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# Information and communication technology engagement and digital reading: How meta-cognitive strategies impact their relationship

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## Abstract

The purpose of the study was to examine the relationships among information and communication technology (ICT) engagement, meta-cognitive strategies and digital reading. Specifically, we used PISA 2018 data to examine whether (a) the behavioural aspect of ICT engagement negatively impacted digital reading, (b) the motivational aspect of ICT engagement positively impacted digital reading and (c) meta-cognitive strategies mediated or moderated the relationship between ICT engagement and digital reading. Our findings revealed that (a) the behavioural aspect of ICT engagement negatively impacted digital reading, whereas the motivational aspect of ICT engagement, except ICT social motivation, positively impacted digital reading; (b) the behavioural aspect of ICT engagement, as well as ICT social motivation, had significant negative indirect effects on digital reading achievement through meta-cognitive strategies, whereas all other motivational aspects of ICT engagement were differentially mediated by the meta-cognitive strategies; (c) the impact of ICT social motivation on ICT engagement was mediated and moderated by meta-cognitive strategies. These findings are discussed in terms of the educational implications, limitations and future directions.

**KEYWORDS**

digital reading, ICT engagement, meta-cognitive strategy, PISA

**Practitioner notes**

What is already known about this topic

- There is ambiguity in the literature regarding the relationship between ICT engagement and achievement.
- The nature of the relationships among ICT engagement, meta-cognitive strategy use and achievement in digital reading remains unclear.

What this paper adds

- The behavioural aspect of ICT engagement, as well as ICT social motivation, had significant negative indirect effects on digital reading achievement through meta-cognitive strategies, whereas all other motivational aspects of ICT engagement were differentially mediated by the meta-cognitive strategies.
- The impact of ICT social motivation on ICT engagement was mediated and moderated by meta-cognitive strategies.

Implications for practice and/or policy

- Practitioners should focus on how to utilize ICT by applying appropriate strategies.
- Students' knowledge about and use of meta-cognitive strategies play positive roles even in the contexts when rote learning activities predominate.

## INTRODUCTION

Information and communication technologies (ICTs) have been rapidly developing for the past decades. It has become part of our daily lives, as we use ICT for almost everything, such as work, study, leisure and socializing (Ferrari, 2012). There is evidence showing that the use of ICT positively impacts students' academic performance (Hu et al., 2018). However, integrating ICT into school and daily life does not guarantee gains in students' academic performance. In addition, the existing literature lacks empirical support for how students' knowledge of meta-cognitive strategies can influence the relationship between ICT engagement and digital reading achievement. In the current study, we address the gap by analysing the Program for International Student Assessment (PISA) 2018 data.

### ICT engagement

Engagement is manifested as energized, directed and sustained actions, and is recognized as the external manifestation of motivation (Wentzel & Miele, 2009). Scholars in the field of education and psychology tend to agree that engagement is a multi-dimensional construct, even though there is a substantial variation about the specific dimensions that constitute it (Fredricks, Filsecker, et al., 2016). According to Fredricks et al. (2004), engagement has behavioural, cognitive and emotional aspects. Behavioural engagement is an individual's involvement in academic activities, which is highly observable, such as participation and attendance. Cognitive engagement is an individual's effort and willingness to learn, which usually deals with self-regulated learning strategy use. Emotional engagement is about the positive and negative reactions to peers, teachers and schools. Social engagement is later added to Fredricks et al.'s engagement framework to reflect the social interactions in learning (Fredricks, Wang, et al., 2016).

This multi-dimensional engagement theory has a substantial overlap with the intrinsic motivation construct in self-determination theory (Deci & Ryan, 2012). From the perspective of self-determination theory, intrinsic motivation is defined as the inherent tendency to seek out novelty and challenges, to extend and exercise one's capacities, to explore and to learn (Ryan & Deci, 2000). It has several subcomponents and predictors, such as interest, competence, choice, value and relatedness (Ryan & Deci, 2017). Interest and enjoyment overlap with emotional engagement, while cognitive engagement overlaps with autonomy, which is one of the psychological needs underlying intrinsic motivation. Another need important for intrinsic motivation is relatedness, which can be mapped to social engagement. Moreover, empirical evidence shows that perceived competence is associated with behavioural engagement and emotional engagement (Rudolph et al., 2001). Therefore, according to the contemporary theories, engagement has behavioural and motivational facets.

ICT engagement refers to the initiation, maintenance and enhancement of an individual's self-determined use of ICT (Goldhammer et al., 2016). Considering engagement's multidimensional nature and its significant overlap with intrinsic motivation, we adopted the categorization proposed by Goldhammer et al. (2016) and distinguished ICT engagement into behavioural aspect and motivational aspect. The behavioural aspect of ICT engagement is an individual's actual use (frequency) of ICT in various contexts, such as in school and outside of school. The motivation aspect of ICT engagement can be further classified into ICT interest (inherent preference for ICT-related activities), ICT competence (perception about one's own knowledge of using ICT), autonomy of ICT use (a sense of agency and volition when using ICT) and ICT social motivation (the social need to share ICT-related things with others).

