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Teacher Digital Support and Self-Regulated Learning in Smart Classrooms: An fsQCA Analysis

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ABSTRACT
This research examines how teacher digital support interacts with students' psychological factors to shape self-regulated learning in smart classrooms. Using fuzzy-set qualitative comparative analysis of 186 undergraduates at pioneering institutions in China, we identified four distinct learning pathways. Key findings reveal self-efficacy and metacognitive strategies as core drivers of effective learning in three pathways, operating independently of teacher support. Technology acceptance played a supplementary role in these configurations. Only one pathway required synergistic interaction between teacher support and metacognitive strategies. These patterns validate Bandura's social cognitive theory while challenging assumptions about teacher support's primacy. They highlight context-dependent causality where personal agency often outweighs environmental factors. Practical implications suggest developing diagnostic teaching strategies that align support with learner profiles. The study demonstrates fsQCA's value in capturing educational complexity beyond traditional methods.

KEYWORDS
Self-regulated learning; Teacher digital support; FSQCA

1 Introduction

With the rapid development of technology, the traditional teaching model in higher education faces severe challenges. The prevalent teacher-centered instruction hinders the cultivation of students' core ability self-regulated learning (SRL) to cope with rapid industry iteration. Students generally have problems such as vague learning goals, lack of strategies, and weak metacognitive monitoring, leading to passive knowledge absorption and fragmented practical abilities. At the same time, the rise of smart classrooms has provided a technical path to solve this dilemma. Empowered by technologies such as the Internet of Things, learning analytics, and real-time interaction, the teaching scenario has shifted from "one-way teaching" to "data-driven dynamic closed-loop". In this context, teacher digital support has become a key lever to activate students' SRL behaviors. However, empirical research on this mechanism in college teaching is still blank. The study, adopted fuzzy set Qualitative Comparative Analysis (fsQCA), illuminates the underlying mechanism shaping students′ self-regulated learning in smart classroom learning. These insights can guide teachers on how to effectively support their students use of technology for self-regulated learning. Besides, the results can assist technology companies in refining educational technologies.

2 Literature review

2.1 Self-regulated learning (SRL)

Self-regulated learning (SRL) was defined as the self-directed process by which learners transformed their mental abilities into academic activities [1]. The theoretical foundations of self-regulated learning models derive principally from Bandura's (1986) social cognitive theory, which conceptualizes self-regulation as a goal-oriented process mediated by reciprocal interactions between individuals and their environments [2]. Different theories of self-regulated learning focus on different aspects of the process. Despite these differences, researchers generally agree that self-regulated learning is a broader process that refers to the monitoring and control of behavior, cognition, motivation, and the environment [3].

2.2 Teacher support in smart classroom

A smart classroom is commonly defined as technology-assisted closed space that enhances teaching and learning experience [4]. A smart classroom aids knowledge transfer using technological advancement in the fields of signal processing, web technologies, hardware and software, making the environment more conducive for teaching and learning[5].

The nature of teacher support has undergone significant transformation in smart learning environments. Smart learning environments provide students with opportunities to engage in self-regulated learning [6]. However, little research has examined how teachers leverage these opportunities. Teacher support is an important external stimulus that students perceive in the learning process. It is essential for promoting self-regulated learning when teachers provide clear and structured instruction, offer feedback and model self-regulated learning behaviors. The emergence of the smart classroom has introduced new concepts to transform general education and reform the teaching mode. Here, teachers need to develop their technological pedagogical content knowledge (TPACK) ability to create new pathways for need satisfaction and pedagogical support in class [7].

Chiu (2021) defined teacher digital support here refers to the design of technological learning environments to support students' innate needs. In the context of smart classroom learning, teacher support is a multi-dimensional systematic project, the core of which is to help students overcome barriers to technology application, establish recognition of technology value, and realize the deep integration of technology and learning through multi-level interaction. We mainly drew on the classification of teacher support provide by Chiu (2021), which were digital autonomy support, digital competence support and digital relativeness support [8]. In this study, teacher digital support represented a form of technology-mediated pedagogical teacher support in smart learning settings.

2.3 Mediating role of personal factors

Technology Acceptance Model (TAM) is that users' perceptions of technology, specifically their perceptions of perceived ease of use and usefulness, play a pivotal role in shaping their acceptance and use intentions [9]. Self-efficacy (SE) was defined by Bandura (1986) as a self-generated capability that integrates individuals' skills into real world situations, stimulating cognition, motivation, and emotion to develop practical problem-solving strategies. Metacognitive strategies (SMS), also referred to as Metacognitive Skills, can be subclassified in planning, monitoring, and evaluating.

