Secondly, the survey and interview data facilitated an exploration of students' perceptions regarding their SDL experience and satisfaction with online learning. However, this study did not delve into the examination of learning outcomes substantiated by SDL. Consequently, there is an avenue for future research to investigate the relationships between students' SDL practices and their learning achievements. Thirdly, the framework utilized in this study was adapted from Garrison's [41] SDL model, and the questionnaire instrument was constructed based on his framework and validated through the authors' [58] prior studies. Nevertheless, the nine items designed to measure motivation could be enhanced for a more comprehensive assessment of motivation in the future. Fourth, the study was conducted during the COVID-19 pandemic, given that student participants could not distinguish emergency remote teaching and traditional online learning, this study did not specifically distinguish the terms. The generation of the study findings should be cautious in traditional online educational settings. Lastly, it is noteworthy that the sample for this study was drawn exclusively from CSE students at a single Midwest university. As such, caution must be exercised when attempting to generalize the findings of this study to other contexts and settings. To establish more comprehensive insights, future research could encompass a larger and more diverse sample size, thereby extending and corroborating the findings of this study.

7. Conclusion

The purpose of this study was to examine CSE online learners' perceptions of SDL readiness, strategies, and satisfaction with online learning. The research findings provide recommendations for educators to facilitate learners' SDL strategies and increase learners' satisfaction with online learning in higher education. The study found that students leveraged diverse strategies for SDL. To stay motivated, students used both extrinsic motivation, such as deadlines, a study routine, a specific learning environment, and study groups, as well as intrinsic motivation, such as eagerness to learn. To manage time and resources, students used planners and calendars to keep them on track and set up their study schedules. This finding aligned with prior studies (i.e., [75]) that the flexible time required for online learning challenged students' SDL skills. Diverse cognitive and metacognitive strategies were used as well. Overall, participants' satisfaction with online learning depended on the specific design and delivery of the course. The findings provide insights for instructors on CSE students' perceptions of effective strategies so instructors can provide instruction and support for online SDL during and after the COVID-19 pandemic.

Declarations

Availability of data and materials

The datasets used and/or analyzed during the current study are not publicly available due to their personal and private nature but are available from the corresponding author on reasonable request.

Funding

No funding

CRediT authorship contribution statement

Meina Zhu: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – review & editing. **Sarah Berri:** Formal analysis, Writing – review & editing. **Yaoxian Huang:** Methodology, Writing – review & editing. **Sara Masoud:** Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Not applicable

