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Effective Deep Learning Requires a "Balance" between Need for Cognition, Flow Experience, and Positive Academic Emotions

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As deep learning emphasizes the development of higher-order thinking, criticality, and creativity, it has higher requirements for cognitive motivation (such as the need for cognition, NFC) and positive academic emotion investment, but excessive physiological and emotional arousal may reduce learning efficiency. Therefore, deep learning seems to require an optimal, balanced mind-body engagement (into a state of flow experience). However, there is a lack of empirical research on the interaction between NFC, positive academic emotion, flow experience and deep learning. To this end, 503 undergraduates and senior high school students were recruited to investigate the interrelationships among NFC, deep learning strategies, flow experience, and positive academic emotions with self-rating scales. Through the analysis of the mediation and moderation model, the results suggested that: 1) a substantial positive correlation exists between deep learning and NFC, flow experience and positive academic emotions; 2) flow experience exerts a significant mediating effect on the relationship between NFC and deep learning; 3) the moderating effect of positive academic emotion between NFC and deep learning is different from that between flow experience and deep learning. An excessively high NFC may attenuate the beneficial effect of positive academic emotions on deep learning, but an elevated level of positive academic emotion has a more facilitative association between flow experience and deep learning. These results imply that optimization of deep learning necessitates a considerable "balance" among NFC, flow experience, and positive academic emotions.

Key words: deep learning, NFC, flow experience, positive academic emotion

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Introduction

Deep learning is described as a higher learning journey where people tend to understand deeply and reveal links between various seemingly unrelated bits of knowledge. It has a wide definitional span, including "soft" concepts, such as intrinsic motivation and meaning-making (Kovač et al., 2023). Many studies have suggested that deep learning can substantially forecast academic success, problem-solving capabilities, and innovative thinking (Dolmans et al., 2016). As a promising learning paradigm, the process of deep learning has higher requirements for cognitive motivation and positive academic emotion investment (Chen & Li, 2024; Zheng, 2019), which is supported by constructivist and cognitivist learning theories, as well as some empirical research.

Constructivism holds that people actively construct or develop their knowledge and that reality is determined by the experiences of the learners (Elliott et al., 2000). Meanwhile, cognitivism theory puts forward the idea that learners actively engage in the learning experience through cognitive processes, and asserts that learners play an active role in information processing to develop areas such as knowledge, memory, thinking, and problem-solving (Garnham, 2019). This promotes deeper learning and understanding because deep learning as a learning strategy includes several aspects of meaning construction (Kovač et al., 2023). Some empirical studies indicate positive academic emotions and the need for cognition (NFC) – a stable individual difference in people's tendency to engage in and enjoy effortful cognitive activity – positive associations with students' motivational levels, and scholastic success (Kiuru et al., 2020; Özhan & Kocadere, 2020). However, the relationship between learning outcome, learning motivation and academic emotion is not simply linear. Students' academic achievement requires coordination and interaction between different aspects of motivation (Amrai et al., 2011). Perhaps an optimal state known as flow experience is more conducive to deep learning. However, to the authors' knowledge, there is little empirical research regarding the interactive relationship of NFC, positive academic emotion, and flow experience in deep learning. Consequently, this study aims to investigate the interaction effect between NFC, flow experiences, and positive academic emotions about deep learning.

NFC and Deep Learning

NFC is a psychological construct that refers to an individual's desire for, and enjoyment of, intellectually engaging activities. A substantial amount of research has shed light on how NFC is associated with numerous positive outcomes, such as learning and academic success (Cacioppo & Petty, 1982; Jebb et al., 2016), information processing and personality variables (Fleischhauer et al., 2014; Mussel, 2013), as well as cognitive engagement and creative behavior (He et al., 2019; Kramer et al., 2021). All these studies implied NFC is likely to have a potential positive effect on deep learning.