However, empirical research on how teacher digital support influences students' self-regulated learning behaviors in the emerging smart learning environment remains limited. This study aims to examine whether teacher digital support as an emerging support effect on student self-regulated learning in smart classroom learning setting. Grounded in Bandura's (1986) social cognitive theory, the study explores the dynamic interplay among teacher digital support (environmental factor), the self-regulated learning (behavioral factor) and personal determinants including technology acceptance, self-efficacy, and metacognitive strategies.

3 Methods

This study was conducted at demonstration universities for smart education in China, and 186 questionnaires were collected from these universities. This study employs fuzzy-set Qualitative Comparative Analysis (fsQCA), a methodological approach grounded in fuzzy-set theory and Boolean logic. Particularly suited for analyzing asymmetric data, fsQCA identifies how combinations of antecedent conditions lead to an outcome, enabling the examination of causal complexity and configurational paths [10]. This study was conducted at demonstration universities for smart education in China, which are recognized as pioneers in smart classroom learning. A total of 186 questionnaires were administered and completed at the participating universities. The questionnaire comprised two sections. The first section collected demographic information, including gender, age, academic major, grade level, and prior experience with smart classroom learning. The second section incorporated five validated scales, followed by 20 items. This study employed a modified version of established scales from the literature, which was adapted to align with the current research objectives.

4 Data analysis and results

The study conducted a fuzzy-set qualitative comparative analysis (fsQCA), examining how teacher digital support (TDS), technology acceptance (TA), student metacognitive strategies (SMS), and self-efficacy (SE) influenced SRL. We set three calibration points in fsQCA4.1 using 95%, 50%, and 5% thresholds for full membership, crossover, and full non-membership respectively, adjusting 0.5 membership values by +0.001 for inclusion.

On the basis of data calibration, a necessity analysis is conducted on the antecedent condition variables of SRL to test whether there are necessary conditions for a given result. The necessary conditions of the result variable are analyzed through a single condition variable. The results show that the consistencies of all condition variables are less than 0.9 [10], that is, they do not constitute a necessary condition for high/low self-regulated learning. That is to say, the level of self-regulated learning is not determined by a single process-type activity. Conditional configuration analysis is needed to explore the combination of process-type activities of self-regulated learning.

Referring to the existing practice, in this study, the case frequency threshold is set to 2, the consistency threshold is set to 0.8, and the PRI (proportional reduction in inconsistency) threshold is set to 0.65 [11]. The results of configurational analysis show that there are four sufficient configurational paths for achieving self-regulated learning. The consistency of the overall solution is 0.766, the consistency of each path is higher than 0.8 and solution coverage was 0.794, indicating that the obtained configuration has strong explanatory power.

According to whether teacher digital support existed, four configurations were divided into two modes (Figure 1). The sufficient condition configuration for Mode one (configuration 1-3) is personal psychology (self-efficacy*student's metacognitive strategies*technology acceptance) without teacher digital support, where self-efficacy and student's metacognitive strategies are core conditions, and technology acceptance is an auxiliary condition. In Configuration 1 (50% coverage), self-efficacy independently promoted self-regulated learning as a core condition. Configuration 2 (65% coverage) presented the synergistic effect of self-efficacy (core condition) and Technology Acceptance (auxiliary condition). Configuration 3 (64% coverage) confirmed that the combination of self-efficacy and students' metacognitive strategies constituted a sufficient condition. while teacher digital support did not show an impact. Consistence with the results of structure equation model, these findings revealed that the individual psychological factors of self-efficacy and student's metacognitive strategies played a crucial role in self-regulated learning, and the existence of external factors such the teacher digital support did not lead to changes in self-regulated learning. In other words, the teacher support had to first cause changes in students' psychological factors before it was possible to influence self-regulated learning behavior in the smart classroom learning context.

The sufficient condition Mode tow (configuration 4) was the environment and individual psychology, where teacher digital support and student's metacognitive strategies were the core conditions, technology acceptance was the auxiliary condition, and self-efficacy was an optional condition. In the smart classroom learning setting, self-regulated learning was jointly supported by teachers' digital support and students' metacognitive strategies, with the assistance of technology acceptance, with a 54% explanation of the sample cases.

