

The relationship between formative assessment, science interest, and science achievement: a mediation model

Di Zhang, Lan Yang, Zi Yan, John Chi Kin Lee & Keith Chan

To cite this article: Di Zhang, Lan Yang, Zi Yan, John Chi Kin Lee & Keith Chan (2025) The relationship between formative assessment, science interest, and science achievement: a mediation model, *Educational Psychology*, 45:3, 359-376, DOI: [10.1080/01443410.2025.2470829](https://doi.org/10.1080/01443410.2025.2470829)

To link to this article: <https://doi.org/10.1080/01443410.2025.2470829>



© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



Published online: 25 Feb 2025.



Submit your article to this journal [↗](#)



Article views: 1258




View related articles [↗](#)



View Crossmark data [↗](#)

The relationship between formative assessment, science interest, and science achievement: a mediation model

Di Zhang^a , Lan Yang^b , Zi Yan^b , John Chi Kin Lee^b  and Keith Chan^b 

^aDepartment of Early Childhood Education, The Education University of Hong Kong, Hong Kong, China;

^bDepartment of Curriculum and Instruction, The Education University of Hong Kong, Hong Kong, China

ABSTRACT

This study explored the mediating roles of interest in broad science topics (IBST) on the effects of students' perceptions of teachers' formative assessment on science achievement, using data from PISA 2015. We focused on 9,841 15-year-old students from Mainland (B-S-J-G) China. The results revealed that: (1) a classical suppression effect, where the near-zero association between students' perceptions of teacher feedback and science achievement was combined with a direct negative effect on science achievement alongside positive indirect effects; (2) students' perceptions of adaptive instruction positively influenced science achievement; (3) students' perceptions of formative assessment strategies (i.e. teacher feedback and adaptive instruction) directly and positively affected IBST, which positively affected science achievement; and (4) IBST mediated the relationships between students' perceptions of formative assessment strategies and science achievement. The theoretical and practical implications of research on teacher formative assessment and its potential synergy with students' interest are discussed.

ARTICLE HISTORY

Received 31 January 2024

Accepted 19 February 2025

KEYWORDS

Formative assessment; feedback; adaptive instruction; science interest; science achievement

Formative assessment has emerged as an important facilitator of students' learning (Bennett, 2011; Clark, 2012). Teachers' feedback and adaptive instruction are two key strategies of formative assessment that reflect the nature of teacher-student interaction, with their effective implementation being critical to enhancing students' academic achievement (Black & Wiliam, 1998a). Research indicates that both teachers' feedback and adaptive instruction can influence students' motivation (e.g. Fong et al., 2019; Jansen et al., 2022) and academic achievement (e.g. Brooks et al., 2021; Katsantonis et al., 2023; Wisniewski et al., 2019; Yan et al., 2021). However, empirical evidence regarding the impact of these powerful formative assessment strategies on students' motivation and achievement remains inconclusive (Fong et al., 2019; Katsantonis et al., 2023).

According to the Situated Expectancy Value Theory (SEVT), students' learning experiences, such as teacher feedback and adaptive instruction they perceived, can affect their subjective task value (e.g. intrinsic value) and interest, subsequently influencing their performance (Eccles & Wigfield, 2020; Wigfield & Eccles, 2020). Theoretically, students with high interest may assign greater intrinsic value to information that addresses their learning needs and feel satisfied with their learning experience, which could mediate the effectiveness of their perceived teacher feedback and adaptive instruction. However, empirically, even if evidence has revealed that student's interest in specific subject positively predicts his or her academic achievement (e.g. Katsantonis et al., 2023; Schiefele et al., 1992; Tan, 2024; Zhang & Wang, 2020; Zhang et al., 2021; Zhou et al., 2022), the impact of students' perceptions of teacher feedback and adaptive instruction on interest remains controversial (Fong et al., 2019; Katsantonis et al., 2023; Yan et al., 2021). Therefore, the mechanisms by which students' perceptions of teacher feedback and adaptive instruction influence their academic achievement, particularly when considering the role of interest, are unclear. This study aims to explore how students' perceptions of formative assessment (i.e. teacher feedback and adaptive instruction), along with their interest in broad science topics (IBST), interact with science achievement using data from PISA 2015.

Literature review

Formative assessment and its link with student learning

Black and Wiliam (1998b) define assessment as the activities that provide information about students' learning as feedback to adapt teaching and learning activities. They also noted that formative assessment occurs when evidence is actually used to modify instruction to meet students' needs (Black & Wiliam, 1998b). Teachers benefit greatly from formative assessment by identifying students' strengths and weaknesses and tailoring their instruction accordingly (Black & Wiliam, 1998a, 1998b). Building on Black and Wiliam's (1998a, 1998b, 2009) work, a framework regarding formative assessment was conceptualised by Wiliam and Thompson (2008), namely the 'five key strategies' and one 'big idea'. The 'five key strategies' are sharing learning expectations, questioning, feedback, self-assessment, and peer assessment. The 'big idea' in Black and Wiliam (1998a) formative assessment theory is adaptive instruction, which involves teachers making adjustments to instructional methods, content, resources, and activities based on data gathered from formative assessment to better meet students' individual learning needs. Moreover, formative assessment is a three-step process that involves identifying where learners are in their learning, establishing their goals or standards, and providing feedback and adaptive instruction to close any gaps (Black & Wiliam, 1998a, 1998b). The third step is particularly crucial as it answers the question of 'how to get learners there [to their goals]' (National Research Council, 2001; Wiliam & Thompson, 2008). Formative assessment enables teachers to make targeted adaptive instruction based on the information gathered from classrooms. This process of adaptive instruction involves direct interactions between teachers and students. These interactions allow for previously identified problems to be solved,

misunderstandings to be clarified, and scaffolding and support to be provided where needed (see Bennett, 2011; Kruijer et al., 2022). These targeted approaches to instruction involved in the process of adaptive instruction, enabled by formative assessment, have the potential to help students learn more effectively and achieve better outcomes (Clark, 2012).