On the one hand, studies have shown that people with high NFC can actively search and process information. Individuals with higher NFC tend to employ the fine processing mode in problem-solving scenarios (Cacioppo & Petty, 1982) and tend to mobilize more involuntary attention and cognitive resources for cognitive activities (Engeser & Rheinberg, 2008), actively search for relevant information, and generate task-related responses. Conversely, individuals with a lower NFC may prefer peripheral processing strategies, eschewing cognitive effort and depending more heavily on the information itself (Curşeu, 2011). Even in group learning, individuals with high NFC tend to show a stronger pattern of information exchange (Kearney et al., 2009). On the other hand, studies have shown that NFC levels were associated with increase in action orientation and thereby showing rather flexible responses to situations (Grass et al., 2019). Individuals with a low NFC are susceptible to influence by salient external cues of achievement (Dickhäuser et al., 2009). Conversely, individuals with high NFC are willing to accept challenges and show more commitment (Weissgerber et al., 2018).

Given the nature of deep learning, it seems that NFC may be an especially important factor and prerequisite of this learning type. In particular, deep learning is characterized as the ability to take what was learned in one situation and apply it to new situations (Council, 2012). At its heart is a set of competencies students must master to develop a keen understanding of academic content and apply their knowledge to problems in the classroom and on the job (Foundation, W. a F. H., 2013). Deep learning, as a meaningful learning activity based on deep and flexible understanding involves knowing how the concepts are currently viewed in the domain, requires keeping up with new knowledge, and entails knowing why something is a certain way, and what purposes it serves (Grotzer, 2020). Therefore, it is bound to have higher requirements for learners' information processing ability and ability to resist temptation and interference. The stronger the learner's intrinsic NFC for learning and the more cognitive effort the individual is willing to make in challenging deep learning tasks, the more it can promote the individual to resist temptation and interference and carry out active and deep cognitive processing, to better complete the deep learning task. Studies have also shown that NFC is directly and positively correlated with cognitive strategies, which further has a positive impact on second language achievement (Mcintosh & Noels, 2004) and creative learning achievement since the higher NFC correlates with the more flexible brain networks (He et al., 2019). Consequently, we hypothesize that NFC as a critical cognitive motivational variable has a positive association with deep learning (H1).

The Mediating Role of Flow Experience

Since Csíkszentmihályi (1975) proposed the concept of flow, hundreds of empirical studies have been conducted from a diversity of fields including educational psychology. Despite the lack of a standard definition of flow (Abuhamdeh, 2020), flow is viewed as a positively-valenced state, resulting from an activity that has been appraised as an optimal challenge, characterized by optimized physiological activation for full concentration on coping with environmental/task demands (Peifer & Tan, 2021). According to Csikszentmihalyi's flow theory, certain conditions must be met for a flow experience to manifest, including at least three antecedent factors: well-defined goals, a balance between skills and challenges, and prompt feedback; along with three cognitive factors: the merging of action and awareness, focused attention, and robust self-regulation (Nakamura & Csikszentmihalyi, 2014). If viewed from the learning or problem-solving process, these processes or factors involve the use of good learning strategies, self-regulation strategies. For example, clear specific action goals and immediate feedback are good problem-solving strategies. Balance between skills and challenges and high concentration all require good self-regulation strategies to keep individuals focused and fluent. According to the body of previous research on NFC, this is the "advantage" of people with high NFC, which made them have higher self-efficacy (Chen et al., 2023) and self-control ability (Grass et al., 2019), and be able to make cognitive efforts and devote themselves to tasks. This indicates that experiencing flow necessitates a significant level of NFC.

In addition, the experience of flow as a "deeply engaging state" has a significant predictive effect on creative behaviors (Kong & Lin, 2022). Flow experience can not only significantly affect individuals' willingness to continue learning, make learners willing to re-engage in learning and form stable learning motivation (Wei et al., 2017), but it can also improve individuals' learning understanding and task performance, such as showing better performance in the test of mathematical comprehension ability (Sedig, 2007). Therefore, we hypothesize that a focused and immersive flow experience exerts a positive mediating effect between NFC and deep learning (H2).

