Understanding the Relationship Between Cognitive Activation and Academic Emotions: A Comparison Between Students with Different Mathematics Achievements

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Previous studies have identified the relationship between cognitive activation and academic emotions. However, little is known about the underlying process behind this relationship. Considering that cognitive activation strategies may have different effects on students of different abilities, latent multi-group structural equation modelling was used to compare the mechanism mentioned above. Findings showed that (1) academic self-concept and value significantly mediated the link between cognitive activation and academic emotions among students with different mathematics achievements; (2) the mediating effects of academic self-concept and value are more significant in the below-average students than in the above-average students.

Quality of teaching, a core element of classroom environment, has been theoretically and empirically suggested to be a critical factor in impacting students' emotions and learning-related beliefs and values (e.g., Lazarides & Buchholz, 2019; Pekrun, 2006; Zhang et al., 2021). Evidence during the past decade showed that teaching characteristics, such as clear and activating teaching, well-organised classrooms, or supportive and cooperative teaching, could induce students' positive learning experiences and lower students' negative emotions (Goetz et al., 2020; King et al., 2012; Zhang et al., 2021). As an essential component of teaching quality, cognitive activation integrates the critical characteristics of mathematics teaching, including activation of prior knowledge, challenging tasks, and participation in practice related to the teaching content (Klieme et al., 2009). What remains scarcer is the knowledge about how cognitive activation is associated with emotions in the learning situation. As implied by the control-value theory (Pekrun, 2006), cognitive activation may, directly and indirectly, affect students' emotions. Specifically, teaching may influence students' emotions via two cognitive appraisals (i.e., academic control and value appraisals). However, such a mediation assumption of the control-value theory has been rarely tested. Therefore, the study reported in this paper examined the underlying process behind the relationship between cognitive activation and academic emotions. In line with the definition of Pekrun (2006), academic emotions are defined as emotions closely related to students' academic success or failure.

Another purpose of this study was to compare the link mentioned above between cognitive activation and academic emotions among students with different prior mathematical knowledge. Prior research work revealed that students with high mathematical performance reported more positive emotions (e.g., pride and enjoyment) but less negative emotions (e.g., anxiety and boredom; Holm et al., 2017; Wu et al., 2014). However, few studies have examined the effect of activating teaching on students' emotions, focusing on their different mathematics achievements. Klieme et al. (2009) have described that cognitive activation may increase students' negative emotions, particularly for students with mathematical difficulties. Reflection on this topic would shed more light on how an activating teaching approach could be employed in mathematics, considering students' different prior knowledge.

Theoretical Framework

The control-value theory provides a sound framework in examining the link between cognitive activation and academic emotions (Pekrun, 2006). One central idea of the control-

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value theory is that the classroom environment is a distant influencing factor of students' emotions, with proximal antecedents, such as academic control and value, having an indirect influence on emotions. Control appraisal is often conceptualised as academic self-concept or self-efficacy in existing research. It refers to students' competence beliefs in achieving academic success or completing learning-related tasks well (Pekrun, 2006). Academic self-concept is used in this study because students' confidence in mathematics learning is emphasised rather than their capability to solve specific mathematics problems successfully. Value appraisal denotes students' perceived significance or importance of learning mathematics (Pekrun, 2006).

In education, researchers classified academic emotions in three dimensions: valence (i.e., positive or negative emotions), activation level (i.e., high- and low-activating emotions), and object focus (i.e., activity- and outcome-focused emotions; Pekrun, 2006). For example, enjoyment is a positive and high-activating emotion focusing on the activity itself, while anxiety is a negative and high-activating emotion focusing on the outcome. The detrimental effect of negative emotions on students' engagement and outcomes has attracted more research attention, such as anxiety and boredom (Passolunghi et al., 2019; Preckel et al., 2010; Yi & Na, 2020). Good learning experiences, however, accompany positive emotions, contributing to the enhancement of students' engagement and interest and, in turn, their academic performance (Zhang et al., 2021). In the past decade, enjoyment received increasing attention with positive psychology. Existing evidence enhanced our understanding of the promoting role of enjoyment in mathematics achievement (Tze et al., 2021), classroom engagement (Liu et al., 2019), and homework effort (Luo et al., 2016). Given that enjoyment, anxiety, and boredom are frequently reported by students (see Pekrun et al., 2002), these three emotions will be measured in the study, as will the fact that these three emotions cover the three dimensions of academic emotions.

