Impact of information literacy, self-directed learning skills, and academic emotions on high school students' online learning engagement: A structural equation modeling analysis

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Abstract

The adoption of online learning for adolescent students accelerated with the outbreak of the COVID-19 pandemic. However, few studies have investigated the mechanisms influencing adolescent students' online learning engagement systematically and comprehensively. This study applied the Presage-Process-Product (3P) model of learning to investigate the direct effects of presage factors (i.e., information literacy and self-directed learning skills) and process factors (i.e., academic emotions) on high school students' online learning engagement; and the mediating role of process factors. Data from 1993 high school students in China (49.3% males and 50.7% females) were analyzed using structural equation modeling. The result showed that students' information literacy, self-directed learning skills, and positive academic emotions positively predicted their online learning engagement. Moreover, the positive impact of self-directed learning skills on students' online learning engagement was significantly and largely enhanced through the mediation effects of positive academic emotions ($\beta = 0.606$, 95% CI = [0.544, 0.674]). Based on these results, to enhance adolescent students' online learning engagement, it is important for school administrators, teachers, and parents to improve students' information literacy, self-directed learning skills, and positive academic emotions.

Keywords Online learning engagement · 3P model · Information literacy · Self-directed learning skills · Academic emotions

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1 Introduction

Online learning has received extensive attention and global prominence because it offers students a high level of flexibility to pursue education (Wong et al., 2021; Dumford & Miller, 2018). Many colleges and professional organizations have continued to offer online courses and online programs for college students and adults (Turk et al., 2022). Numerous studies have found that engagement is a key determinant of online learning achievement (Vayre & Vonthron, 2017; Dumford & Miller, 2018). Therefore, students' online learning engagement plays a pivotal role in online learning and has received considerable critical attention (Wang et al., 2022; Robinson & Hullinger, 2008). Online learning engagement refers to students' heightened attention, involvement, and participation in online learning activities toward a certain achievement goal (Fredricks et al., 2004; Linnenbrink-Garcia et al., 2011). There are four aspects of online learning engagement: behavioral, cognitive, affective, and social (Hoi & Le Hang, 2021). *Behavioral engagement* refers to students' disposition and conduct when approaching and undertaking online learning activities (Ben-Eliyahu et al., 2018; Archambault & Dupéré, 2017). *Cognitive engagement* reflects the level of students' psychological investment in online learning activities. *Affective engagement* refers to students' feelings, attitudes, interests, and perceptions when approaching online learning activities. *Social engagement* refers to students' interaction with teachers and peers for the purpose of co-constructing knowledge, including sharing ideas and collaborating on online learning tasks (Lu & Churchill, 2014). There is a growing body of literature that investigates the factors influencing students' online learning engagement (Zhao et al., 2021; Carroll et al., 2021; Wang et al., 2022; Richardson & Newby, 2006; Buelow et al., 2018; Yang et al., 2018). However, much of the research has focused on college students and adult learners rather than adolescent students. A systematic understanding of what and how key factors contribute to adolescents' online learning engagement is still needed (Borup, 2016; Yang et al., 2018).

The adoption of online learning for adolescent students accelerated with the outbreak of the COVID-19 pandemic; for many students, online learning became a full replacement for traditional face-to-face classroom instruction (Tay et al., 2021). For example, in China, 180 million primary and secondary school students engaged in online learning activities (e.g., attending online courses, participating in online discussions, and completing online homework) at home during the COVID-19 lockdown period (Ministry of Education of the People's Republic of China, 2020). The prolonged pandemic unexpectedly disrupted traditional teaching worldwide, leading to a full migration in learning methods and forcing the K-12 education system to become more flexible, resilient, and enriching (Yang et al., 2020b). While online learning offers unprecedented opportunities for adolescent students, it also creates several challenges (Tang et al., 2021), particularly concerning the level of engagement. For example, recent studies found that many students failed to actively engage in online learning activities during the COVID-19 lockdown period, leading to low learning achievement

(Yang et al., 2021; Zhao et al., 2021). Organization for Economic Co-operation and Development (OECD) (2020) also reported that nearly 70% of students in primary and secondary schools in 28 countries gained less knowledge through online learning during the COVID-19 lockdown period. Previous studies have suggested that engagement is an important indicator of online learning achievement (Jung & Lee, 2018; Dumford & Miller, 2018). In addition, learning engagement contributes to adolescent students' physical and mental health as well as their social development (Strayhorn, 2008). Failing to actively engage in online learning, adolescent students' social development has been seriously hindered during the COVID-19 lockdown period (Magson et al., 2021). Therefore, there is an urgent need to promote adolescent students' online learning engagement and identify its key influencing factors.