It is well documented that formative assessment is associated with students' academic achievement (e.g. Bennett, 2011; Hattie, 2009; Katsantonis et al., 2023; Winstone et al., 2017; Wisniewski et al., 2019; Yang, 2021). For example, Ruiz-Primo and Furtak (2007) found that effective formative assessment practices may promote students' science performance in scientific inquiry classes. Herman et al. (2015) also revealed that students' science learning was positively impacted by teachers' formative assessment practices. Teachers' feedback or adaptive instruction that provides constructive information about students' learning and explicitly identifies where and how they do next can positively affect their learning outcomes (Hattie, 2009; Hattie & Timperley, 2007). When students perceive feedback as accurate, timely, supportive, and sustained, they are more likely to engage actively with it and take steps to improve their learning (Carless et al., 2011; Weaver, 2006). However, the effect of students' perceptions of teacher feedback has also been revealed to be negative (e.g. Katsantonis et al., 2023; Wisniewski et al., 2019; Yan et al., 2021). For instance, Katsantonis et al. (2023) found that students' perceptions of teacher feedback negatively predicted science achievement. Despite this, a recent meta-analysis by Cai et al. (2023) has shown that feedback has a positive medium effect on students' academic achievement, with an overall effect size of approximately $g=0.44$. Adaptive instruction is essential for ensuring that feedback is effective and that students are supported in their learning. Teachers can use data from formative assessments to adjust their instruction, such as providing additional support or challenging students with more advanced content, which can help students achieve their learning goals (e.g. Bennett, 2011; Butterfuss et al., 2022). Empirical studies have revealed a positive relation between students' perceptions of adaptive instruction and academic achievement (e.g. Oliver et al., 2021; Yan et al., 2021). Based on the theoretical and empirical evidence presented, we hypothesised that students' perceptions of teacher feedback and adaptive instruction are positively correlated with science achievement in this study.

Formative assessment, science interest, and science achievement

Previous research has also revealed the role of formative assessment in increasing students' interest (e.g. Deci et al., 1999; Katsantonis et al., 2023; Rakoczy et al., 2019). Formative assessment can be viewed as an effective strategy for fostering students' science interest, particularly if it is perceived positively by them (Osborne & Dillon, 2008). For example, Burns et al. (2019) and Katsantonis et al. (2023) have shown that students' perceptions of teacher feedback positively predicted science interest. Students' interest may increase when they perceive formative feedback as useful (Rakoczy et al., 2019). Those who have perceived formative feedback in science are more likely to develop IBST (Burns et al., 2019; Katsantonis et al., 2023). In addition, from the perspective of SEVT, students' subjective task values—such as intrinsic value and

interest—are shaped by their learning experiences, which include the feedback they receive from teachers and the adaptability of instructional methods tailored to their individual needs (Eccles & Wigfield, 2020; Wigfield & Eccles, 2020). When students' perceptions of feedback align with their specific needs, it not only clarifies expectations but also encourages them to engage more deeply with the content. Similarly, when their perceptions of adaptive instruction resonate with their individual learning styles and paces, this further supports their engagement. As students experience teaching methods that match their learning preferences, they are more likely to find the material relevant and meaningful, which increases their IBST.

Research has shown that children develop an initial interest in science even before they reach middle school (Dabney et al., 2013; Maltese & Tai, 2010; Tai et al., 2006). This early interest can serve as a foundation for the development of more sustained individual interest in science over time (Krapp et al., 1992). Individual interest is defined as a student's relatively sustained propensity to specific content over time and the immediate psychological state when this propensity is activated (Hidi & Renninger, 2006). Individual interest in science, which is typically associated with deeper understanding of the subject matter, positive emotions, and increasing reference value (Krapp et al., 1992), can have a significant impact on students' science learning and achievement. In the PISA 2015 assessment, IBST was measured with specific science topics. This aligns with Hidi and Renninger's (2006) concept of individual interest as an enduring predisposition to specific content. Therefore, in this study, IBST is considered a form of individual interest.

Empirically, numerous studies have consistently found a positive correlation between students' science interest and their science achievement (e.g. Burns et al., 2019; Katsantonis et al., 2023; Liou, 2021; Schiefele et al., 1992; Tan, 2024). This relationship is expected to be strong because science subjects are often considered challenging and more dependent on students' motivation levels (Schiefele et al., 1992). For instance, Katsantonis et al. (2023) found that among various motivational beliefs, science interest emerged as one of the strongest predictors of science achievement. Collectively, students' science interest plays an important role in science achievement.

It is worth noting that SEVT suggests a possible indirect mechanism between students' perceptions of formative assessment and their academic achievement via science interest (Eccles & Wigfield, 2020; Wigfield & Eccles, 2020). According to SEVT, students' experiences, like their perceptions of teacher feedback or adaptive instruction, can influence the development of intrinsic value and interest, subsequently affecting their science achievement (Eccles & Wigfield, 2020; Wigfield & Eccles, 2020). When students perceive feedback as constructive and instruction as responsive to their individual needs, they are more likely to find the learning material valuable and engaging. This enhanced intrinsic value and interest can lead to greater motivation and persistence in their studies, ultimately resulting in improved academic performance in science. Empirical evidence has been found to support this indirect relationship (e.g. Burns et al., 2019; Katsantonis et al., 2023). For example, Burns et al. (2019) have found that students' perceptions of formative feedback indirectly affected their science achievement via intrinsic valuing in a significant way. As Burns et al. (2019) measured intrinsic valuing of science as a higher-order factor using two scales from PISA 2015: enjoyment of science and IBST, each with five items, it is necessary to investigate

whether IBST, as individual interest, continues to play an important role between students' perceptions of specific formative assessment strategies and science achievement when excluding enjoyment.

The present study

Based on the SEVT and the aforementioned literature, students' perceptions of teachers' formative assessment, especially their perceptions of teacher feedback and adaptive instruction in science classes may positively influence their individual interest in science and science achievement when their needs are satisfied (Eccles & Wigfield, 2020; Wigfield & Eccles, 2020). Additionally, students' individual interest in science can also positively affect their science achievement (e.g. Cheng & Wan, 2016; Lau & Ho, 2022; Osborne et al., 2003; Tan, 2024). In this study, we sought to propose a mediation model to understand the potential impact of students' perceptions of teacher feedback and adaptive instruction in science class on IBST, as well as the direct and indirect effects of these factors on science achievement. Figure 1 displays the hypothesised model. The specific hypotheses were tested in this study:

- H1.** Students' perceptions of teacher feedback are positively associated with IBST and science achievement.
- H2.** Students' perceptions of adaptive instruction are positively associated with IBST and science achievement.
- H3.** IBST mediates the relationship between students' perceptions of teacher feedback and science achievement.
- H4.** IBST mediates the relationship between students' perceptions of adaptive instruction and science achievement.