The Moderating Effect of Positive Academic Emotion

Although flow experience shares similarities with positive emotions, it specifically emphasizes immersion in cognitive and practical tasks, which is a qualitative distinction from positive emotions. Flow experience, being immersive, may not yield positive emotions throughout the entire duration of an activity (Abuhamdeh & Csikszentmihalyi, 2012), whereas positive academic emotion refers to the beneficial emotional response elicited within a particular educational context. The emphasis is on the emotional experiences and sentiments of the learners. Positive academic emotions may be more effective at improving certain aspects of learning effects, especially in high school and college students. In educational settings, positive academic emotions are considered to be a key factor affecting learning (Pekrun et al., 2002), and a lot of studies have shown that positive academic emotions may be more effective at improving certain aspects of learning effects, especially in high school and college students (Tan et al., 2021). Meanwhile, research has shown how academic emotions are related to achievement and to cognitive/motivational variables that promote achievement (Villavicencio & Bernardo, 2013).

There is a body of studies which investigated the relationship among cognitional factors (e.g., cognitional flexibility), academic emotions, and learning outcomes. Some studies indicated a positive association between cognitional factors and academic emotions (Pekrun et al., 2002). Ouano (2011) also found that intrinsic motivation was positively related to positive academic emotions. According to the broaden-and-build theory of positive emotions, positive emotions can effectively integrate individual internal and external resources such as attention, openness to thinking, mental toughness, and other positive qualities (Fredrickson et al., 2008). Students who experienced positive emotions were more likely to pay more attention and think more actively in positive emotional states (Fredrickson & Branigan, 2005), and use different types of cognitive and metacognitive strategies (King & Areepattamannil, 2014), thereby enhancing learning outcomes.

However, some studies also suggest that NFC and positive academic emotions may have an interaction effect on learning outcomes (Liu & Nesbit, 2023; Tan et al., 2021). Some experiment-based studies have found low NFC individuals display larger increases in cognitive effort in response to monetary reward incentives than high NFC individuals (Sandra & Otto, 2018). In contrast, for individuals with high NFC, reward incentives increased task effort at high loads, but decreased task effort at lower loads (Zhang et al., 2022). In addition, according to the inverse U hypothesis of Yerkes and Dodson, excessive arousal may reduce the learning effect (Yerkes & Dodson, 1908). Therefore, we hypothesize that positive academic emotions may have a

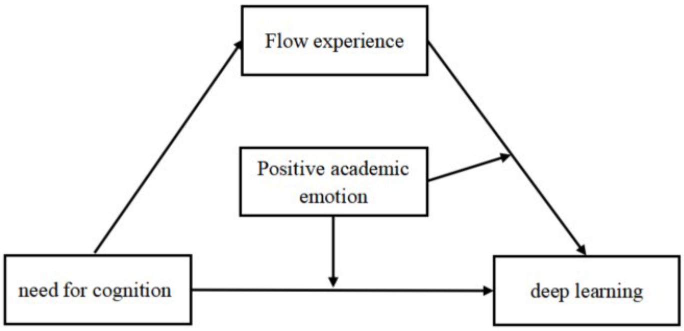


Figure 1 Diagram of the mediated model

greater effect on learning promotion with low NFC than with high NFC in the absence of rewards (H3).

On the other hand, positive academic emotions may have different regulatory effects between flow and deep learning. Flow as an optimized experience is the result of synchronization between attentional and reward networks that occurs when the challenge of a situation is balanced with the skill of the person experiencing the situation (Weber et al., 2009). However, NFC may have higher requirements for attention resources, where flow is a state of effortless attention that allows a person to meet an increase in demand with a sustained level of efficacy but without an increase in felt effort (Bruya, 2010). Some studies suggested that positive emotions can improve the psychological function of flow experience through individual psychological resilience (Chen & Padilla, 2022; Kiuru et al., 2020), such as improving learners' attention, memory, and executive function (Li et al., 2020; Yüvrük et al., 2020), as well as facilitating individuals to seek the next level of thinking and skills to meet a new challenge (Dawoud et al., 2015). Thus, we hypothesize that positive academic emotion has a moderate effect on flow and deep learning (H4).

In summary, this study proposes the theoretical hypothesis that interconnections exist among NFC, flow experience, positive academic emotion, and deep learning, as depicted in Figure 1.