To fill the existing research gap, this study conducted a large-scale investigation among high school students who engaged in online learning during the COVID-19 lockdown period, and introduced the Presage-Process-Product (3P) model to explore the mechanisms influencing high school students' online learning engagement systematically and comprehensively. It is hoped that this study will contribute to a deeper understanding of adolescent students' online learning engagement, and help educators improve the effectiveness of online learning by targeting key factors that influence students' engagement in that environment.

2 Theoretical framework

2.1 The 3P model and research questions

Based on Dunkin and Biddle's (1974) model of teaching, Biggs (1993) proposed the 3P model to conceptualize the relationships among students, the teaching context, the learning process, and learning outcomes. The 3P model organizes the variables in a learning event into three categories: presage, process, and product. *Presage* mainly refers to the personal abilities that students have already possessed before they start learning, including prior knowledge and learning skills, such as students' information literacy (Guo et al., 2022; Hu et al., 2020). *Process* refers to how students approach learning and focuses on how students conduct the learning tasks, which results from the interaction among presage factors, including students' learning strategies and motivation (Li & Tsai, 2020). *Product* refers to students' learning outcomes, including the knowledge, skills, and expertise gained once a particular learning activity is complete (Lee & Lee, 2021b). In the 3P model, product factors are typically hypothesized as dependent variables, whereas presage factors affect product factors through both direct pathways and indirect pathways mediated by process factors (Lee et al., 2020).

The 3P model was originally designed to capture student learning in traditional learning environments (Biggs et al., 2001). More recently, the model has been widely applied to explain the complex learning process and to describe the predictive factors shaping learning outcomes in the context of online learning. For example, Ganotice and Chan (2019) found that students' achievement in computer-supported

interprofessional team-based learning (product) was influenced by their motivation, enjoyment, and perceived usefulness (process), which was determined by students' perceptions related to engaging in activities prior to learning (presage). Li and Tsai (2020) also introduced the 3P model in a study, finding that students' prior domain knowledge and web experience (presage) related to their patterns of accessing time in a text structure learning system (process). This eventually affected their learning performance (product).

To this end, this study examined high school students' online learning engagement as a product, by using their information literacy and self-directed learning skills as presage factors and both positive and negative academic emotions as process factors. The following two research questions guided this study:

RQ1. Which presage factors (i.e., students' information literacy and self-directed learning skills) and process factors (i.e., students' positive and negative academic emotions) predict the product factor (i.e., students' online learning engagement)?

RQ2. How do presage factors indirectly influence the product factor through the process factors?

2.2 Hypotheses development

2.2.1 Information literacy and online learning engagement

Information literacy is defined as the ability to recognize information needs and to identify, evaluate, and use information effectively to gain knowledge, solve problems, and make appropriate decisions in formal and informal learning environments (Bruce, 1997; Zhu et al., 2020a) proposed that students' information literacy mainly involves the following four dimensions: information awareness and attitude, information knowledge and skills, information thinking and behavior, and information society responsibility. Information awareness and attitude refer to students' sensitivity to information, awareness of using information, and information security awareness. Information knowledge and skills refer to students' understanding and mastery of information and communication technology (ICT) knowledge, and the use of common software or tools to complete digital tasks. Information thinking and behavior mainly refer to students' ability and tendency to use ICT to assist their critical and computational thinking, as well as students' behaviors and habits when using ICT. Information society responsibility refers to students' understanding and practice of information morality and ethics, and information management laws and regulations.