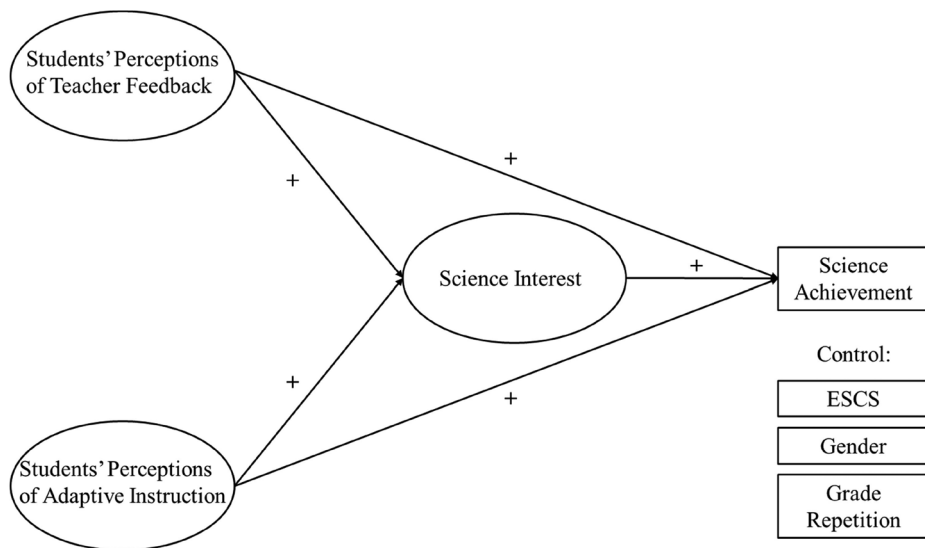


Figure 1. Hypothesised model depicting the association between the constructs.

Method

Participants

This study used data from PISA 2015, focusing on 9,841 15-year-old students from four participating regions in China : Beijing, Shanghai, Jiangsu, and Guangdong (B-S-J-G [China]). Beijing, along with these three regions located on the Southeastern coast of China are considered more economically developed areas in China (GDP per capita: over US\$10,000, National Bureau of Statistics of China, 2016). In these regions, local educational decisions are generally made with a great deal of autonomy (Hu, 2022). The sample in PISA was selected using a complex two-stage sampling method (OECD, 2017b). In the first phase, schools were chosen by probability proportional to size (PPS) sampling method. During the second phase, systematic sampling method was used to sample students with equal probability. The selected students (average age: 15.7 years old, female: 47.6%) were from 268 schools.

Measures

Teachers' formative assessment

Items measuring students' perceptions of teachers' formative assessment were drawn from student questionnaires. Students' perceptions of teachers' formative assessment practices in science classes were categorised into students' perceptions of teacher feedback and adaptive instruction.

Students' perceptions of teacher feedback. The PISA 2015 survey quantitatively assessed students' perceptions of the feedback they received in science classes by measuring the frequency of teacher communication concerning performance-related information. The survey included five distinct items: (1) Performance Assessment—how often students receive information about their overall performance, (2) Strengths Identification—the frequency of feedback on students' strengths, (3) Areas for Improvement—how regularly students are informed of areas where they can improve, (4) Improvement Strategies—the frequency at which improvement methods are suggested, and (5) Goal Guidance—the regularity of guidance on setting performance-related goals. These items were designed to capture the specific aspect of feedback provided by teachers, influencing how students perceive and react to the feedback.

Four-point Likert scales were given to participants for their responses ('never or almost never = 1', 'some lessons = 2', 'many lessons = 3', and 'every lesson or almost every lesson = 4'). This scale had an internal consistency reliability of .913. Confirmatory factor analysis (CFA) results showed a good fit between the data and the one factor model ($\chi^2 = 21.758$, $df=4$, $p < .001$; CFI = .998, TLI = .995, RMSEA = .022, SRMR = .007).

Students' perceptions of adaptive instruction. PISA asked students to report their experience of teachers' adaptive instruction via the adaptive instruction scale consisting of three items (e.g. 'How frequently does this happen in <science lessons>? The teacher adapts the lesson to my class's needs and knowledge'). Students rated the frequency on a four-point Likert scale ('never or almost never = 1', 'some lessons = 2', 'many

lessons = 3', and 'every lesson or almost every lesson = 4'). The adaptive instruction scale had an internal consistency reliability of .781. Fit indices for the one factor model of the construct were $\chi^2 = .000$, $df=0$, $p < .001$; CFI = 1.000, TLI = 1.000, RMSEA = .000, SRMR = .000. This is 'an identified model with zero degrees of freedom' (Raykov et al., 2013, p. 164), indicating that there is a unique solution for the model parameters that can be determined from the data. It also suggested the model was able to precisely estimate parameters that reproduced the data.

Interest in broad science topics

IBST scale was developed to measure students' interest in science topics. There are five items, such as Biosphere (e.g. ecosystem services, sustainability). As these items assess students' relatively enduring predisposition to specific science topics, rather than being a situational response to immediate cues (Hidi & Renninger, 2006), this study has considered it to be a scale of assessing students' individual interests. Students declared the degree of their interest levels on a scale ('not interested = 1', 'hardly interested = 2', 'interested = 3', 'highly interested = 4', and 'I don't know what this is = 5'). According to the PISA 2015 technical report, the last category has been recoded as missing (OECD, 2017b). The reliability (Cronbach's alpha) of the IBST scale was .787. According to the CFA results, the one factor model fit the data well ($\chi^2 = 69.333$, $df=4$, $p < .001$; CFI = .987, TLI = .968, RMSEA = .041, SRMR = .020).

Science achievement

Science was the main subject assessed in PISA 2015. Scientific literacy reflects a student's 'ability to engage with science-related issues, and with the ideas of science, as a reflective citizen' (OECD, 2017a). While PISA documents use terms like 'literacy', 'competency', 'achievement', and 'performance' interchangeably (OECD, 2017a, 2017b), numerous studies using PISA data have widely employed the term 'science achievement' (e.g. Burns et al., 2019; Katsantonis et al., 2023). For consistency with existing literature, this study adopts the term 'science achievement' to represent scientific literacy. Science achievement was assessed through three competencies: (1) explain phenomena scientifically; (2) evaluate and design scientific enquiry; and (3) interpret data and evidence scientifically (OECD, 2017a). Three classes of items (i.e. simple multiple choice, complex multiple choice, and constructed response) were used for assessing the competencies and scientific knowledge. Each of the three categories accounted for approximately one-third of the total items. The PISA 2015 database has provided 10 proficiency plausible values for science achievement. In this study, the 10 plausible values were calculated following the suggested procedure in the PISA data analysis manual (OECD, 2009).

Covariates

Students' demographic details have been demonstrated to play a significant role in their learning. For example, students with lower socioeconomic status (SES) tend to underperform in academic achievement compared to those with higher SES (e.g. Korous et al., 2022). Similarly, gender differences in achievement are well documented

(e.g. Reilly et al., 2015). Additionally, repeating a grade level is associated with lower academic achievement compared to those who did not (e.g. Allen et al., 2009) and has been considered a covariate in studies using the PISA dataset (e.g. Yan et al., 2021). SES has been operationalised by PISA 2015 with the index of economic, social, and cultural status (ESCS) (OECD, 2017b). Thus, this study included these demographic variables (i.e. ESCS, gender, and grade repetition) as covariates.