Cognitive activation refers to a wide range of teaching practices that enable students to participate in higher-level and abstract thinking, promote conceptual understanding by connecting facts and ideas, and provide opportunities for students to reflect on, evaluate, and openly discuss their perceptions (Förtsch et al., 2017). In a recent longitudinal study, Lazarides and Buchholz (2019) observed that cognitive activation was favorably related with enjoyment but negatively connected with boredom; besides, the influence of cognitive activation on anxiety was not significant. Contrary to this conclusion, Kunter et al. (2013) only found the relationship of cognitive activation with mathematics achievement but not with enjoyment. Concerning the relationship between cognitive activation, cognitive appraisals, and academic emotions, although currently there is no empirical evidence, such a relationship might exist. More recent research provided limited evidence on the relationship between cognitive activation and students' self-concept (Kitsantas et al., 2021) that would further influence students' emotions according to the control-value theory. Lastly, given that students' prior mathematical knowledge is an essential factor in determining academic emotions (Pekrun et al., 2017), further exploring the relationship between variables in students with different mathematics achievements is also very necessary for the activating strategy use in the classroom.

Current Study

Using the control-value theory and the previously provided empirical information, this study explores the cognitive activation/academic emotions relation via control and value appraisals in two groups of students with high and poor mathematics achievements. Evidence showed that students' emotions begin to decrease as their age increases, especially during the transition from primary to secondary school (Vierhaus et al., 2016). Meanwhile, the development and modification of academic emotions start in the early stages of adolescence

(Pekrun et al., 2002). Furthermore, students' emotions in mathematics are more intense than in other disciplines (e.g., Science and English; Goetz et al., 2006). Combining with the domain-specificity of academic emotions (Goetz et al., 2007), junior high school students in mathematics classrooms were investigated in this study. The following two research questions framed the study:

(1) What are the relationships among cognitive activation, cognitive appraisals and academic emotions in above- and below-average students?

(2) Are there any differences in the relations among students with different mathematics achievement?

Method

Participants

This study comprised 470 middle-school students who participated in the survey that included questions about quality of teaching, cognitive appraisals, and academic emotions. These students were randomly selected from 16 mathematics classrooms in three schools in Jiangsu, China. Educational resources were abundant in Jiangsu and intense educational reforms had been implemented to improve students' academic performance and provide positive learning experiences. There were 220 boys and 247 girls who participated in the investigation, and three other students who failed to report their gender. Furthermore, 203 students were in Grade 7, 233 in Grade 8, and 32 in Grade 9, with two students failing to report their grade. Ethical approval was obtained from the Human Research Ethics Committee of the author's university before data were collected.

Instrument

In addition to demographic information (e.g., gender and grade), the current study contains six self-reported variables (i.e., cognitive activation, control and value appraisals, enjoyment, anxiety, and boredom). All variables were assessed using a 5-point Likert scale that ranged from 1 (strongly disagree) to 5 (strongly agree).

Eight items from the PISA 2012 Student Questionnaire (Organisation For Economic Co-operation and Development, 2012) were used to assess cognitive activation. Respondents were asked to evaluate how often a set of facts came up in class with their mathematics teacher. The sample item is "The teacher provides problems in various situations so that students may assess their understanding of the concepts." Because of the growing criticism leveled against Cronbach's alpha, which may exaggerate the reliability of results, McDonald's omega coefficient was employed in the current study (Dunn et al., 2013; Flora, 2020). The omega coefficient for cognitive activation was 0.918, implying that data had good reliability.