Methods

Participants

A total of 550 students from four universities (one technical university and three comprehensive universities) and two common senior high schools in Chongqing China were recruited as participants through a convenience sampling method for a paper-based questionnaire survey[1]. After eliminating questionnaires with no response, incomplete answers, and patterned responses, a total of 503 valid questionnaires were collected. Of these, 175 (34.8%) were male, and 328 (65.2%) were female. The sample included 221 (43.9%) senior high school students and 282 (56.1%) university students. The percentage of freshmen, sophomores, and juniors in high school was 22.1%, 11.1%, and 10.7%. The percentage of freshmen, sophomores, juniors, and seniors

[1] In China, the majority of high school students are between 15 and 18 years old, and college undergraduates are between 19 and 23 years old.

was 5.6%, 32.6%, 13.5%, and 4.4%. All participants received an informed consent to sign. The study was approved by the academic Ethics committee of the first author's institution. Data can be available from the following address: https://osf.io/x8ywf/.

Measures

Deep Learning Scale

Deep learning was measured by the Deep Learning Scale developed by Li et al. (2018). Deep learning was viewed as a series of complex information processing processes that start from motivation control, such as deep understanding, information integration, reflection and criticism, and transfer and application, and finally achieve the improvement of higher-order thinking, problem-solving, transfer, and application (Li et al., 2018; Zheng, 2019). The construction of the dimensions of deep learning and the compilation of items are based on the student's learning skills in the 21st century (Fadel & Trilling, 2009), the "5C" competence framework (Bellanca, 2010), and the 3P deep learning process evaluation model (Biggs, 1987; Kember et al., 2020). The compilation of items refers to items in existing scales, such as the National Survey of Student Engagement (NSSE) (Kuh, 2009), and the Learning Motivation scale (Zhu et al., 2005). This scale comprises 36 items, encompassing four dimensions: deep learning motivation, deep learning engagement, deep learning strategy, and deep learning outcome. The deep learning motivation dimension consists of 4 items (e.g., "studying a problem excites me as much as reading/watching a good novel/movie"). The learning engagement dimension consists of 6 items (e.g., "I will devote a lot of time to study and academic activities"). The learning strategy dimension includes 15 items (e.g., "Connect the new knowledge learned in class and online with the previous knowledge"). The learning outcome dimension consists of 11 items (e.g., ability to think critically). A 5-point Likert scale was used, ranging from 1 *(completely disagree*) to 5 (*completely agree*) – the higher the total score, the higher the degree of deep learning. Employing the unweighted least squares method as suggested by Morata-Ramirez et al. (2015), AMOS 26 was utilized to evaluate the scale's structure. According to the author guidelines for reporting scale development and validation results (Cabrera-Nguyen, 2010; Toplu Yaşlıoğlu & Yaslioglu, 2020), the results indicated the four-factor model has a good fit: $\chi^2(588) = 3200.666$, $p < 0.001$, $GFI = 0.957$, $AGFI = 0.951$, *Cronbach's* $\alpha = 0.93$.

NFC Scale

NFC Scale was developed by Cacioppo and Petty (1982), and was used to measure the tendency to engage in and enjoy thinking as a stable individual difference. The Chinese version was revised by Kuang et al. (2005), and was composed of 17 items (e.g., "I prefer complex questions to simple ones"). Eight items are scored positively and 9 items are scored in reverse. The Chinese version of NFC scale adopts the 7-point Likert scoring method, with 1 representing *completely inconsistent* and 7 representing *completely consistent*. The higher the total score, the higher the cognitive demand tendency of the individual. Both exploratory and confirmatory factor analyses indicated that the Chinese version of NFC scale has sound psychometric properties for the Chinese undergraduate population (Kuang et al., 2005). The Cronbach's α in the current study is 0.867.

Flow Scale

Flow was measured with the Flow Short Scale (FSS) (Rheinberg et al., 2007). The FSS can measure the flow state in different contexts such as computer games or experimental settings and under everyday conditions (work, learning situations, sports, leisure time). The FSS consists of a total of 16 items. Items 1-10 assess components of the flow experience. The first 10 flow items (e.g., "My mind is completely clear") can be used alone as a pure flow measure. These 10 items are subdivided into two subscales: Fluency and Absorption. These items are to be answered on a seven-point Likert scale from "strongly disagree" to "strongly agree. This study uses the first 10 flow items to measure the flow experience. The Flow Short Scale was validated and successfully used in various applications ranging from experimental and correlational studies (Schüler, 2007). Using the unweighted least square method recommended by Morata-Ramirez et al. (2015), AMOS 26 was used to test the structure of the scale. The results showed that the one-factor model has a good fit: $\chi^2(34) = 325.199$, $p < 0.001$, $GFI = 0.986$, $AGFI = 0.977$, Cronbach's $\alpha = 0.879$.