Many studies have found that students' information literacy can predict learning engagement (Avcı & Ergün, 2022; Bergdahl et al., 2020; Prior et al., 2016). For example, Fosnacht (2020) found that information literacy was positively and significantly correlated with student engagement in higher-order learning and reflective and integrative learning activities. Bergdahl et al. (2020) reported that stronger ICT skills were significantly associated with greater engagement in technology-enhanced

learning. Based on the discussion above, we set the following null and alternative hypotheses:

H01. Students' information literacy did not predict their online learning engagement.

Ha1. Students' information literacy significantly and positively predicted their online learning engagement.

2.2.2 Self-directed learning skills and online learning engagement

Having self-directed learning skills is defined as the ability to diagnose learning needs against given performance standards, formulate meaningful learning goals, monitor learning performance, and identify resources for accomplishing learning objectives (Garrison, 1997; Kicken et al., 2009). Findlater et al. (2012) found that self-directed learning skills improved students' motivation to engage in learning activities, leading to deeper learning and a better understanding of knowledge. Li et al. (2021) concluded that students with stronger self-directed learning skills tended to engage in more planning and monitoring activities in a goal-oriented active learning system. Based on the discussion above, we set the following null and alternative hypotheses:

H02. Students' self-directed learning skills did not predict their online learning engagement.

Ha2. Students' self-directed learning skills significantly and positively predicted their online learning engagement.

2.2.3 Academic emotions and online learning engagement

Academic emotions refer to emotions directly linked to learning activities, and are critically important for students' learning motivation, learning performance, and identity development (Pekrun et al., 2011). Generally, there are two types of academic emotions: positive academic emotions (e.g., enjoyment, hope, and pride) and negative academic emotions (e.g., anxiety, hopelessness, and boredom) (Bieleke et al., 2021; Dewaele & Li, 2021) found that students who experienced more enjoyment and less boredom in English class tended to engage in more classroom activities. Similarly, Kahu et al. (2015) reported that positive emotions of enjoyment and interest were central to affective engagement and were important predictors of behavioral and cognitive engagement; in contrast, the negative emotions of boredom, anxiety, and frustration inhibited students' learning engagement. Based on this discussion, we set the following null and alternative hypotheses:

H03. Students' positive academic emotions did not predict their online learning engagement.

Ha3. Students' positive academic emotions significantly and positively predicted their online learning engagement.

H04. Students' negative academic emotions did not predict their online learning engagement.

Ha4. Students' negative academic emotions significantly and negatively predicted their online learning engagement.

2.2.4 Information literacy and academic emotions

Previous studies found that information literacy was an important predictor of students' academic emotions (Lee & Lee, 2021a; Hamad et al., 2021; Blažič & Blažič, 2020). For example, Guo et al. (2015) found that information-literate individuals could effectively find, evaluate, seek, filter, and use information. This enhanced their motivation, confidence, and enjoyment of learning. Furthermore, Yang et al. (2020a) reported that students from less developed areas, with low levels of information literacy, generally showed negative perceptions of online learning during the COVID-19 pandemic. Likewise, Lee and Lee (2021a, b) found that the students who lacked the ability to use ICT experienced anxiety and boredom when dealing with learning tasks. Negative emotions appeared to be particularly strong in informal online learning settings. Based on this, we set the following null and alternative hypotheses:

H05. Students' information literacy did not predict their positive academic emotions.

Ha5. Students' information literacy significantly and positively predicted their positive academic emotions.

H06. Students' information literacy did not predict their negative academic emotions.

Ha6. Students' information literacy significantly and negatively predicted their negative academic emotions.

2.3 Self-directed learning skills and academic emotions

Many studies have found that self-directed learning skills are significantly related to students' academic emotions (Kara, 2022; Schweder, 2020; Zhoc & Chen, 2016). For example, Zhoc and Chen (2016) found that stronger self-directed learning skills led to more positive emotions (e.g., the traits of emotional stability and optimism) and fewer negative emotions (e.g., neuroticism and tension) when students addressed learning tasks. Kruk and Zawodniak (2018) found that encouraging students to take control over their own learning created a good opportunity for them to mitigate boredom in the classroom. Based on this, we set the following null and alternative hypotheses:

H07. Students' self-directed learning skills did not predict their positive academic emotions.