Academic self-concept was examined with four items using the Motivated Strategies for Learning Questionnaire (MSLQ; see Pintrich, 1999). The sample item is "I am confident I can understand the basic concepts taught in mathematics." Similarly, three items from the MSLQ were used to measure academic value. The sample item is "I am very interested in the content area of mathematics." The omega coefficients for self-concept and value were 0.856 and 0.766, respectively.

Academic emotions were measured with 12 items, which were selected and modified from the Achievement Emotions Questionnaire-Mathematics (AEQ-M; Pekrun et al., 2005). The following are some examples of items. "I am motivated to attend to mathematics class because it is fascinating" was used to assess enjoyment, "I am concerned that others will comprehend more than me" was used to assess anxiety, and "When I feel bored, my mind begins to wander" was used to assess boredom. The omega coefficients for enjoyment, anxiety and boredom were 0.890, 0.770 and 0.919, respectively.

Students' mathematics achievement was reported by themselves. In Jiangsu, students are not given specific scores after taking the examination but grades (i.e., A-plus, A, B-plus, B, C, and D). A denotes excellence, B represents the average, C denotes below-average, and D indicates failure. In this study, students who obtained A-plus, A, and B-plus were classified into the above-average group, while the other students were classified into the below-average group.

Data Analysis

Missing data should be considered before examining the mediation assumption. The missingness of each measurement item is no more than 0.4%. Results of Little's MCAR test showed that the missingness was not entirely at random (χ^2 (278) = 382.518, $p < .001$). Therefore, it is not recommended to remove missing data directly using the Listwise delete method (Little & Rubin, 2019). Instead, the default function of full-information maximum likelihood (FIML) in the Mplus was used (Muthén & Muthén, 1998–2015).

Then, the confirmatory factor analysis (CFA) was used to test the fit indices of the measurement model. Several fit indices in the study of Hu and Bentler (1999) were reported in this study, such as *TLI/CFI* (≥ 0.95), *RMSEA* (≤ 0.06), and *SRMR* (≤ 9.08). Because measurement invariance (*MI*) is an unavoidable issue or prerequisite in multi-group analysis, configural, metric, and scalar invariance will be examined to see whether the mediation assumption between students with different prior mathematical knowledge is comparable (Shahzad et al., 2020). A series of fitting indices of *MI* were proposed. Byrne (2001) argued that a significant $\Delta\chi 2(\Delta df)$ means a significant change in the model fit. As a result, the differences in model fit of the three nested models were assessed using changes in the chi-square and the degree of freedom.

Results

Preliminary Results

Table 1 shows the descriptive and correlation analysis of the measured variables. In addition to gender and cognitive activation/academic emotions, other variables were correlated. Furthermore, results of the measurement model suggested a good model fit, with several fit indices showing that χ^2 (193) = 425.820, *TLI* = 0.961, *CFI* = 0.953, *RMSEA* = 0.052 and *SRMR* = 0.043. The factor loading of the measurement items ranged from 0.556 to 0.907. As Hair et al. (2006) described, a good convergent validity necessitates significant standardised factor loading higher than 0.5.

Table 1
Descriptive and Correlation Analysis Among Main Variables

	M (*SD*)	1	2	3	4	5	6
1. Gender	-	-					
2. CA	4.357 (.656)	-.079	-				
3. Self-concept	3.469 (.857)	$-.226^{**}$	$.326^{**}$	-			
4. Value	4.202 (.617)	$-.125^{**}$	$.434^{**}$	$.475^{**}$	-		
5. Enjoyment	4.199 (.643)	-.066	$.433^{**}$	$.487^{**}$	$.515^{**}$	-	
6. Anxiety	3.071 (1.075)	.070	$-.112^{*}$	$-.363^{**}$	$-.186^{**}$	$-.251^{**}$	-
7. Boredom	1.680 (.763)	.065	$-.504^{**}$	$-.391^{**}$	$-.476^{**}$	$-.541^{**}$	$.268^{**}$

Note. CA means cognitive activation. $^{**}p < 0.01$. $^{*}p < 0.05$.