Positive Academic Emotion Scale

Positive academic emotion was measured using the Chinese Adolescent Academic Emotion Scale developed by Yan and Guoliang (2007). According to the circumplex structure theory of emotion (Barrett & Russell, 1999) and the Academic Emotions Questionnaire (Pekrun et al., 2002), Yan and Guoliang (2007) developed an Academic Emotions Questionnaire in the Chinese context. The Chinese Academic Emotion Scale is composed of four factors, including positive-high arousal emotions (pride, enjoyment, and hope), positive-low arousal emotions (contentment, calmness, and relaxation), negative-high arousal emotions (anxiety, shame, and anger) and negative-low arousal emotions (boredom, hopelessness, depression, and fatigue). Since more than 80 percent of the students reported positive emotions such as enjoyment, pride, and relaxation in Yan and Guoliang's (2007) investigation, then enjoyment in 5 items (e.g., "Study brings me a lot of happiness"), pride in 5 items (e.g., "I am proud of my good academic record"), and relaxation in 6 items (e.g., "I feel relaxed when I do my homework") were selected in this study to measure positive academic emotions, totaling 16 items. Likert's 5-point scale was adopted, ranging from 1 *completely disagreeing* to 5 *completely agreeing*. The higher the total score, the higher the individual's positive academic emotion. Using the unweighted least square method recommended by Morata-Ramirez et al. (2015), AMOS 26 was used to test the structure of the scale. According to the author's guidelines for reporting scale development and validation results (Cabrera-Nguyen, 2010), the results showed that the three-factor model has a good fit: $\chi^2(101) = 620.781$, $p < 0.001$, $GFI = 0.911$, $AGFI = 0.881$, $RMR = 0.095$, Cronbach's $\alpha = 0.853$.

Research Process and Data Processing

Participants were enlisted from a mental health elective course and requested to complete the questionnaire. Following the completion of the questionnaire, participants received a small token of appreciation (some candy and nuts) to enhance their participation willingness. Collected questionnaires were entered into a database, and data analysis was conducted using SPSS 22.0 and AMOS 26.

Result Analysis

Common Method Bias

In this study, SPSS 22.0 was utilized to perform Harman's single-factor test for common method bias (Hao & Li-rong, 2004), and a total of 18 factors with eigenvalues greater than 1 were extracted. The variance explained by the first factor was 22.90% (less than 40%), suggesting that common method bias was not significant in this study.

Descriptive Statistics and Correlation Analysis

The descriptive statistics and correlation analysis of the main variables are presented in Table 1. Deep learning shows a positive correlation with NFC, flow experience, and positive academic emotion. A significant positive correlation was observed between NFC and both flow experience and positive academic emotion. Flow experience also exhibited a significant positive correlation with positive academic emotion. Given the absence of significant differences between university students and high school students in scores for flow experience and academic emotion, this study merged the data from the two cohorts for subsequent mediation and moderation analyses.

Testing the Moderated Mediation Model

Using NFC as the independent variable, flow as the mediator, positive academic emotion as the moderator, and deep learning as the outcome variable, AMOS 26 was employed to assess the model. The interaction term for positive academic emotion and NFC was formed by multiplying the three factors of positive academic emotion by the scores of NFC. Similarly, the interaction term for positive academic emotion and flow was created by the product of the three factors of positive academic emotion and the two factors of flow (fluency and absorption).