Ha7. Students' self-directed learning skills significantly and positively predicted their positive academic emotions.
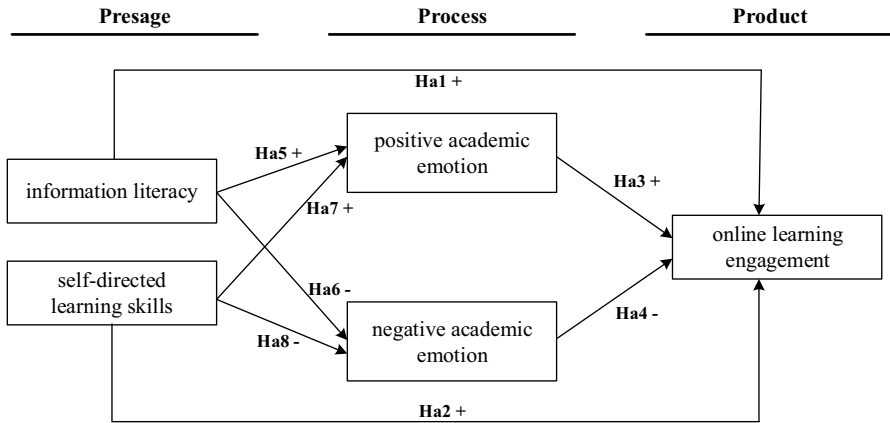
Fig. 1 Research model based on the 3P model

H08. Students' self-directed learning skills did not predict their negative academic emotions.

Ha8. Students' self-directed learning skills significantly and negatively predicted their negative academic emotions.

Based on the 3P model and the research hypotheses, Fig. 1 shows this study's research model.

3 Methods

3.1 Participants and data collection

The subjects participating in this study were 1993 tenth and eleventh-grade students from four high schools in Wuhan, China. Wuhan was the first city affected by the COVID-19 pandemic. During the COVID-19 pandemic lockdown period, all high school students in Wuhan could only study online at home, and they have been accustomed to online learning with rich experience. Therefore, this study selected high school students in Wuhan for research. Participants' ages ranged from 15 to 18 years, and they were all from urban areas. There were slightly more participants in the eleventh grade (59.2%) compared to the tenth grade (40.8%). Participants represented genders evenly, with 49.3% males and 50.7% females.

The data were collected in October 2021, when the COVID-19 pandemic has been in an ongoing stage of regular prevention and control in China. The survey used in this study was developed by our research team, which gathered standardized test questions about students' information literacy and self-reported information about students' self-directed learning skills, academic emotions, and online learning engagement. Before the surveys were directed, the selected schools granted permission to conduct this research. And the participants as well as their teachers

and parents were informed of the research objective and were promised that their information would only be used for educational research. All the responses were completed voluntarily and anonymously.

3.2 Instruments

3.2.1 Information literacy

Students' information literacy was measured using an online Student Information Literacy Test (Zhu et al., 2020a, b, 2021; Yu et al., 2021). This test included 52 multiple-choice items, assessing the following four dimensions of information literacy: Information Awareness and Attitude (15 items), Information Knowledge and Skills (13 items), Information Thinking and Behavior (12 items), and Information Society Responsibility (12 items). The test assessed scores out of 100; the grading weights of the four dimensions of information literacy were 29.5%, 17.0%, 28.9%, and 24.6%, respectively.

3.2.2 Self-directed learning skills

A self-directed learning skills scale was used to assess students' self-directed learning ability during home-based online learning; the scale had four items adopted from Hung et al. (2010). A representative item is: "I can carry out my learning plan before online learning." The Cronbach's alpha coefficient was 0.909 for this study's sample.

3.2.3 Academic emotions

An academic emotions scale was used to assess students' academic emotions during home-based online learning, which included a positive academic emotions subscale and a negative academic emotions subscale. The scale included 18 items (nine items for each subscale), adopted from Bieleke et al. (2021). A representative item from the positive academic emotions subscale is: "I enjoy the challenges of online learning." A representative item from the negative academic emotions subscale is: "Online learning is so boring that I find myself daydreaming." The Cronbach's alpha coefficient values for the positive academic emotions scale and the negative academic emotions scale were 0.959 and 0.925, respectively.