Table 2 shows the results of the measurement invariance test, and findings supported the configural and metric model ($\Delta\chi 2$ = 19.287, Δdf = 16, $p > 0.05$) but not the scalar model ($\Delta\chi 2$ = 48.335, Δdf = 32, $p < 0.05$) in the above-average and below-average students. According to Cheung and Rensvold (1999), a multi-group model is acceptable when the weak invariance (i.e., metric invariance) is supported.

Table 2
Results of the Measurement Invariance Test

Model	χ^2	*df*	*CFI*	*TLI*	*RMSEA*	*SRMR*	$\Delta\chi^2$	Δdf	*p*-value
1.Configural	780.821	388	.926	.912	.070	.062			
2. Metric	800.108	404	.926	.915	.069	.066	19.287	16	$p > 0.05$
3. Scalar	829.156	420	.923	.916	.069	.071	48.335	32	$p < 0.05$

Results of the Multi-group Analysis

The latent multiple-group structural equation model of all samples indicated a good model fit (χ^2 (418) = 838.200, *CFI* = 0.921, *TLI* = 0.913, *RMSEA* = 0.070, *SRMR* = 0.086). Figure 1 presents the results of the multi-group analysis between students with different mathematics achievements. Results suggested the multiple mediating roles of academic self-concept and value in the relationship between cognitive activation and academic emotions. There was, however, no significant relationship between value and anxiety (or self-concept and boredom) among below-average students. Furthermore, as shown in Table 3, the relationship between cognitive activation and academic emotions was stronger among below-average students than above-average students. Lastly, by comparing the model fit between an unconstrained and a path-constrained model (Byrne, 2001), only the path from value to anxiety showed significant differences between the two groups.

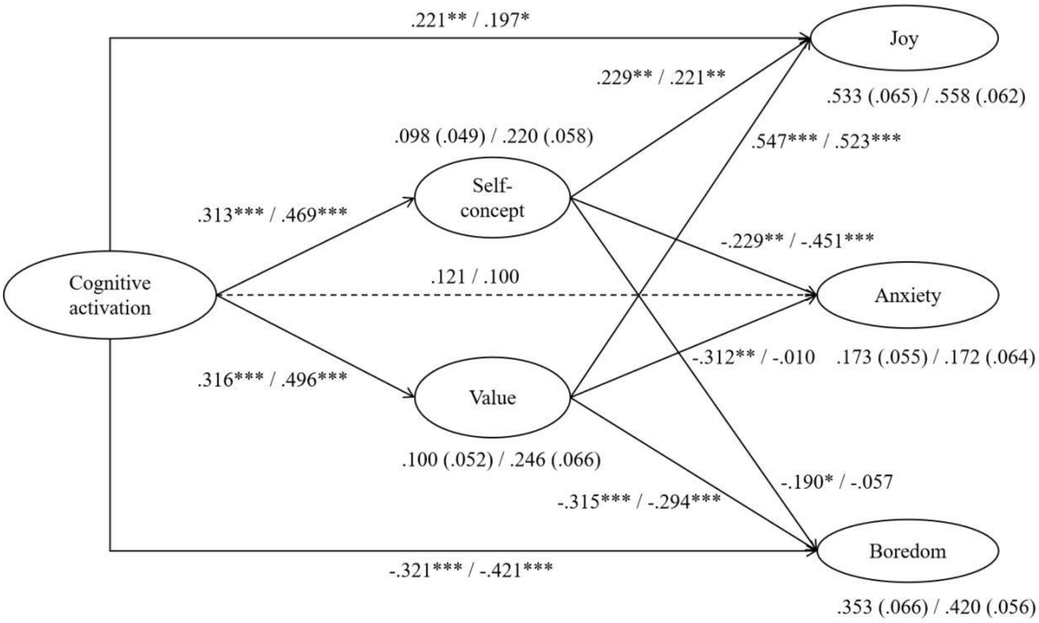

Figure 1. The mediating effects model of above-average/below-average students in mathematics.