Self-regulated learning				
	Mode 1			Mode 2
Configuration	1	2	3	4
TCS	⊗			●
TA				•
SE	●	•	●	
SMS		●	●	●
consistency	0.830086	0.802311	0.831098	0.843422
raw coverage	0.484969	0.652481	0.639058	0.537143
unique coverage	0.026461	0.026457	0.029503	0.060604
solution consistency	0.766376			
solution coverage	0.794135			

● =Core causal condition present
⨂ =Core causal condition absent
• =Complementary causal condition present
⊗ =Complementary causal condition present

Abbreviations: TCS, teacher-technology collaborative support; TA, technology acceptance; SMS, students' metacognitive strategies; SE, self-efficacy

Figure 1 Results of configuration analysis

5 Discussion

The fsQCA findings reveal a nuanced and contingent picture of how self-regulated learning (SRL) emerges in smart classroom environments, challenging simplistic narratives about the direct impact of teacher digital support (TDS). The identification of four distinct causal configurations underscores the principle of equifinality—multiple pathways can lead to high SRL, but these pathways are non-linear and asymmetrical. This complexity necessitates a deeper examination of the interplay between environmental inputs (TDS) and personal psychological factors.

Configurations 1–3 (Mode 1) collectively demonstrate that SRL can thrive without direct teacher digital support when robust personal psychological factors are present. The centrality of self-efficacy (SE) across all three configurations (as a core condition in C1–C3) highlights its foundational role in activating SRL. This aligns with Bandura's (1986) emphasis on self-efficacy as a critical driver of goal-directed behavior. Notably, Configuration 1 (50% coverage) shows SE alone can sufficiently foster SRL, suggesting that highly self-efficacious students leverage smart classroom technologies autonomously. Meanwhile, Configurations 2 and 3 reveal synergistic effects: SE combines with technology acceptance (TA) as an auxiliary enhancer (C2) or with metacognitive strategies (SMS) as a corequisite (C3). This reinforces Zimmerman's (2002) assertion that metacognition—encompassing planning, monitoring, and evaluation—enables learners to strategically deploy resources. Critically, TDS's absence in these high-SRL pathways challenges assumptions that digital tools inherently catalyze self-regulation; rather, they merely enable it when students possess the SE and SMS to harness them.

Configuration 4 (Mode 2) presents a divergent pathway where TDS is essential—but only when combined with metacognitive strategies (SMS) and technology acceptance (TA). Here, TDS and SMS act as core conditions, while TA serves as an auxiliary catalyst. This configurational logic implies that teacher support cannot compensate for deficits in metacognition; instead, it amplifies existing metacognitive capacities. For instance, teachers' technology-mediated scaffolding (e. g., real-time feedback via learning analytics) may help students refine goal-setting and monitoring practices, but only if students already possess baseline metacognitive awareness. This resonates with Dignath & Veenman's (2021) observation that teacher interventions succeed when they "activate" rather than "implant" self-regulatory skills [12]. Furthermore, SE's role as an optional condition here suggests teacher support can partially substitute for low self-efficacy—a finding with critical practical implications.

These findings substantially advance Social Cognitive Theory by revealing how Bandura's triadic reciprocity functions through interconnected conditions. Environmental factors like teacher digital support prove neither universally necessary nor sufficient, as their influence depends critically on personal factors. Behavioral outcomes such as self-regulated learning emerge from specific combinations of conditions rather than isolated variables, reinforcing Fiss's case for modeling complex causality. Importantly, the asymmetric pathways—where teacher support is absent in some high self-regulation contexts yet essential in others—highlight limitations of conventional linear analyses. Practically, this demands differentiated teaching strategies. Educators should minimize intervention for learners with strong self-efficacy and metacognitive skills, encouraging autonomous technology use through self-paced modules. Conversely, students needing support benefit most when digital tools are paired with explicit metacognitive strategy guidance, such as reflective prompts embedded in learning dashboards. Success hinges on developing teachers' technological pedagogical knowledge with a focus on diagnostic judgment: recognizing when digital intervention is necessary versus when to foster student-driven learning.

6 Conclusion

This study employed fsQCA to analyze how teacher digital support (TDS) and psychological factors collectively shape self-regulated learning (SRL) in smart classrooms. These findings validate Bandura's Social Cognitive Theory in digital environments while challenging the assumed centrality of teacher support. They reveal that environmental factors (TDS) require specific personal conditions to trigger SRL, demanding context-sensitive pedagogical approaches: prioritizing SE/SMS development for autonomous learners while integrating TDS with metacognitive scaffolding for others. Methodologically, the study proves fsQCA's power in uncovering causal complexities invisible to traditional statistical methods, advancing research on educational technology's nuanced impacts.

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