Statistical analyses

After excluding the number of valid skips for students' perceived teacher feedback and adaptive instruction (6.5%), the missing values for perceived teacher feedback, perceived adaptive instruction, and IBST were 0.9%, 0.9%, and 1.4%, respectively, all of which were less than 5% of the whole sample (Rubin et al., 2007). Therefore, in this study, we analysed missing data using the default settings of the Mplus command.

In the subsequent data analysis, the final student weights, 80 balanced repeated replication values, 10 plausible values, and the recommended calculation in the PISA data analysis manual were adopted due to the sampling design and measurement uncertainty (OECD, 2009). Mplus 8.3 programme was used to perform structural equation modelling (SEM) analysis. A robust maximum likelihood estimator was used to validate the scale's construct. Next, we performed SEM using robust maximum likelihood to estimate the parameters to test the hypothesised model (see Figure 1). In addition, the indirect effect was further examined through bootstrapping analysis by resampling and replacing data 10,000 times. Both the bias-corrected interval and the confidence interval were at 95% (Taylor et al., 2008).

Results

Preliminary analyses

According to the CFA results, the three factors structure (students' perceptions of teacher feedback, students' perceptions of adaptive instruction and IBST) showed a good fit with $\chi^2 = 1464.873$, $df=62$; $p < .001$; CFI = .942; TLI = .927; RMSEA = .048; SRMR = .034. All items had factor loadings above .6, except for two loadings of .505 and .483 for items 4 and 5 of the IBST scale, respectively.

Table 1 displays the descriptive statistics and correlations for the main variables and covariates. Students' perceptions of teacher feedback were significantly and positively correlated with their perceptions of adaptive instruction ($r = .494$, $p < .01$) and IBST ($r = .259$, $p < .01$), but negatively related to science achievement ($r = -.069$, $p < .01$). Students' perceptions of adaptive instruction were positively correlated with IBST ($r = .248$, $p < .01$) and science achievement ($r = .164$, $p < .01$). Similarly, IBST was positively correlated with science achievement ($r = .175$, $p < .01$).

Direct effect and the effects of covariate variables

Data fit well with the direct model: $\chi^2 = 2095.565$, $df=110$; $p < .001$; CFI = .932; TLI = .918; RMSEA = .043; SRMR = .052. The results revealed that students' perceptions

Table 1. Descriptive statistics and correlations between the studied variables.

	Mean	SD	1	2	3	4	5	6
1. PFEED	.25	.93	1					
2. AI	.06	.92	.494**	1				
3. IBST	.45	.81	.259**	.248**	1			
4. ESCS	-1.07	1.10	.034**	.125**	.111**	1		
5. Gender	.53	.50	.102**	-.041**	.165**	.014**	1	
6. Grade repetition	.21	.41	.051**	-.047**	-.016**	-.187**	.096**	1
7. Science achievement	517.78	100.21	-.069**	.164**	.175**	.444**	.047**	-.272**

Notes: PFEED=students' perceptions of teacher feedback; AI=students' perceptions of adaptive instruction; IBST=interest in broad science topics; ESCS=economic, social, and cultural status.

** $p < .01$.

of teacher feedback had a significant and negative direct effect on science achievement ($\beta = -.252, p < .001$), whereas their perceptions of adaptive instruction had a significant and positive direct effect on science achievement ($\beta = .197, p < .001$). Additionally, science achievement was significantly influenced by covariates. Specifically, students with higher ESCS achieved higher science achievement than those with lower ESCS ($\beta = .378, p < .001$), boys performed better than girls in science achievement ($\beta = .066, p < .001$), and students who did not repeat the grade had higher science achievement than those who did ($\beta = -.186, p < .001$).

Mediation effect of interest in broad science topics

The results also showed significant and positive predictive effects of students' perceptions of teacher feedback and adaptive instruction on IBST ($\beta = .115, p < .001$; $\beta = .284, p < .001$, respectively), and IBST on science achievement ($\beta = .231, p < .001$) (see Figure 2). In addition, the bootstrapping analysis revealed that the mediation effects along both paths were significant (see Table 2). Specifically, IBST significantly mediated the relationship between students' perceptions of teacher feedback and science achievement; similarly, IBST played a mediating role in the association between students' perceptions of adaptive instruction and science achievement. Based on the PISA data, this model revealed that 30.4% of the variance in science achievement could be explained by students' perceptions of adaptive instruction, their perceptions of teacher feedback, and individual interest in science, suggesting these factors collectively contribute to improving students' achievement in science.

Discussion

The present study examined the association between students' perceptions of teachers' formative assessment practices in science lessons (i.e. teacher feedback and adaptive instruction), and IBST and science achievement using the data of B-S-J-G (China) in PISA 2015. The primary results were as follows: students' perceptions of teacher feedback were negatively correlated with science achievement, whereas their perceptions of adaptive instruction were positively related to science achievement. Students' perceptions of formative assessment strategies (i.e. teacher feedback and adaptive instruction) directly and positively influenced IBST, and IBST was positively related to

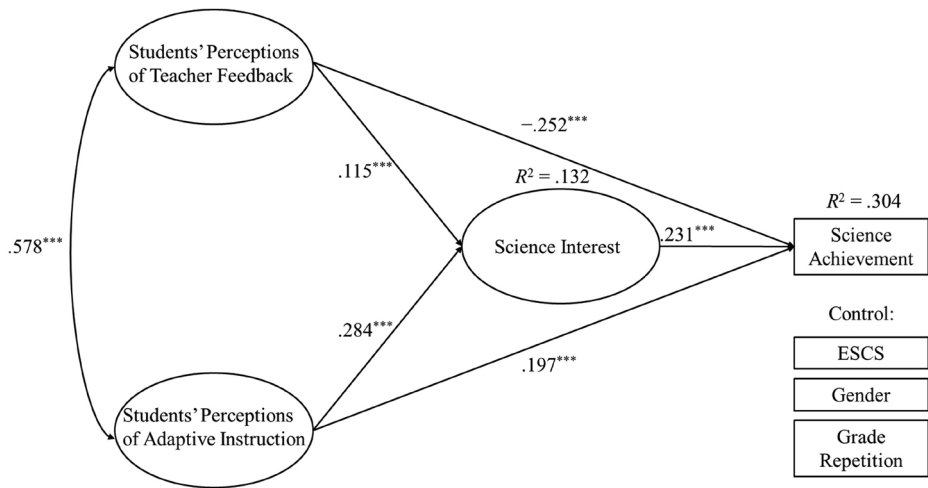


Figure 2. Structural equation model for students’ perceptions of teacher feedback, their perceptions of adaptive instruction, interest in broad science topics and science achievement. *** $p < .001$.

Table 2. Bootstrap test on mediation effects.