References

[1] U.S. Bureau of Labor Statistics. Department of labor, occupational outlook handbook. U.S: Computer and Information Research Scientists; 2022. https://www.bls.gov/ooh/computer-and-information-technology/home.htm.
[2] Gardner L. Covid-19 Has Forced Higher Ed to Pivot to Online Learning. Here Are 7 Takeaways So Far. The Chronicle of Higher Education; 2020. https://proxy.lib.wayne.edu/login?url=https://www.proquest.com/trade-journals/covid-19-has-forced-higher-ed-pivot-online/docview/2639988149/se-2?accountid=14925.
[3] Kelly R. 4,000-Plus U.S. higher ed institutions impacted by COVID-19; more than 25 million students affected. Campus Technology; 2020. https://campustechnology.com/articles/2020/04/16/4000-plus-us-higher-ed-institutions-impacted-by-covid19-more-than-25-million-students-affected.aspx.
[4] Payne, C. (2022, February 2). Best Online Computer Science Programs of 2022. https://www.bestcolleges.com/computer-science/bachelors/.
[5] Park J, Choi HJ. Factors influencing adult learners' decision to drop out or persist in online learning. Educ Technol Soc 2009;12(4):207–17.
[6] Milligan C, Littlejohn A. Supporting professional learning in a massive open online course. Int RevRes Open Distance Learn 2014;15(5):197–213. https://doi.org/10.19173/irrodl.v15i5.1855.
[7] Yustina Y, Halim L, Mahadi I. The effect of 'fish diversity' book in Kampar district on the learning motivation and obstacles of Kampar high school students through online learning during the COVID-19 period. J Innov Educ Cult Res 2020;1(1):7–14. https://doi.org/10.46843/jiecr.v1i1.2.
[8] Wang CH, Shannon D, Ross M. Students' characteristics, self-regulated learning, technology self-efficacy, and course outcomes in online learning. Distance Educ 2013;34(3):302–23. https://doi.org/10.1080/01587919.2013.835779.
[9] Broadbent J. Comparing online and blended learner's self-regulated learning strategies and academic performance. Internet High Educ 2017;33:24–32. https://doi.org/10.1016/j.iheduc.2017.01.004.
[10] Broadbent J, Poon WL. Self-regulated learning strategies & academic achievement in online higher education learning environments: a systematic review. Internet High Educ 2015;27:1–13. https://doi.org/10.1016/j.iheduc.2015.04.007.
[11] Richardson M, Abraham C, Bond R. Psychological correlates of university students' academic performance: a systematic review and meta-analysis. Psycholog Bull 2012;138(2):353. https://doi.org/10.1037/a0026838.
[12] Geng S, Law KMY, Niu B. Investigating self-directed learning and technology readiness in blending learning environment. Int J Educ Technol Higher Educ 2019;16(1):1–22. https://doi.org/10.1186/s41239-019-0147-0.
[13] Chu RJ, Tsai C. Self-directed learning readiness, internet self-efficacy and preferences towards constructivist internet-based learning environments among higher-aged adults. J Comput Assisted Learn 2009;25(5):489–501. https://doi.org/10.1111/j.1365-2729.2009.00324.x.
[14] Hung M, Chou C, Chen C, Own Z. Learner readiness for online learning: scale development and student perceptions. Comput Educ 2010;55(3):1080–90. https://doi.org/10.1016/j.compedu.2010.05.004.
[15] Durnali M. The effect of self-directed learning on the relationship between self-leadership and online learning among university students in turkey. Tuning J Higher Educ 2020;8(1):129–65. https://doi.org/10.18543/tjhe-8(1)-2020pp129-165.
[16] Karatas K, Arpaci I. The role of self-directed learning, metacognition, and 21st century skills predicting the readiness for online learning. Contemp Educ Technol 2021;13(3):ep300. https://doi.org/10.30935/cedtech/10786.
[17] Wei H, Chou C. Online learning performance and satisfaction: do perceptions and readiness matter? Distance Educ 2020;41(1):48–69. https://doi.org/10.1080/01587919.2020.1724768.
[18] Banday MT, Ahmed M, Jan TR. Applications of e-learning in engineering education: a case study. Procedia Soc Behav Sci 2014;123:406–13. https://doi.org/10.1016/j.sbspro.2014.01.1439.
[19] Potkonjak V, Gardner M, Callaghan V, Mattila P, Guetl C, Petrović VM, Jovanović K. Virtual laboratories for education in science, technology, and engineering: a review. Comput Educ 2016;95:309–27. https://doi.org/10.1016/j.compedu.2016.02.002.
[20] Roy J. Engineering by the numbers. American society for engineering education. American Society for Engineering Education; 2019. p. 1–40.
[21] Alkhatib OJ. An interactive and blended learning model for engineering education. J Comput Educ 2018;5(1):19–48. https://doi.org/10.1007/s40692-018-0097-x.
[22] King CE, Trevino C, Biswas P. Online laboratory experiment learning module for biomedical engineering physiological laboratory courses. Biomed Eng Educ 2021;1(1):201–8. https://doi.org/10.1007/s43683-020-00034-9.