Existing research using PISA data has found a strong association between ICT engagement and achievement (eg, Hu et al., 2018; Hu & Yu, 2021; Kong et al., 2022; Lee & Wu, 2012; Li et al., 2020; Luu & Freeman, 2011; Meng et al., 2019). For instance, by using PISA 2015 data, Li et al. (2020) found that ICT autonomy and ICT interest positively correlated with science achievement, whereas ICT social relatedness had a negative correlation with science achievement, and ICT competence had no significant correlation with science achievement. They further looked at the potential gender differences and found that there were indeed gender differences in ICT competence, ICT interest and ICT autonomy. Kong et al. (2022) compared PISA 2018 data from the United States, Finland and Singapore. Their findings revealed that students' attitudes towards ICT use (ie, interest, competence and autonomy using ICT) were positively correlated with their digital reading achievement in all three countries. But they also found that excessive use of digital devices, which can be interpreted as the behavioural aspect of ICT engagement, led to suboptimal digital reading performance. Moreover, rather than focusing on one PISA cycle, Hu and Yu (2021) analysed four cycles of PISA data (PISA 2009, 2012, 2015, 2018) and found that the use of ICT-based social media negatively correlated with digital reading performance. However, this relationship varied in terms of the purpose behind ICT use and different types of social media.

A close look at the relevant studies shows that there is ambiguity in the literature regarding the relationship between ICT engagement and achievement, even though different cycles of PISA data have been analysed (eg, Chen & Hu, 2020; PISA 2006, 2015; Tømte & Hatlevik, 2011), different cultures have been compared (eg, Wu & Peng, 2017) and different designs have been examined (cross-sectional data in Kong et al., 2022; longitudinal data in Hu & Yu, 2021). More specifically, some studies showed that frequent ICT use led to improved students' achievement (eg, Gilleece & Eivers, 2018; Mullis et al., 2017), while other studies revealed different results—frequent use of ICT was negatively associated with achievement (eg, Gubbels et al., 2020; Kong et al., 2022). It is possible that different aspects of ICT engagement, such as interest and competence, have distinct effects on achievement

(Li et al., 2020), which contributes to the ambiguity in the existing literature regarding ICT engagement and achievement.

## Meta-cognitive strategies

Compared with traditional classroom environments, ICT-supported learning environments provide students more freedom and more choice to learn in a less structured manner. Take the hypermedia learning environment as an example, students can take advantage of the technology to decide the sequence, pace or content on their own (Gerjets et al., 2009; Scheiter & Gerjets, 2007). This autonomy may require them to have a higher level of self-regulated learning skills (Cho & Shen, 2013; Papamitsiou & Economides, 2019). What plays a central role in self-regulated learning is meta-cognition, which is 'the awareness of and knowledge about one's own thinking" (Zimmerman, 2002, p. 65). Meta-cognitive skills, which can be used to regulate one's cognitive processes and behaviours, typically involve strategies such as rehearsing and memorizing, self-evaluation, help seeking and goal setting and planning (Zimmerman & Pons, 1986). There is evidence showing that individuals' meta-cognitive skills are closely associated with learning. For instance, Vidal-Abarca et al. (2010) conducted two experiments with 7th- and 8th-grade students and found that successful readers had a higher level of meta-cognitive skills, such as being able to detect inconsistencies in questions and searching information to answer questions, compared with less successful readers. In addition, Zimmerman and Pons (1986) used a structured interview procedure to collect verbatim data from 80 high-school students, among whom 40 were considered high achievers and the rest low achievers. Their findings revealed that the use of meta-cognitive strategies positively correlated with English and mathematics scores. By using PISA 2000 data, Xu et al. (2023) investigated the relationship among strategy use (ie, control strategy, memorization strategy and elaboration strategy), perseverance, motivation and achievement. Their findings demonstrated that the control strategy positively predicted achievement, whereas the memorization strategy and the elaboration strategy both negatively predicted achievement. However, the relationships among the variables differed between East Asian and Western contexts. For students in Western cultures, both the control strategy and the memorization strategy had larger effects, whereas the elaboration strategy had a positive effect for Western students and a negative effect for East Asian students.

Findings from two key review papers shed some light on the relationship between meta-cognitive strategies and ICT. Broadbent and Poon (2015) reviewed 10 empirical studies reported from 2004 to 2014 that focused on online learning in higher education. They found that using meta-cognitive strategies significantly correlated with online learning outcomes. The size of the average correlation was small ($r = 0.06$), and there were substantial variations among these correlations. Moreover, they suggested that meta-cognitive strategies may play a crucial role as a moderator or a mediator in online learning. Cadamuro et al. (2019) closely examined the literature to seek evidence of the relationship among meta-cognition, ICT and learning outcomes. Their literature review demonstrated that the use of ICT can enhance meta-cognition, which in turn, impacts the learning outcomes, demonstrating that meta-cognition could act as a mediator. Meanwhile, they further found that meta-cognition could be a potential moderator of the relationship between ICT use and learning outcomes. Students with sufficient knowledge of meta-cognitive strategies can better utilize ICT for the improvement of their learning outcomes, compared with their peers without that kind of knowledge. Hence, Cadamuro et al. argued that there is a reciprocal link between ICT and meta-cognitive strategies.