3.2.4 Online learning engagement

An online learning engagement scale was used to assess students' learning engagement during home-based online learning, which consisted of four subscales (behavioral, cognitive, affective, and social engagement subscale). There were 16 items (four items for each subscale), adopted from Hoi and Le Hang (2021). A representative item from the behavioral engagement subscale is: "I take notes when I participate in online discussions." A representative item from the cognitive engagement

subscale is: "I try to connect what I am learning online with what I learned before." A representative item from the affective engagement subscale is: "I feel comfortable participating in online discussions." A representative item from the social engagement subscale is: "I respond to other classmates' questions in online discussion boards." The Cronbach's alpha coefficient of the behavioral, cognitive, affective, and social engagement subscales were 0.913, 0.936, 0.937, and 0.927, respectively.

All the instruments used in this study have been confirmed to have good reliability and validity and were widely used by many researchers. And the items in the scales were evaluated on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

3.3 Data analysis

Confirmatory factor analysis (CFA) was conducted to assess the reliability and validity of the measurement model, and structural equation modeling (SEM) was conducted to evaluate the fit indices of the structural model using Amos 24.0. In general, to assess the goodness-of-fit indices in the two steps of SEM, the following indices have been used (Jackson et al., 2009; Byrne, 2010): chi-square (χ^2), degrees of freedom (*df*), the comparative fit index (CFI), the goodness of fit index (GFI), the adjusted GFI (AGFI), the Tucker-Lewis index (TLI), and the root mean square error of approximation (RMSEA). However, as a general statistical fact, as a sample size increases, the chi-square value also continues to increase, and therefore rejects any model (Hu & Bentler, 1999; Steiger, 2007). As such, the chi-square was not used to measure the model fit in this study, due to the large sample size of this study ($N = 1993$). For CFI, GFI, AGFI, and TLI, values greater than 0.90 indicate a good fit. The value below 0.08 for RMSEA indicates an acceptable fit. Moreover, we applied a bootstrapping approach to analyze the mediating role of students' academic emotions. A total of 5000 bootstrapping samples were used. The bootstrap estimates indicated a significant indirect effect if the 95% confidence interval (CI) did not include zero (Hayes, 2009).

4 Results

4.1 Assessment of measurement model

The measurement model was assessed using composite reliability (CR), convergence validity, and discriminant validity. Specifically, the convergence validity was measured using the average variance extracted (AVE). An initial examination of the factor loading of each observed variable found loadings of less than the recommended value of 0.5 (Peterson, 2000) for the following items: one item associated with the positive academic emotions variable, four items associated with the negative academic emotions variable, and eight items associated with the online learning engagement variable.

Table 1 The reliability and validity of the measurement model

Variables	factor loading	CR	AVE	discriminant validity			
				SDLS	PAE	NAE	OLE
SDLS	0.816–0.868	0.909	0.715	**0.846**			
PAE	0.782–0.894	0.954	0.722	0.786	**0.850**		
NAE	0.667–0.871	0.882	0.603	−0.066	−0.034	**0.777**	
OLE	0.775–0.868	0.946	0.686	0.692	0.811	−0.053	**0.828**

Note: SDLS = self-directed learning skills; PAE = positive academic emotions; NAE = negative academic emotions; OLE = online learning engagement; the diagonal values in bold represent the square roots of the AVE, and the non-diagonal values represent the correlations among the latent variables

Table 1 shows that after removing these items, all factor loadings of the variables exceeded 0.6, and the CR values of all constructs ranged from 0.882 to 0.954. These values all exceeded the recommended cut-off value 0.6 (Bagozzi & Yi, 1988), indicating satisfactory internal consistency. All AVE values were also greater than 0.6, meeting the recommended criteria of 0.5 (Fornell & Larcker, 1981). The square roots of the AVE of constructs were greater than the correlation coefficients of related constructs, indicating that the measurement model had adequate discriminant validity. The indices indicated that the measurements demonstrated a good model fit (CFI = 0.964, GFI = 0.927, AGFI = 0.912, TLI = 0.960, RMSEA = 0.054).

4.2 Assessment of structural model

Next, we performed SEM to assess the initial hypotheses about the relationships between variables (Fig. 1). The indices indicated that the proposed structural model fit the data well (CFI = 0.961, GFI = 0.926, AGFI = 0.912, TLI = 0.957, RMSEA = 0.049). Table 2 presents the results of the structural model.