According to Asparouhov and Muthén (2018), when the chi-square does not reject even if SRMR> 0.08, the model should be considered well-fitting. Then, the fit indices indicated a good model fit: $\chi^2(140) = 879.179$, $p < 0.001$, $GFI = 0.998$, $AGFI = 0.997$. The results are shown in Table 2 and Figure 2. The results suggest that flow plays a mediating role between NFC and deep learning. The interaction term between positive academic emotion and NFC is significant in the moderating effect analysis. The interaction term of positive academic emotion and flow was also significant in the moderating effect analysis. Then, we conducted a simple slope analysis. All variables are centralized before simple slope analysis. It suggested that (Figure 3): within the group expressing low positive academic emotion, higher scores of NFC were associated with increased levels of deep learning ($\beta_{simple} = 0.26$, $t = 5.96$, $p < 0.01$). Conversely, the group with high positive academic emotion demonstrated a weaker predictive relationship between NFC and deep learning ($\beta_{simple} = 0.12$, $t = 2.6$, $p > 0.01$). As shown in Figure 4, the group with low positive academic emotion has less effect on deep learning and flow experience ($\beta_{simple} = 0.35$, $t = 7.17$, $p < 0.01$), the higher positive learning group had a more significant effect

Table 1 *Descriptive statistics and correlations of study variables (N = 503)*

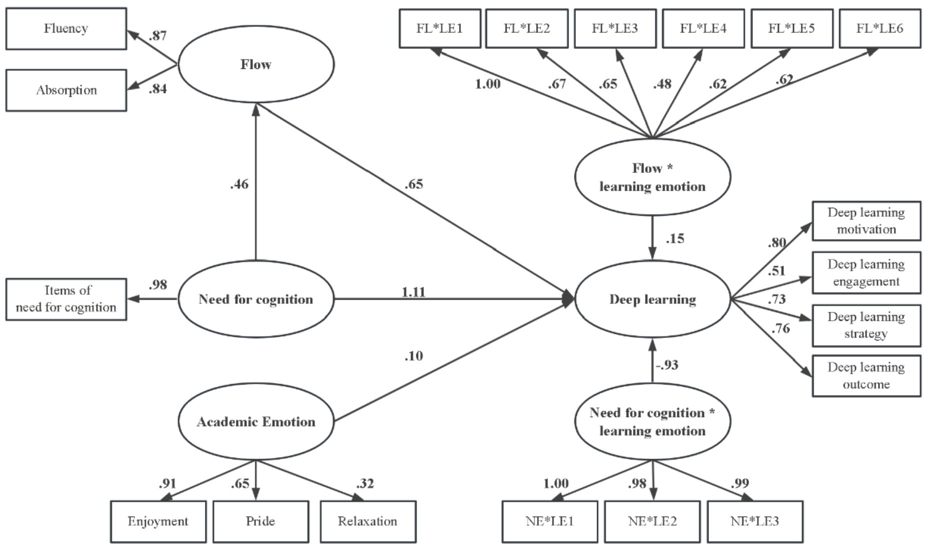
	M	*SD*	1	2	3	4
1. Deep learning	3.47	0.47	1			
2. NFC	4.38	0.83	0.47**	1		
3. Flow experience	4.39	0.94	0.66**	0.41**	1	
4. Positive academic emotion	3.55	0.51	0.57**	0.41**	0.51**	1

on deep learning and flow experience (β_{simple} = 0.52, t = 11.12, p < 0.01).

A multi-group analysis shows that the two groups of models have a good fit under the conditions of the five measurement models. Among the five measurement weight models, structural weight model, structural covariance model, structural residual model, and measurement residual model had *GFI* > 0.95, *AGF* > 0.94, p < 0.001. The baseline comparison results for the five models indicated that *NFI* > 0.925, *RFI* > 0. 922. These findings demonstrate that both groups exhibit strong invariance.