[23] Tricot A, Sweller J. Domain-specific knowledge and why teaching generic skills does not work. Educ Psychol Rev 2013;26(2):265–83. https://doi.org/10.1007/s10648-013-9243-1.
[24] Greiff S, Wüstenberg S, Csapó B, Demetriou A, Hautamäki J, Graesser AC, Martin R. Domain-general problem solving skills and education in the 21st century. Educ Res Rev 2014;13:74–83. https://doi.org/10.1016/j.edurev.2014.10.002.
[25] Chidambaram K, Mugundhan D, Rao MP. A glimpse of a stratagem for endorsing communication skills in the line of engineering for career excellence. Res J Adv Soc Sci 2020;1. https://royalliteglobal.com/rjass/article/view/260.
[26] Loji K. Toward teaching methods that develop learning and problem-solving skills in engineering students. South Afr J Higher Educ 2016;26(1):120–35. https://doi.org/10.20853/26-1-154.
[27] Daley J, Baruah B. Leadership skills development among engineering students in higher education - an analysis of the Russell group universities in the UK. Eur J Eng Educ 2021;46(4):528–56. https://doi.org/10.1080/03043797.2020.1832049.
[28] Valentine A, Belski I, Hamilton M. Developing creativity and problem-solving skills of engineering students: a comparison of web- and pen-and-paper-based approaches. Eur J Eng Educ 2017;42(6):1309–29. https://doi.org/10.1080/03043797.2017.1291584.
[29] Loyalka P, Liu OL, Li G, Chirikov I, Kardanova E, Gu L, Ling G, Yu N, Guo F, Ma L, Hu S, Johnson AS, Bhuradia A, Khanna S, Froumin I, Shi J, Choudhury PK, Beteille T, Marmolejo F, Tognatta N. Computer science skills across China, India, Russia, and the United States. Proc Natl Acad Sci - PNAS 2019;116(14):6732–6. https://doi.org/10.1073/pnas.1814646116.
[30] Nguyen DQ. The essential skills and attributes of an engineer: a comparative study of academics, industry personnel and engineering students. Glob J Eng Educ 1998;2(1):65–75.
[31] Ghazi-Saidi L, Criffield A, Kracl CL, McKelvey M, Obasi SN, Vu P. Moving from face-to-face to remote instruction in a higher education institution during a pandemic: multiple case studies. Int J Technol Educ Sci (IJTES) 2020;4(4):370–83. https://files.eric.ed.gov/fulltext/EJ1271208.pdf.
[32] Jensen SA. *In-class* versus *online video lectures: similar learning outcomes, but a preference for in-class*. SAGE Publications; 2011. https://doi.org/10.1177/0098628311421336.
[33] Martin F, Wang C, Sadaf A. Student perception of helpfulness of facilitation strategies that enhance instructor presence, connectedness, engagement and learning in online courses. Internet Higher Educ 2018;37:52–65. https://doi.org/10.1016/j.iheduc.2018.01.003.
[34] Vaughan ND, Cleveland-Innes M, Garrison DR. eBook Academic Collection - North America, & DOAB: Directory of Open Access Books. 2014. Teaching in blended learning environments: creating and sustaining communities of inquiry. AU Press; 2013.
[35] Knowles M. Self-directed learning. New York: Associations Press; 1975.
[36] Bandura A. Social foundations of thought and action: a social cognitive theory. Prentice-Hall; 1986.
[37] Martin J. Self-regulated learning, social cognitive theory, and agency. Educ Psychol 2004;39(2):135–45. https://doi.org/10.1207/s15326985ep3902_4.
[38] Schunk DH, Gunn TP. Self-efficacy and skill development: influence of task strategies and attributions. J Educ Res 1986;79(4):238–44. https://doi.org/10.1080/00220671.1986.10885684.
[39] Karatas K, Zeybek G. The role of the academic field in the relationship between self-directed learning and 21st century skills. Bull Educ Res 2020;42(2):33–52. https://files.eric.ed.gov/fulltext/EJ1281054.pdf.
[40] Morris NP, Swinnerton B, Coop T. Lecture recordings to support learning: a contested space between students and teachers. Comput Educ 2019;140:103604. https://doi.org/10.1016/j.compedu.2019.103604.
[41] Garrison DR. Self-directed learning: toward a comprehensive model. Adult Educ Q 1997;48(1):18–33. http://journals.sagepub.com/doi/pdf/10.1177/074171369704800103.
[42] Rohs M, Ganz M. MOOCs and the claim of education for all: a disillusion by empirical data. Int Rev Res Open Distance Learn 2015;16(6). https://doi.org/10.19173/irrodl.v16i6.2033.
[43] Abd-El-Fattah SM. Garrison's model of self-directed learning: preliminary validation and relationship to academic achievement. Span J Psychol 2010;13(2):586–96. https://doi.org/10.1017/S1138741600002262.
[44] Järvelä S, Hadwin AF. New frontiers: regulating learning in CSCL. Educ Psychol 2013;48(1):25–39. https://doi.org/10.1080/00461520.2012.748006.
[45] Chou P. The relationship between engineering students self-directed learning abilities and online learning performances: a pilot study. Contemp Issues Educ Res (Littleton) 2012;5(1):33. https://doi.org/10.19030/cier.v5i1.6784.
[46] Zhu M, Bonk CJ, Doo MY. Self-directed learning in MOOCs: exploring the relationships among motivation, self-monitoring, and self-management. Educ