Table 3
Indirect Effects of the Multi-group Structural Equation Model

Indirect paths	Above-average students		Below-average students	
	Standardised β	95% CI	Standardised β	95% CI
CA→Self→Joy	.072*	[.009, .135]	.104**	[.041, .178]
CA→Value→Joy	.173**	[.072, .274]	.259***	[.142, .377]
CA→Self→Anxiety	-.094*	[-.176, -.012]	-.211***	[-.318, -.105]
CA→Value→Anxiety	-.099*	[-.183, -.014]	-.083	[-.097, .087]
CA→Self→Boredom	-.060	[-.122, .033]	-.027	[-.096, .043]
CA→Value→Boredom	-.100*	[-.178, -.022]	-.146**	[-.232, .061]

Note. ***p < 0.01. **p < 0.01. *p < 0.05

Conclusion

The predictive power of cognitive activation on academic emotions was examined in students with different mathematics achievements, focusing on middle-school mathematics classrooms. In line with the control-value theory (Pekrun, 2006), findings showed the multiple mediators in the cognitive activation-emotions relationship. For example, for students of different abilities, cognitive activation enhanced their positive learning experience by enhancing their competence beliefs and academic values. Findings regarding enjoyment mean that the joy or fun students get from mathematics learning was related to their control and value perception, supporting previous findings that value and control are two essential antecedents of enjoyment (Buff, 2014; Goetz et al., 2010). However, such a mediation assumption does not always exist among below-average students. Specifically, academic self-concept mediated the teaching-anxiety relation, while academic value mediated the teaching-boredom relation among the below-average students. That finding means, for below-average students, their anxiety was more rooted in a lack of confidence while their boredom was strongly related to the less value perception in mathematics. Activating teaching approaches could deepen students' conceptual understanding from a higher cognitive level and contribute to their value perception, resulting in less boredom during mathematics learning (Pekrun et al., 2014). Notably, Chinese mathematics teachers emphasise basic concepts in their instruction, and learners of varying ability levels are considered, whether in variation teaching, classroom interaction, or training practice (Fan et al., 2015). In daily classroom teaching, teachers usually aim to enable each student to grasp the most basic knowledge and concepts, rather than focusing only on high-achieving students' cognitive needs and development. In this sense, cognitive activation may decrease below-average students' anxiety via increasing their self-concept.

Based on the result of multiple-group latent variable analysis, this study found that the mediating effects of academic self-concept and value were significantly higher in the below-average students than above-average students. That requires further explanation, combined with consideration of the Chinese mathematics education context. Cognitive activation requires reflective or high-level thinking, which challenges students to relate new lesson content to previous knowledge or everyday life experience (Baumert et al., 2010). In Chinese mathematics classrooms, teachers often encourage students to solve the same problem in different ways; meanwhile, when a student gives an answer, the teacher usually discusses it in front of the class and asks the student to explain the answer (Fan et al., 2015; Gu et al., 2004). However, constrained by the set teaching time and a significant amount of teaching content, teachers cannot provide all students with sufficient time to think and understand what is being taught. Students with ordinary or low ability levels sometimes require more time comprehending the information and learning the meaning of various strategies. Therefore, the influence of cognitive activation on below-average students' emotions is more considerable.

The findings reported in this paper make a vital contribution to the existing literature by demonstrating different path coefficients from cognitive activation to academic emotions via cognitive appraisals. Meanwhile, there are several practical implications. When activating teaching approaches are used, teachers should give students more time to think, reflect, and understand. Besides, in daily teaching, teachers should cultivate students' confidence and transfer more mathematical value during teaching.

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