Table 2 Results of the structural model

Paths	B	β	S.E.	P	R^2
IL→OLE	0.005	0.031	0.002	*	0.726
SDLS→OLE	0.093	0.099	0.029	**	
PAE→OLE	0.714	0.764	0.032	***	
NAE→OLE	-0.018	-0.017	0.016	0.246	
SDLS→PAE	0.849	0.844	0.021	***	0.713
IL→PAE	0.002	0.014	0.002	0.379	
IL→NAE	-0.019	-0.142	0.003	***	0.025
SDLS→NAE	-0.059	-0.068	0.021	**	

Note: $^*P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$; B = unstandardized path coefficient; β = standardized path coefficient; S.E. = standard error; IL = information literacy; SDLS = self-directed learning skills; PAE = positive academic emotions; NAE = negative academic emotions; OLE = online learning engagement
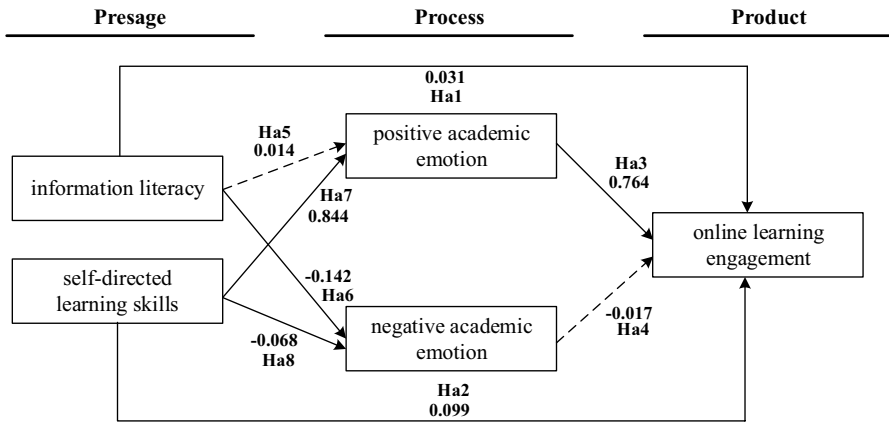
Fig. 2 The final structural model of relations. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

Specifically, information literacy ($\beta = 0.031$, $p < 0.05$), self-directed learning skills ($\beta = 0.099$, $p < 0.01$), and positive academic emotions ($\beta = 0.764$, $p < 0.001$) positively predicted online learning engagement (collectively accounting for 72.6% of R^2), rejecting H01, H02, and H03, and confirming Ha1, Ha2, and Ha3. In addition, self-directed learning skills ($\beta = 0.844$, $p < 0.001$) had significantly positive effects on positive academic emotions (accounting for 71.3% of R^2), rejecting H07, and confirming Ha7. Information literacy ($\beta = -0.142$, $p < 0.001$) and self-directed learning skills ($\beta = -0.068$, $p < 0.01$) negatively predicted negative academic emotions (collectively accounting for 2.5% of R^2), rejecting H06 and H08, and confirming Ha6 and Ha8. However, negative academic emotions did not negatively predict online learning engagement ($\beta = -0.017$, $p = 0.246$), confirming H04, and rejecting Ha4. Information literacy did not positively predict positive academic emotions ($\beta = 0.014$, $p = 0.379$), confirming H05, and rejecting Ha5. Figure 2 shows the final structural model with the relationships between factors.

4.3 Mediation analysis

Table 3 shows the mediating effects of students' positive and negative academic emotions.