Paths	Standardised β	SE	Bias-corrected percentile 95% CI	
			Lower	Upper
PFEED \rightarrow IBST \rightarrow SACH	.027***	.006	.016	.038
AI \rightarrow IBST \rightarrow SACH	.066***	.007	.053	.080

Note: PFEED= students’ perceptions of teacher feedback; AI=students’ perceptions of adaptive instruction; IBST=interest in broad science topics; SACH=science achievement. *** $p < .001$.

science achievement. Furthermore, IBST mediated the relationships between students’ perceptions of formative assessment strategies and science achievement.

The findings of our study showed that students’ perceptions of teacher feedback were negatively correlated with science achievement, which contradicted our initial hypothesis. Upon examining the table of simple correlations and the regression equations, the results indicated the presence of ‘classical suppression’ (Horst, 1941; Watson et al., 2013). The correlation between students’ perceptions of teacher feedback and science achievement was near zero ($r = -.069$, accounting for less than 1% of the variation). The correlation between students’ perceptions of teacher feedback and adaptive instruction, and between students’ perceptions of teacher feedback and IBST were both positive and moderate. When all three variables were entered into a multiple regression, the relationships between students’ perceptions of adaptive instruction and science achievement ($\beta = .197$) and between IBST and science achievement ($\beta = .231$) were both ‘strengthened’ over their simple correlations ($r = .164$ and $r = .175$, respectively). Simultaneously, the relationship between students’ perceptions of teacher feedback and science achievement transitioned from near zero to moderate, but negative ($\beta = -.252$). This more negative relationship observed in the regression (i.e. direct effect) can be understood as a classical suppression effect, where students’

perceptions of teacher feedback acted as a suppressor that suppressed irrelevant variation and strengthened the relationships between IBST and students' perceptions of adaptive instruction on science achievement. In other words, this suppression occurs because students' perceptions of teacher feedback, despite showing a near-zero correlation with science achievement, help clarify and enhance the predictive validity of the other variables when included in the model. Thus, the total effect ($\beta = -.075$) of students' perceptions of teacher feedback on science achievement, which was close to zero, could be interpreted as a combination of a negative direct effect and positive indirect effects that nearly cancelled each other out.

On one hand, the inverse relationship between students' perceptions of teacher feedback and science achievement may suggest that students who struggle in science elicit more frequent feedback from their teachers. This interpretation aligns with the pedagogical practices of providing targeted support to students who need it most. Teachers may employ feedback more frequently with lower-achieving students as a deliberate instructional strategy, believing in its potential to support and improve learning outcomes for these students. This approach reflects teachers' professional judgement in allocating more intensive interventions to those who may benefit most from them. Furthermore, this finding highlights the importance of not only how feedback is perceived but also how students engage with it, a concept known as agentic engagement in feedback practices (Winstone et al., 2017). According to Winstone et al. (2017), effective feedback must be actionable and perceived as valuable, requiring a synergistic approach between how it is delivered, received and used. This synergy is crucial for maximising the impact of teacher feedback on students' learning outcomes in science classes, emphasising the need to enhance both the delivery of feedback and students' active engagement with it to improve educational effectiveness.

From a methodological perspective, this tension may arise from the fact that measuring students' perceptions of teacher feedback can introduce variability that does not necessarily reflect the actual quality or effectiveness of the feedback itself. For example, students might report a high frequency of simple feedback evaluating their science performance, strengths, or areas for improvement while indicating a lower frequency of elaborative feedback. The latter is often more time-consuming and challenging for teachers to provide. However, a recent meta-analysis by Cai et al. (2023) has shown that elaborative feedback, particularly explanatory feedback, was typically more effective than simple feedback types and was the most effective type for enhancing learning outcomes. As such, while students may report high frequencies of teacher feedback on various aspects of science learning, these perceptions do not always accurately represent the quality of feedback or lead to improved academic outcomes. Instead, frequent use of simple feedback may be associated with lower achievement levels, as it may not provide the depth of understanding necessary for struggling students to improve their performance effectively.

On the other hand, students' perceptions of teacher feedback may stimulate their interest and intrinsic value in science learning, which may facilitate their science achievement (Wigfield & Eccles, 2020). Concurrently, students' perceptions of adaptive instruction, which were closely related to their perceptions of teacher feedback, also enhanced their science learning engagement. This synergy between students' perceptions of teacher feedback and adaptive instruction positively contributes to

improving science performance, alongside IBST. These dynamics will be elaborated upon in greater detail in the following sections, highlighting how students' perceptions of teacher feedback and adaptive instruction can foster IBST and promote science achievement.

Our findings also revealed that students' perceptions of adaptive instruction were positively correlated with science achievement. Previous research has also found that instructional adjustments are beneficial to students' achievement (e.g. Yan & Chiu, 2023; Yan et al., 2021). Teachers' adaptive instruction aims to satisfy students' needs, which may be regarded as a cost-effective teaching strategy (McMillan et al., 2013; Wiliam & Leahy, 2007). This result echoes Wiliam and Leahy's (2007) argument that adaptive instruction is essential to effective formative assessment because it helps meet students' actual learning needs (Wiliam & Thompson, 2008). However, as we mentioned before, how to implement it effectively is an issue that plagues many science teachers (Furtak et al., 2019). Time has been proven repeatedly to be a challenge that teachers struggle with when adapting their instruction (e.g. Gotwals, 2018; Sezen-Barrie & Kelly, 2017). There have been some good examples of practice in enabling teachers to achieve shorter cycles (e.g. day by day or minute by minute) from obtaining information about students to adapting instruction (Wiliam & Thompson, 2008), which can inform science teaching practice.

In line with SEVT (Eccles & Wigfield, 2020; Wigfield & Eccles, 2020) and previous empirical studies (e.g. Burns et al., 2019), the findings of this study also showed that students' perceptions of formative assessment strategies (i.e. teacher feedback and adaptive instruction) impact science achievement indirectly via IBST. According to SEVT (Eccles & Wigfield, 2020; Wigfield & Eccles, 2020), students' perceptions of teacher feedback or adaptive instruction may promote their intrinsic value and interest. Students with higher interest are more likely to actively participate in such activities, experience deep learning and achieve better achievement (Wigfield & Eccles, 2020). Thus, teachers' feedback and adaptive instruction in science perceived by students may stimulate their IBST by satisfying their needs and deepening their understanding of science content, which, in turn, may boost their science achievement (Ashford & De Stobbeleir, 2013; Burns et al., 2019). The findings of this study highlight the significance of IBST in the mechanism between students' perceptions of formative assessment (i.e. teacher feedback and adaptive instruction) and science achievement.