Technol Res Dev 2020;68:2073–93. https://doi.org/10.1007/s11423-020-09747-8.
[47] Mynard J, Stevenson R. Promoting learner autonomy and self-directed learning: the evolution of a SALC curriculum. SiSAL J 2017:169–82. https://doi.org/10.37237/080209.
[48] Hagaman JL, Reid R. The effects of the paraphrasing strategy on the reading comprehension of middle school students at risk for failure in reading. Remedial Spec Educ 2008;29(4):222–34. https://doi.org/10.1177/0741932507311638.
[49] Wu H, Li S, Zheng J, Guo J. Medical students' motivation and academic performance: the mediating roles of self-efficacy and learning engagement. Med Educ Online 2020;25(1):1742964. https://doi.org/10.1080/10872981.2020.1742964.
[50] Alemayehu L, Chen H. The influence of motivation on learning engagement: the mediating role of learning self-efficacy and self-monitoring in online learning environments. Interact Learn Environ 2021:1–14. https://doi.org/10.1080/10494820.2021.1977962.
[51] Jung Y, Lee J. Learning engagement and persistence in massive open online courses (MOOCS). Comput Educ 2018;122:9–22. https://doi.org/10.1016/j.compedu.2018.02.013.
[52] Tsai Y, Lin C, Hong J, Tai K. The effects of metacognition on online learning interest and continuance to learn with MOOCs. Comput Educ 2018;121:18–29. https://doi.org/10.1016/j.compedu.2018.02.011.
[53] Zhang F, Zhao L, Zeng Y, Xu K, Wen X. A comparison of inquiry-oriented teaching and lecture-based approach in nursing ethics education. Nurse Educ Today 2019;79:86–91. https://doi.org/10.1016/j.nedt.2019.05.006.
[54] Rajabalee YB, Santally MI. Learner satisfaction, engagement and performances in an online module: implications for institutional e-learning policy. Educ Inf Technol 2021;26(3):2623–56. https://doi.org/10.1007/s10639-020-10375-1.
[55] Kent C, Laslo E, Rafaeli S. Interactivity in online discussions and learning outcomes. Comput Educ 2016;97:116–28. https://doi.org/10.1016/j.compedu.2016.03.002.
[56] Wei H, Peng H, Chou C. Can more interactivity improve learning achievement in an online course? effects of college students' perception and actual use of a course-management system on their learning achievement. Comput Educ 2015;83:10–21. https://doi.org/10.1016/j.compedu.2014.12.013.
[57] Zhu M, Bonk CJ. Designing MOOCs to facilitate participant self-monitoring for self-directed learning. Online Learn 2019;23(4):106–34. https://doi.org/10.24059/olj.v23i4.2037.
[58] Zhu M, Bonk CJ, Berri S. Fostering self-directed learning in MOOCs: motivation, learning strategies, and instruction. Online Learn 2022;26(1):153–73. https://doi.org/10.24059/olj.v26i1.2629.
[59] Doo MY, Zhu M, Bonk CJ. Influence of self-directed learning on learning outcomes in MOOCs: a meta-analysis. Dis Educ 2023;44(1):86–105. https://doi.org/10.1080/01587919.2022.2155618.
[60] Biner PM, Welsh KD, Barone NM, Summers M, Dean RS. The impact of remote-site group size on student satisfaction and relative performance in interactive telecourses. Am J Distance Educ 1997;11(1):23–33. https://doi.org/10.1080/08923649709526949.
[61] Chang SH, Smith RA. Effectiveness of personal interaction in a learner-centered paradigm distance education class based on student satisfaction. J Res Technol Educ 2008;40(4):407–26. https://doi.org/10.1080/15391523.2008.10782514.
[62] Liao PW, Hsieh JY. What influences Internet-based learning? Soc Behav Pers 2011;39(7):887–96. https://doi.org/10.2224/sbp.2011.39.7.887.