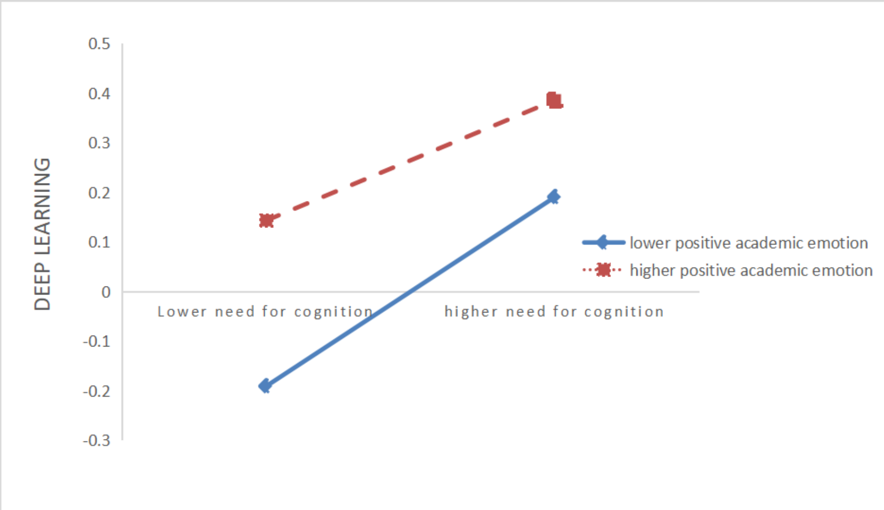
Table 2 *Estimates of standardized regression weights*

Parameter			Estimate	Lower	Upper	*p*
Flow experience	←	NFC	.459	.373	.543	.001
Deep learning	←	Flow experience	.646	.539	.743	.001
Deep learning	←	NFC	1.11	.772	1.84	.001
Deep learning	←	Positive emotion	.097	-.087	.248	.226
Deep learning	←	NFC * Positive emotion	-.935	-1.55	-.621	.001
Deep learning	←	Flow * Positive emotion	.147	.038	.244	.013



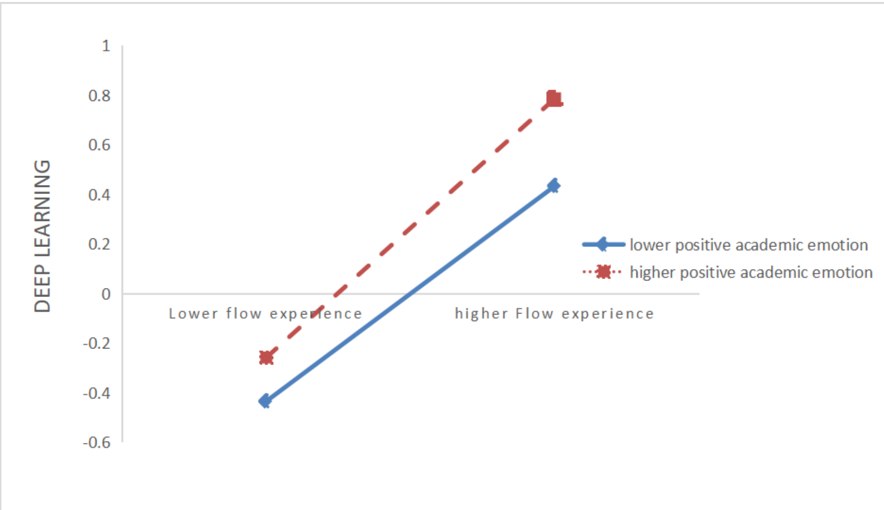
Note. NE*LE represents the interaction term of NFC multiplied by three factors of positive academic emotion. FL*LE represents the interaction term of the two factors of flow multiplied by three factors of positive academic emotion.

Figure 2 The factor loadings, and standardized regression coefficients of the moderated mediation model.



Note. Lower need for cognition = -1SD below mean, Higher need for cognition = +1SD above mean.

Figure 3 Simple slopes analysis of positive academic emotion and needs for cognition.



Note. Lower flow experience = -1SD below mean, Higher flow experience = +1SD above mean.

Figure 4 Simple slopes analysis of positive academic emotion and flow experience.

Discussion

The cross-sectional approach was used to explore the interaction between NFC, flow, positive academic emotion, and deep learning. The results showed that flow has a significant mediating effect between NFC and deep learning, while positive academic emotion has a significant regulating effect between NFC and deep learning. Moreover, the results of this study show that the model is valid in both high school students and college students, and there is no group difference.