The results confirm that positive academic emotions played a mediating role between self-directed learning skills and online learning engagement (95% CI = [0.544, 0.674], $p < 0.001$). The indirect effect of self-directed learning skills on online learning engagement accounted for 86.7% (0.607/0.700) of the total effect. This indicated that positive academic emotions act as partial mediators between self-directed learning skills and online learning engagement. However, the data did not find that negative academic emotions mediated the relationship between self-directed learning skills and online learning engagement (95% CI = [-0.001, 0.005], $p > 0.05$). Moreover, the indirect effects of information literacy on online learning engagement through positive academic emotions (95% CI = [-0.002, 0.005],

Table 3 Analysis of the indirect and total effects

	Mediation path	B	S.E.	95% CI		Account (Indirect/ Total)
				Lower	Upper	
IL→OLE						29.7%
Direct effect		0.0045	0.002	0.000	0.009	
Indirect effect	IL→PAE→OLE	0.0019	0.002	-0.002	0.005	
	IL→NAE→OLE	0.0000	0.000	0.000	0.001	
Total effect		0.0064	0.003	0.001	0.012	
SDLS→OLE						86.7%
Direct effect		0.093	0.035	0.026	0.163	
Indirect effect	SDLS→PAE→OLE	0.606	0.033	0.544	0.674	
	SDLS→NAE→OLE	0.001	0.001	-0.001	0.005	
Total effect		0.700	0.023	0.065	0.746	

Note: B = the strength of the effect; S.E. = standard error; IL = information literacy; SDLS = self-directed learning skills; PAE = positive academic emotions; NAE = negative academic emotions; OLE = online learning engagement

$p > 0.05$) and negative academic emotions (95% CI = [0.000, 0.001], $p > 0.05$) were not significant.

5 Discussion and conclusion

Using the 3P model, this study investigated the key influencing factors affecting high school students' online learning engagement, and the internal relationships of these factors in the context of online learning. The study found that students' information literacy, self-directed learning skills, and positive academic emotions positively predicted their online learning engagement, supporting RQ1. This finding aligns with previous research, which found that the same three factors played a supporting role for students in engaging in online learning activities (Bergdahl et al., 2020; Alemayehu & Chen, 2021; Dewaele & Li, 2021). Therefore, to enhance students' online learning engagement, educators should consider encouraging these three factors when designing, developing, implementing, and evaluating online learning activities.

Despite this finding, negative academic emotions did not negatively affect students' online learning engagement. This finding contrasts with previous studies, which found that negative emotions of boredom, anxiety, and frustration may inhibit college students' learning engagement (Kahu et al., 2015). This study's outcome may have resulted from the reality that all participants in this study were adolescent students, who have been forced to study at home during the COVID-19 lockdown (Sari, 2020). College students and adults can generally independently choose the time and place of online learning, and even stop online courses when they lose interest in learning. However, adolescent students experience online learning under the control of their teachers. While adolescent students may feel bored or frustrated

during the online learning process, they have to complete the learning tasks to achieve learning goals. In addition, the influencing mechanism of negative academic emotions is complex and does not always have a negative impact on learning. For instance, anxiety could prompt students to work harder and engage more in the current task to avoid failure, though it may lead to increased thinking unrelated to the learning task and distract students (Zaccoletti et al., 2020).

Students' positive academic emotions mediated the effect of their self-directed learning skills on online learning engagement ($\beta = 0.606$, 95% CI = [0.544, 0.674]), supporting RQ2. This result aligns with findings by Sadoughi and Hejazi (2021), who found the same mediating effect ($\beta = 0.327$, 95% CI = [0.367, 0.656]). Zhen et al. (2017) also reported that positive academic emotions could mediate the relations between both competence ($\beta = 0.026$, 95% CI = [0.001, 0.051]) and relatedness satisfaction ($\beta = 0.029$, 95% CI = [0.002, 0.055]) to learning engagement. The results above indicate that the indirect effect of self-directed learning skills on online learning engagement was significantly greater than its direct effect. This indicated that students' online learning engagement was largely augmented by enhancing their positive academic emotions when they already had sufficient self-directed learning skills. This finding might be explained by the fact that students' positive academic emotions represented a strong motivation and enthusiasm for learning, leading them to actively and deeply devote themselves to online learning activities, resulting in a higher level of online learning engagement (Dewaele & Li, 2021). This unique conclusion further highlights the significance of encouraging positive academic emotions when considering ways to improve students' online learning engagement.

Based on these findings, the following recommendations are proposed for school administrators, teachers, and parents, with the goal of increasing students' online learning engagement.