[63] Ali A, Ahmad I. Key factors for determining student satisfaction in distance learning courses: a study of allama iqbal open university. Contemp Educ Technol 2011;2(2):118. https://doi.org/10.30935/cedtech/6047.
[64] Yukselturk E, Yildirim Z. Investigation of interaction, online support, course structure and flexibility as the contributing factors to students' satisfaction in an online certificate program. Educ Technol Soc 2008;11(4):51–65. https://www.jstor.org/stable/10.2307/jeductechsoci.11.4.51.
[65] Bolliger DU. Key factors for determining student satisfaction in online courses. Int J E-learning 2004;3(1):61–7. https://www.learntechlib.org/primary/p/2226/.
[66] Eichelberger A, Ngo HTP. College students' perception of an online course in special education. Int J Educ Media Technol 2018;12(2):11–9. http://jaems.jp/contents/icomej/vol12-2/02_Eichelberger_Ngo.pdf.
[67] Paechter M, Maier B, Macher D. Students' expectations of, and experiences in e-learning: their relation to learning achievements and course satisfaction. Comput Educ 2010;54(1):222–9. https://doi.org/10.1016/j.compedu.2009.08.005.
[68] Sahin I, Shelley M. Considering students' perceptions: the distance education student satisfaction model. Educ Technol Soc 2008;11(3):216–23. https://www.jstor.org/stable/10.2307/jeductechsoci.11.3.216.
[69] Taskin N, Erzurumlu K. Investigation into online learning readiness of higher education students during COVID-19 pandemic. Malaysia Online J Educ Technol 2021;9(3):24.
[70] Yilmaz R. Exploring the role of e-learning readiness on student satisfaction and motivation in flipped classroom. Comput Human Behav 2017;70:251–60. https://doi.org/10.1016/j.chb.2016.12.085.
[71] Stokes, S.P. (2003). *Temperament, learning styles, and demographic predictors of college student satisfaction in a digital learning environment.*.
[72] Bawa P. Retention in online courses: exploring issues and Solutions—A literature review. Sage Open 2016;6(1):1–11. https://doi.org/10.1177/2158244015621777.
[73] Hu PJ-H, Hui W. Examining the role of learning engagement in technology-mediated learning and its effects on learning effectiveness and satisfaction. Decis Support Syst 2012;53(4):782–92. https://doi.org/10.1016/j.dss.2012.05.014.
[74] Palmer A, Koenig-Lewis N. The effects of pre-enrolment emotions and peer group interaction on students' satisfaction. J Mark Manage 2011;27(11–12):1208–31. https://doi.org/10.1080/0267257X.2011.614955.
[75] Sun JCY, Rueda R. Situational interest, computer self-efficacy and self-regulation: their impact on student engagement in distance education. Br J Educ Technol 2012;43(2):191–204. https://doi.org/10.1111/j.1467-8535.2010.01157.x.
[76] Creswell JW, Plano-Clark VL. Designing and conducting mixed methods research. 3rd ed. Thousand Oaks, CA: Sage; 2017.
[77] Fraenkel JR, Wallen NE. The nature of qualitative research. *How to design and evaluate research in education*. 7th ed. Boston: McGraw-Hill; 2009. p. 420.
[78] Guest G, Bunce A, Johnson L. How many interviews are enough? An experiment with data saturation and variability. Field methods 2006;18(1):59–82. https://doi.org/10.1177/1525822x05279903.
[79] Patton MQ. Two decades of developments in qualitative inquiry: a personal, experiential perspective. Qual Soc Work 2002;1(3):261–83. https://doi.org/10.1177/1473325002001003636.