Deep Learning and NFC

This study showed that the score of NFC was significantly correlated with the score of deep learning. From the connotation of deep learning in this study, it means that NFC has a significant positive correlation with deep learning motivation, deep learning engagement, deep learning strategy (such as daring to challenge their original views on problems during the learning process), and deep learning outcome. This is consistent with the results of many previous studies. For example, some studies suggested that NFC is linked to more elaborate learning strategies, such as critical processing (Cazan & Indreica, 2014) and academic achievement (Shi Zifu, 2021). An experimental study suggested that the willingness to invest cognitive effort was related to NFC and cognitive capacity, but not general academic motivation (Kramer et al., 2021). This means that NFC is a "hunger mindset" that is central to determining differences in individual academic achievement (von Stumm et al., 2011) or a necessary condition (Heijne-Penninga et al., 2010), which, compared to general learning motivation, seems to play a more important role in the process of "starting" and "sustaining" deep learning.

The Mediating Role of Flow Experience

This research determined that flow experience acts as a partial mediator between NFC and deep learning, indicating that NFC has a positive association with flow experience and, consequently, has a positive effect on deep learning. NFC has been associated with an increase in flow experience (Juric, 2017), potentially due to the enhanced autonomy provided by NFC in cognitive processing. Research indicates that individuals exhibiting a high NFC possess greater autonomy, are less susceptible to external or ancillary disruptions, and are capable of making more rational judgments and decisions (Jie & Ning, 2010). This fosters an optimal environment for flow experiences, laying the groundwork for immediate feedback within the flow state. Furthermore, sustained flow experiences can perpetuate motivation for problem-solving. Studies have shown that ongoing flow experiences can amplify the level of an individual's engagement in activities and persistent effort, leading to the display of highly motivated goal-oriented behaviors in such contexts and yielding more favorable anticipated outcomes (Ibrahim, 2019). These studies collectively furnish insights and substantiation for comprehending the interplay among NFC, flow experience, and deep learning from various perspectives.

The Moderation Effect of Positive Academic Emotion

This study also identified the moderating effect of positive academic emotion on the relationship between NFC and deep learning, as well as between flow experience and deep learning. According to the results from the simple slope analyses, the moderating effects of positive academic emotion differ in these two relationships. Simple slope analysis revealed that with higher levels of positive academic emotion, flow experience becomes a stronger association with deep learning. Perhaps we can rationalize this result in this way. Flow states, which do not require more cognitive and attention resources (Bruya, 2010), seem to provide a larger capacity of processing "space" for deep learning, and this space can facilitate the learner's positive emotions (Rodríguez-Ardura & Meseguer-Artola, 2017), to avoid the inverted U effect of decreased learning efficiency caused by excessive physiological arousal. Positive academic emotion serves as a motivational factor that encourages students' deep learning.

However, the moderating effect of positive academic emotion in the context of NFC and deep learning varies. When NFC is low, positive academic emotion tends to increase learners' willingness to engage in learning. However, as NFC scores rise, the beneficial effect of high positive academic emotion on deep learning diminishes. When NFC exceeds a certain threshold, those with high positive academic emotion exhibit low-magnitude positive association with deep learning compared to their counterparts with lower positive academic emotion. Perhaps high NFC, do not seem to need too much positive emotion but rely on epistemic curiosity or intellectual engagement to push them into challenging learning tasks (Jebb et al., 2016).

Research Significance and Limitations

Previous studies have mainly examined the effect of academic emotion on deep learning from a single perspective and failed to examine the relationship between cognitive style differences, flow experience, positive emotions, and deep learning simultaneously. The current study did it and initially revealed an important relationship between these variables. Taken together, this study provides an important pedagogical insight that for deep learning, we cannot simply emphasize the importance of a certain positive factor, such as positive academic emotion, as its effect on deep learning is neither linear nor single. We should pay attention to the interaction between multiple factors and balance to achieve the best state.

There are some limitations to this study. First of all, this study is a cross-sectional study and cannot reflect the causal relationship between variables. Secondly, this study investigated two groups of high school students and undergraduates. Considering that studies have shown that NFC changes slightly over time as individuals grow (Bruinsma & Crutzen, 2018) and other studies have found that there are different potential categories of NFC in junior high school students, which have different associations with math academic performance (Shi Zifu, 2021), future longitudinal studies are needed to explore the relationship between the profile changes of different NFC and deep learning.

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