The present study has several limitations. One limitation is the cross-sectional design of the data, which is insufficient to verify the cause-and-effect relationships of the variables. Although our hypothesised model was well-established based on SEVT and empirical research, the relationship between science interest and science achievement may be bidirectional. Science achievement could potentially be both an outcome and a source of interest. A longitudinal design would be more appropriate for investigating the causal relationships between these variables and capturing their potential reciprocal nature over time. Second, apart from the science achievement being measured objectively, all other measures used in this study were self-reported. Thus, response bias could exist (Rosenman et al., 2011). A more direct and objective source of data (e.g. observations) on variables may be considered for future investigations. Third, PISA 2015 failed to cover all formative assessment strategies as suggested by the formative assessment theory (Black & Wiliam, 2009). Future research

can explore the relationship between other formative assessment strategies (e.g. engineering effective classroom discussion, cultivating students as instructional resources for each other, and self-assessment) and additional motivational variables.

Implications for theoretical Research and practice

Theoretically, the findings of this study enrich our understanding of the relationship between students' perceptions of formative assessment (i.e. teacher feedback and adaptive instruction), interest, and science achievement. Our findings contribute to the literature by revealing that students' perceptions of different types of formative assessment strategies may have varying effects on students' science achievement. This study also provides implications for SEVT. As previously discussed, SEVT articulates the importance of intrinsic value stimulated by teacher-student interaction (e.g. formative assessment) for students' achievement. Our findings provide empirical evidence for this mechanism in science by revealing the mediating role of IBST in the relationship between students' perceptions of formative assessment (i.e. teacher feedback and adaptive instruction) and science achievement.

In addition, understanding classical suppression is crucial for interpreting the weak correlation between students' perceptions of teacher feedback and science achievement. This relationship may not accurately reflect the true dynamics at play when multiple variables are considered simultaneously. We should be cautious not to misinterpret these findings as evidence of ineffective feedback; rather, we should recognise that students' perceptions of teacher feedback can play a complex role in educational outcomes.

We found that students' perceptions of teachers' adaptive instruction positively predicted their science achievement. This finding underscores the potential importance of science teachers identifying students' needs and adapting their instruction accordingly. However, it is not an easy job for science teachers to make successful instructional adjustments as it requires a grasp of formative assessment skills and science subject matter (Duschl & Gitomer, 1997), which may often be lacking for science teachers (Sezen-Barrie & Kelly, 2017). Therefore, improving science teachers' formative assessment skills and content knowledge appears crucial to facilitate the effective implementation of instructional adaptations in science classrooms.

IBST has been found to contribute to science achievement in this study. This implies that science teachers need to integrate interesting and attractive information related to broad science topics (e.g. new science discoveries, science topics in life, science history) into their daily science teaching. Besides, teachers or schools can organise science activities or science innovation competitions, which may stimulate students' curiosity about science and provide them with opportunities to showcase their science-related experiences and abilities.

Conclusion

In summary, using the data of B-S-J-G (China) in PISA 2015, we examined the association between students' perceptions of teachers' formative assessment practices in science lessons (i.e. teacher feedback and adaptive instruction), IBST, and science achievement.

The present study is one of the first to explore the relationships between the four variables in a mediation model. Specifically, this study contributes to the existing literature on both formative assessment and interest by revealing: (1) a classical suppression effect in which the near-zero correlation between students' perceptions of teachers' feedback and science achievement was combined with a direct negative effect of students' perceptions of teacher feedback on science achievement and positive indirect effects; (2) students' perceptions of adaptive instruction positively affected science achievement; (3) students' perceptions of teacher feedback and adaptive instruction positively affected IBST, which had a positive effect on students' science achievement; and (4) IBST mediated the relationship between students' perceptions of formative assessment strategies and science achievement. The findings enrich our understanding of the association between students' perceptions of formative assessment, motivational variables, and academic performance. This study also provides valuable information and implications for science teachers in terms of how to use formative assessment strategies (e.g. adaptive instruction and feedback) to enhance students' science interest and support their science learning.

Ethical approval

Ethical approval for this study was granted by The Education University of Hong Kong.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The first author acknowledges partial support from a fellowship awarded by the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. EdUHK PDFS2324-8H06). The preparation of this manuscript was also partially supported by the research cluster fund (Code: R4203) awarded to the corresponding author Dr. Yang Lan by The Education University of Hong Kong.

ORCID

Di Zhang  <http://orcid.org/0000-0003-0926-5753>

Lan Yang  <http://orcid.org/0000-0002-3457-0330>

Zi Yan  <http://orcid.org/0000-0001-9305-884X>

John Chi Kin Lee  <http://orcid.org/0000-0002-3235-0967>

Keith Chan  <http://orcid.org/0000-0001-6462-2632>

References

- Allen, C. S., Chen, Q., Willson, V. L., & Hughes, J. N. (2009). Quality of research design moderates effects of grade retention on achievement: A meta-analytic, multilevel analysis. *Educational Evaluation and Policy Analysis*, 31(4), 480–499. <https://doi.org/10.3102/0162373709352239>
- Ashford, S. J., & De Stobbeleir, K. E. (2013). Feedback, goal setting, and task performance revisited. In E. A. Locke & G. P. Latham (Eds.), *New developments in goal setting and task performance* (pp. 51–64). Routledge.