1. It is important to improve students' information literacy levels. Both schools and families should invest the effort to enhance students' information literacy. First, adequate ICT-enriched infrastructure and digital learning materials should be provided to students in schools, to increase their exposure to ICT and allow them to develop an awareness of applying ICT in daily learning and life (Ismaili, 2020). Second, teachers should consciously integrate ICT with teaching practices and develop students' awareness of using ICT to solve problems encountered in learning contexts (Zhu et al., 2019). Specifically, teachers could design ill-structured problems concerning the teaching content, provide students with diverse ICT-enriched resources and tools, stimulate students' multi-sensory experience, and guide them to utilize ICT to solve problems (Habeeb & Ebrahim, 2019). Third, parents should establish a positive attitude toward online learning, set up a physical learning space at home intended for learning, and encourage children to use the Internet to explore and solve problems boldly (Wu et al., 2020). At the same time, parents should monitor children's Internet usage and guide them to use the Internet responsibly.

2. It is also important to develop students' self-directed learning skills. First, teachers should create a harmonious and independent online learning atmosphere for students, so as to stimulate students' motivation to actively engage in learning

(Zhou et al., 2020). For example, teachers can set more open-ended questions in the teaching process and give students sufficient time to think independently and discuss freely and encourage students to generate different ideas or solutions. Second, teachers can optimize the design of homework and provide students with a variety of optional homework types, such as basic homework, practical homework, and exploratory homework (Akçayır & Akçayır, 2018). In this way, students can flexibly choose the homework according to their own preferences, and they can spontaneously devote more time and energy to completing the homework. Third, teachers and parents should take full advantage of their role as guardians of students' self-directed learning (Tay et al., 2021). Given adolescent students' minds are not mature enough, they are easily affected by the external environment during self-directed learning. In this regard, teachers and parents should pay close attention to students' independent learning status and communicate regularly with each other about the problems that students encountered, so that timely support and guidance can be given to students from the school and family.

3. Effective measures are needed to enhance students' positive academic emotions. First, teachers should optimize the teaching process and enhance students' interaction with teachers and peers, which could effectively improve students' positive academic emotions (Molinillo et al., 2018). For instance, teachers could set project-based learning tasks to encourage students to work in small groups to deeply discuss with each other, present learning outcomes, and conduct peer assessments. Moreover, in addition to increasing opportunities for students to answer questions in class, teachers could also provide individualized tutoring and instructional feedback to students after class. Second, teachers should evaluate students objectively and comprehensively in order to enhance students' self-efficacy, since positive self-perceptions are the motivation and source of positive academic emotions (Lackaye & Margalit, 2006). Specifically, on the one hand, teachers should not only focus on learning outcomes, but also on the learning process, and encourage students who perform well in learning activities; on the other hand, teachers could praise students' learning progress, especially those who are underachiever, thus enabling them to gain self-confidence and motivation to learn. Third, teachers should pay more attention to students who are underperforming in online learning, gain insight into why students are experiencing a variety of negative emotions, and then give timely and individualized instruction to them (Sadoughi & Hejazi, 2021).

To close, as with all studies, this study had some limitations. First, data about online learning engagement was collected using self-reported scales, possibly leading to subjective results. Future studies could attempt to collect fine-grained data (e.g., the frequencies of interaction and the text of forum discussion) that captures students' online learning engagement using online learning platform or tools. This would enable process-based data-driven analyses. Second, one study cannot capture all factors that may influence online learning engagement. Future studies should evaluate other presage factors, such as students' learning styles, and process factors, such as students' learning presence. Third, this study was conducted during the COVID-19 lockdown period in China. As such, the results

should be verified and assessed for generalizability in different cultures and situations.

The critical contribution of this investigation was identifying the mechanisms that influence high school students' online learning engagement, considering the whole learning process using the 3P model. Specifically, students' information literacy and self-directed learning skills in the presage stage, and their positive academic emotions in the process stage, positively predicted their online learning engagement. Enhancing students' positive academic emotions largely encouraged their online learning engagement when they already had sufficient self-directed learning skills. These findings provide insights for researchers, school administrators, teachers, and parents that may help improve students' online learning engagement.

Data availability Researchers may contact the corresponding authors for access to de-identified data.

Declarations

Conflict of interest The authors report no conflict of interest.

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