[80] Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol 2006;3(2):77–101. https://doi.org/10.1191/1478088706qp063oa.
[81] Braun V, Clarke V, Rance N. How to use thematic analysis with interview data. In: Vossler A, Moller N, editors. The counselling & psychotherapy research handbook. London: Sage; 2014. p. 183–97.
[82] Pintrich PR. A motivational science perspective on the role of student motivation in learning and teaching contexts. J Educ Psychol 2003;95:667–86. https://doi.org/10.1037/0022-0663.95.4.667.
[83] Alario-Hoyos C, Estévez-Ayres I, Pérez-Sanagustín M, Delgado Kloos C, Fernández-Panadero C. Understanding learners' motivation and learning strategies in MOOCs. Int Rev Res Open Distrib Learn 2017;18(3):119–37. https://doi.org/10.19173/irrodl.v18i3.2996.
[84] Andrade MS, Bunker EL. A model for self-regulated distance language learning. Dis Educ 2009;30(1):47–61. https://doi.org/10.1080/01587910902845956.
[85] Hromalik CD, Koszalka TA. Self-regulation of the use of digital resources in an online language learning course improves learning outcomes. Dis Educ 2018;39(4):528–47. https://doi.org/10.1080/01587919.2018.1520044.
[86] Rabin LA, Fogel J, Nutter-Upham KE. Academic procrastination in college students: the role of self-reported executive function. J Clin Exper Neuropsychol 2011;33(3):344–57. https://doi.org/10.1080/13803395.2010.518597.
[87] Tuckman, B.W. (2005). Relations of academic procrastination, rationalizations, and performance in a web course with deadlines. Psychol Rep 96(3_suppl), 1015-1021. 10.2466/pr0.96.3c.1015-10.
[88] Seli H. Motivation and learning strategies for college success: A focus on self-regulated learning. Routledge 2019.
[89] Nguyen, Q., Huptych, M., & Rienties, B. (2018). Linking students' timing of engagement to learning design and academic performance. Paper presented at the 141–150. https://doi.org/10.1145/3170358.3170398.
[90] Rienties B, Toetenel L. The impact of learning design on student behavior, satisfaction, and performance: a cross-institutional comparison across 151 modules. Comput Human Behav 2016;60:333–41. https://doi.org/10.1016/j.chb.2016.02.074.
[91] Sun L, Tang Y, Zuo W. Coronavirus pushes education online. Nat Mater 2020;19(6):687. https://doi.org/10.1038/s41563-020-0678-8.
[92] Bond M, Bedenlier S, Marín VI, Händel M. Emergency remote teaching in higher education: mapping the first global online semester. Int J Educ Technol Higher Educ 2021;18(1):1–24. https://doi.org/10.1186/s41239-021-00282-x.
[93] Michael JA, Modell HI. Active learning in secondary and college science classrooms: a working model for helping the learner to learn. Lawrence Erlbaum Associates; 2003. https://elibrary.wayne.edu/record=b2884375~S47.
[94] Castelli FR, Sarvary MA. Why students do not turn on their video cameras during online classes and an equitable and inclusive plan to encourage them to do so. Ecol. Evol. 2021;11(8):3565–76. https://doi.org/10.1002/ece3.7123.
[95] Krüger JM, Vogel F, Schnaubert L. Synchronous online lectures in emergency remote teaching: the role of immersion, social scripts, and group awareness. In: International conference on computers in education, Proceedings. 23; 2020. p. 29–35. ICCE2020-Proceedings-Vol2-5.pdf (apsce.net).
[96] Dragomir VD, Dumitru M. Two years into the COVID-19 pandemic: an analysis of learning outcomes and student engagement at an economics university. J Account Educ 2023;65:100871. https://doi.org/10.1016/j.jaccedu.2023.100871.