- Bennett, R. E. (2011). Formative assessment: A critical review. *Assessment in Education: Principles, Policy & Practice*, 18(1), 5–25. <https://doi.org/10.1080/0969594X.2010.513678>
- Black, P., & Wiliam, D. (1998a). Assessment and classroom learning. *Assessment in Education: Principles, Policy & Practice*, 5(1), 7–74. <https://doi.org/10.1080/0969595980050102>
- Black, P., & Wiliam, D. (1998b). Inside the black box: Raising standards through classroom assessment. *Phi Delta Kappan*, 80(2), 139–144, 146–148.
- Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability*, 21(1), 5–31. <https://doi.org/10.1007/s11092-008-9068-5>
- Brooks, C., Burton, R., van der Kleij, F., Ablaza, C., Carroll, A., Hattie, J., & Neill, S. (2021). Teachers activating learners: The effects of a student-centred feedback approach on writing achievement. *Teaching and Teacher Education*, 105, 103387. <https://doi.org/10.1016/j.tate.2021.103387>
- Burns, E. C., Martin, A. J., & Collie, R. J. (2019). Examining the yields of growth feedback from science teachers and students' intrinsic valuing of science: Implications for student-and school-level science achievement. *Journal of Research in Science Teaching*, 56(8), 1060–1082. <https://doi.org/10.1002/tea.21546>
- Butterfuss, R., Roscoe, R. D., Allen, L. K., McCarthy, K. S., & McNamara, D. S. (2022). Strategy uptake in Writing Pal: Adaptive feedback and instruction. *Journal of Educational Computing Research*, 60(3), 696–721. <https://doi.org/10.1177/07356331211045304>
- Cai, Z., Gui, Y., Mao, P., Wang, Z., Hao, X., Fan, X., & Tai, R. H. (2023). The effect of feedback on academic achievement in technology-rich learning environments (TREs): A meta-analytic review. *Educational Research Review*, 39, 100521. <https://doi.org/10.1016/j.edurev.2023.100521>
- Carless, D., Salter, D., Yang, M., & Lam, J. (2011). Developing sustainable feedback practices. *Studies in Higher Education*, 36(4), 395–407. <https://doi.org/10.1080/03075071003642449>
- Cheng, M. H. M., & Wan, Z. H. (2016). Unpacking the paradox of Chinese science learners: Insights from research into Asian Chinese school students' attitudes towards learning science, science learning strategies, and scientific epistemological views. *Studies in Science Education*, 52(1), 29–62. <https://doi.org/10.1080/03057267.2015.1112471>
- Clark, I. (2012). Formative assessment: Assessment is for self-regulated learning. *Educational Psychology Review*, 24(2), 205–249. <https://doi.org/10.1007/s10648-011-9191-6>
- Dabney, K. P., Chakraverty, D., & Tai, R. H. (2013). The association of family influence and initial interest in science. *Science Education*, 97(3), 395–409. <https://doi.org/10.1002/sce.21060>
- Deci, E. L., Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychological Bulletin*, 125(6), 627–668. <https://doi.org/10.1037/0033-2909.125.6.627>
- Duschl, R. A., & Gitomer, D. H. (1997). Strategies and challenges to changing the focus of assessment and instruction in science classrooms. *Educational Assessment*, 4(1), 37–73. https://doi.org/10.1207/s15326977ea0401_2
- Eccles, J. S., & Wigfield, A. (2020). From expectancy-value theory to situated expectancy-value theory: A developmental, social cognitive, and sociocultural perspective on motivation. *Contemporary Educational Psychology*, 61, 101859. <https://doi.org/10.1016/j.ced-psych.2020.101859>
- Fong, C. J., Patall, E. A., Vasquez, A. C., & Stautberg, S. (2019). A meta-analysis of negative feedback on intrinsic motivation. *Educational Psychology Review*, 31(1), 121–162. <https://doi.org/10.1007/s10648-018-9446-6>
- Furtak, E. M., Heredia, S. C., & Morrison, D. (2019). Formative assessment in science education: Mapping a shifting terrain. In H. L. Andrade, R. E. Bennett, & G. J. Cizek (Eds.), *Handbook of formative assessment in the disciplines*. (pp. 97–125). Routledge. <https://doi.org/10.4324/9781315166933-5>
- Gotwals, A. W. (2018). Where are we now? Learning progressions and formative assessment. *Applied Measurement in Education*, 31(2), 157–164. <https://doi.org/10.1080/08957347.2017.1408626>
- Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. Routledge.

- Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, 77(1), 81–112. <https://doi.org/10.3102/003465430298487>
- Herman, J., Osmundson, E., Dai, Y., Ringstaff, C., & Timms, M. (2015). Investigating the dynamics of formative assessment: Relationships between teacher knowledge, assessment practice and learning. *Assessment in Education: Principles, Policy & Practice*, 22(3), 344–367. <https://doi.org/10.1080/0969594X.2015.1006521>
- Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist*, 41(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4
- Horst, P. (1941). The role of predictor variables which are independent of the criterion. *Social Science Research Council*, 48, 431–436.
- Hu, Z. (2022). Local meanings of international student assessments: An analysis of media discourses of PISA in China, 2010–2016. *Compare: A Journal of Comparative and International Education*, 52(3), 419–439. <https://doi.org/10.1080/03057925.2020.1775553>
- Jansen, T., Meyer, J., Wigfield, A., & Möller, J. (2022). Which student and instructional variables are most strongly related to academic motivation in K-12 education? A systematic review of meta-analyses. *Psychological Bulletin*, 148(1-2), 1–26. <https://doi.org/10.1037/bul0000354>
- Katsantonis, I., McLellan, R., & Torres, P. E. (2023). Unraveling the complexity of the associations between students' science achievement, motivation, and teachers' feedback. *Frontiers in Psychology*, 14, 1124189. <https://doi.org/10.3389/fpsyg.2023.1124189>
- Korous, K. M., Causadias, J. M., Bradley, R. H., Luthar, S. S., & Levy, R. (2022). A systematic overview of meta-analyses on socioeconomic status, cognitive ability, and achievement: The need to focus on specific pathways. *Psychological Reports*, 125(1), 55–97. <https://doi.org/10.1177/0033294120984127>
- Krapp, A., Hidi, S., & Renninger, K. A. (1992). Interest, learning and development. In K. A. Renninger, S. Hidi, & A. Krapp (Eds.), *The role of interest in learning and development* (pp. 3–25). Erlbaum.
- Kruijer, S. M., Leenknrecht, M. J., & Slof, B. (2022). Using scaffolding strategies to improve formative assessment practice in higher education. *Assessment & Evaluation in Higher Education*, 47(3), 458–476. <https://doi.org/10.1080/02602938.2021.1927981>
- Lau, K. C., & Ho, S. C. E. (2022). Attitudes towards science, teaching practices, and science performance in PISA 2015: Multilevel analysis of the Chinese and Western top performers. *Research in Science Education*, 52(2), 415–426. <https://doi.org/10.1007/s11165-020-09954-6>
- Liou, P. Y. (2021). Students' attitudes toward science and science achievement: An analysis of the differential effects of science instructional practices. *Journal of Research in Science Teaching*, 58(3), 310–334. <https://doi.org/10.1002/tea.21643>
- Maltese, A. V., & Tai, R. H. (2010). Eyeballs in the fridge: Sources of early interest in science. *International Journal of Science Education*, 32(5), 669–685. <https://doi.org/10.1080/09500690902792385>
- McMillan, J. H., Venable, J. C., & Varier, D. (2013). Studies of the effect of formative assessment on student achievement: So much more is needed. *Practical Assessment, Research & Evaluation*, 18(2), Article 2. <https://doi.org/10.7275/tmwm-7792>
- National Bureau of Statistics of China. (2016). *China statistical yearbook*. <http://www.stats.gov.cn/sj/ndsj/2016/indexch.htm>
- National Research Council. (2001). *Classroom assessment and the national science education standards*. National Academies Press.
- OECD. (2009). *PISA data analysis manual SPSS* (2nd ed.). OECD Publishing. <https://doi.org/10.1787/9789264056275-en>
- OECD. (2017a). *PISA 2015 assessment and analytical framework: Science, reading, mathematics, financial literacy and collaborative problem solving* (revised ed.). OECD Publishing. <https://doi.org/10.1787/9789264281820-en>
- OECD. (2017b). *PISA 2015 technical report*. OECD Publishing.
- Oliver, M., McConney, A., & Woods-McConney, A. (2021). The efficacy of inquiry-based instruction in science: A comparative analysis of six countries using PISA 2015. *Research in Science Education*, 51(S2), 595–616. <https://doi.org/10.1007/s11165-019-09901-0>

- Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections*. King's College.
- Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, 25(9), 1049–1079. <https://doi.org/10.1080/0950069032000032199>
- Rakoczy, K., Pinger, P., Hochweber, J., Klieme, E., Schütze, B., & Besser, M. (2019). Formative assessment in mathematics: Mediated by feedback's perceived usefulness and students' self-efficacy. *Learning and Instruction*, 60, 154–165. <https://doi.org/10.1016/j.learninstruc.2018.01.004>
- Raykov, T., Marcoulides, G. A., & Patelis, T. (2013). Saturated versus just identified models: A note on their distinction. *Educational and Psychological Measurement*, 73(1), 162–168. <https://doi.org/10.1177/0013164412457367>
- Reilly, D., Neumann, D. L., & Andrews, G. (2015). Sex differences in mathematics and science achievement: A meta-analysis of National Assessment of Educational Progress assessments. *Journal of Educational Psychology*, 107(3), 645–662. <https://doi.org/10.1037/edu0000012>
- Rosenman, R., Tennekoon, V., & Hill, L. G. (2011). Measuring bias in self-reported data. *International Journal of Behavioural & Healthcare Research*, 2(4), 320–332. <https://doi.org/10.1504/IJBHR.2011.043414>
- Rubin, L. H., Witkiewitz, K., Andre, J. S., & Reilly, S. (2007). Methods for handling missing data in the behavioral neurosciences: Don't throw the baby rat out with the bath water. *Journal of Undergraduate Neuroscience Education: JUNE: A Publication of FUN, Faculty for Undergraduate Neuroscience*, 5(2), A71–A77.
- Ruiz-Primo, M. A., & Furtak, E. M. (2007). Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry. *Journal of Research in Science Teaching*, 44(1), 57–84. <https://doi.org/10.1002/tea.20163>
- Schiefele, U., Krapp, A., & Winteler, A. (1992). Interest as a predictor of academic achievement: A meta-analysis of research. In K. A. Renninger, S. Hidi, & A. Krapp (Eds.), *The role of interest in learning and development* (pp. 183–211). Erlbaum.
- Sezen-Barrie, A., & Kelly, G. J. (2017). From the teacher's eyes: Facilitating teachers' noticings on informal formative assessments (IFAs) and exploring the challenges to effective implementation. *International Journal of Science Education*, 39(2), 181–212. <https://doi.org/10.1080/09500693.2016.1274921>
- Tai, R. H., Qi Liu, C., Maltese, A. V., & Fan, X. (2006). Planning early for careers in science. *Science (New York, N.Y.)*, 312(5777), 1143–1144. <https://doi.org/10.1126/science.1128690>
- Tan, C. Y. (2024). Direct and indirect influences of familial socioeconomic status on students' science achievement. *Oxford Review of Education*, 50(2), 207–231. <https://doi.org/10.1080/03054985.2022.2139672>
- Taylor, A. B., MacKinnon, D. P., & Tein, J. Y. (2008). Tests of the three-path mediated effect. *Organizational Research Methods*, 11(2), 241–269. <https://doi.org/10.1177/1094428107300344>
- Watson, D., Clark, L. A., Chmielewski, M., & Kotov, R. (2013). The value of suppressor effects in explicating the construct validity of symptom measures. *Psychological Assessment*, 25(3), 929–941. <https://doi.org/10.1037/a0032781>
- Weaver, M. R. (2006). Do students value feedback? Student perceptions of tutors' written responses. *Assessment & Evaluation in Higher Education*, 31(3), 379–394. <https://doi.org/10.1080/02602930500353061>
- Wigfield, A., & Eccles, J. S. (2020). 35 years of research on students' subjective task values and motivation: A look back and a look forward. In A. J. Elliot (Ed.), *Advances in motivation science* (Vol. 7, pp. 161–198). Elsevier Academic.
- William, D., & Leahy, S. (2007). A theoretical foundation for formative assessment. In J. H. McMillan (Ed.), *Formative classroom assessment: Theory into practice* (pp. 29–42). Teachers College Press.
- William, D., & Thompson, M. (2008). Integrating assessment with instruction: What will it take to make it work? In C. A. Dwyer (Ed.), *The future of assessment: Shaping teaching and learning* (pp. 53–82). Lawrence Erlbaum Associates.
- Winstone, N. E., Nash, R. A., Parker, M., & Rowntree, J. (2017). Supporting learners' agentic engagement with feedback: A systematic review and a taxonomy of recipience processes. *Educational Psychologist*, 52(1), 17–37. <https://doi.org/10.1080/00461520.2016.1207538>

- Wisniewski, B., Zierer, K., & Hattie, J. (2019). The power of feedback revisited: A meta-analysis of educational feedback research. *Frontiers in Psychology, 10*, 3087. <https://doi.org/10.3389/fpsyg.2019.03087>
- Yan, Z., & Chiu, M. M. (2023). The relationship between formative assessment and reading achievement: A multilevel analysis of students in 19 countries/regions. *British Educational Research Journal, 49*(1), 186–208. <https://doi.org/10.1002/berj.3837>
- Yan, Z., King, R. B., & Haw, J. Y. (2021). Formative assessment, growth mindset, and achievement: Examining their relations in the East and the West. *Assessment in Education: Principles, Policy & Practice, 28*(5–6), 676–702. <https://doi.org/10.1080/0969594X.2021.1988510>
- Yang, L. (2021). The role of feedback orientation in converting external feedback to learning opportunities for implementing assessment-as-learning in the context of feedback. In Z. Yan & L. Yang (Eds.), *Assessment as learning: Maximising opportunities for student learning and achievement* (pp. 53–76). Routledge
- Zhang, D., & Wang, C. (2020). The relationship between mathematics interest and mathematics achievement: Mediating roles of self-efficacy and mathematics anxiety. *International Journal of Educational Research, 104*, 101648 <https://doi.org/10.1016/j.ijer.2020.101648>
- Zhang, D., Wang, C., & Yang, Y. (2021). The association between cognitive activation and mathematics achievement: A multiple mediation model. *Educational Psychology, 41*(6), 695–711. <https://doi.org/10.1080/01443410.2021.1917520>
- Zhou, D., Liu, J., Wang, T., Liu, J., & Li, G. (2022). Relationships among problematic smartphone use, mathematics anxiety, learning interest, and achievement: A multiple mediation model. *Computers in Human Behavior, 129*, 107171. <https://doi.org/10.1016/j.chb.2021.107171>