Both Broadbent and Poon (2015) and Cadamuro et al. (2019) indicated the potential moderator or mediator role of meta-cognitive strategies, which has rarely been examined.

Xu et al. (2023) explored the mediation effects of three meta-cognitive strategies (control strategy, memorization and elaboration) using PISA 2000 data. Their findings revealed that control and memorization strategies mediated the relationship between perseverance and reading achievement. By using PISA 2018 data, Chen et al. (2021) found that knowledge of meta-cognitive strategies mediated the relationship between the use of social media and digital reading. To the best of our knowledge, except Lee and Wu (2013) and Liu and Wang (2022), the moderating effect of meta-cognitive strategies has been mostly addressed in experimental research (eg, Zhao et al., 2020; Bergey et al., 2015; Koh et al., 2018; Leopold & Leutner, 2012). Using PISA 2009, Lee and Wu (2013) distinguished two online activities—information seeking and social entertainment. Students' knowledge of meta-cognitive strategies was impacted by the frequencies of these two activities. They further found that students' high level of meta-cognitive strategy knowledge predicted optimal digital reading literacy, whereas their low knowledge of meta-cognitive strategies resulted in poor digital reading literacy, which indicates the potential moderating role of meta-cognitive strategies. In addition, as previously mentioned, there is also experimental research evidence reported in the literature. For instance, Zhao et al. (2020) specifically investigated the effects of the summarizing strategy in two interactive environments: a virtual reality environment or an interactive video environment. Their findings indicated that this meta-cognitive strategy moderated the effects of interactive learning environments on cognitive load and intrinsic motivation. However, they did not explore potential mediational mechanisms.

As can be seen from the literature, researchers have been using a variety of methods, including survey, qualitative and experimental methods, to understand the relationship between the use of ICT and meta-cognitive strategies. For instance, Wu and Peng (2017) analysed PISA 2009 data and reported the findings that the use of strategies, such as remembering and summarizing, was not only a positive predictor of reading score on the digital media, but also a positive predictor of reading score on the printed media. By using the think-aloud method, Akyel and Erçetin (2009) collected data from 10 English learners to understand their strategy use when reading in a hypermedia environment. They found that these learners utilized a variety of cognitive and meta-cognitive strategies, such as paraphrasing and monitoring, which were similar to the strategies used for reading printed materials. There is also experimental evidence showing the effects of a specific strategy in a specific digital learning environment. For instance, Salmerón et al. (2006) investigated the effectiveness of two strategies on reading hypertext, one being selecting the text that was related to the previous reading and the other being choosing the most interesting text. The results of their two experiments revealed that the effects of the two strategies on comprehension depended upon learners' prior knowledge. Zuo and Lin (2022) investigated the effects of summarizing in a computer-based environment where learners either observed a hand tracing on the material or used their index finger to trance on the material. Their experiment revealed that the use of the summarizing strategy improved retention but not transfer, regardless which form of tracing was applied.

In summary, although there is evidence in the literature showing the relationship between meta-cognitive strategies and ICT, it is still difficult to elucidate the specific relationship among ICT engagement, meta-cognitive strategy use and achievement in digital reading based on the existing findings.

## Overview of the current study

The purpose of the study was to examine the relationship among ICT engagement, meta-cognitive strategies and digital reading. As described in the previous sections, the impact of ICT engagement on digital reading is still inconclusive, which signals the need for further

research. There are indications from the existing literature that students' meta-cognitive strategy use may moderate or mediate the relationship between ICT engagement and digital reading, although the evidence is very limited (Chen et al., 2021; Lee & Wu, 2013). To clarify the ambiguity, we examined how meta-cognitive strategies would play a role in influencing the relationship between ICT engagement and digital reading.

To fill the existing gap in the literature, we utilized PISA 2018 data, which is a large-scale database with data obtained through systematic stratified sampling across 80 countries and regions across the globe. As a result, our study is able to overcome the generalizability problems associated with convenience sampling.

We categorized ICT engagement into the behavioural aspect (ICT use at school and ICT use outside of school) and motivational aspect (ICT interest, ICT competence, autonomy of ICT use and ICT social motivation). Digital reading was to assess students' 'reading literacy skills that include finding, selecting, interpreting, integrating and evaluating information' in computer-based environments (OECD, 2019a). Meta-cognitive strategies included understanding and remembering, summarizing and assessing credibility. Assessing credibility was a newly added meta-cognitive variable in the PISA 2018 questionnaires. Considering the importance of dealing with misinformation and evaluating different sources of scientific evidence (Brennan et al., 2020; Sinatra & Lombardi, 2020), it would be worthwhile examining how meta-cognitive strategies with this newly added variable played a role in the relationship between ICT engagement and digital reading.

In the current study, we addressed the following research questions and hypotheses, which can shed light on the relationship among ICT engagement, meta-cognitive strategies and digital reading (Figure 1).

a. How does ICT engagement, specifically ICT use at school, ICT use outside of school, ICT interest, ICT competence, autonomy of ICT use and ICT social motivation, impact digital reading achievement?

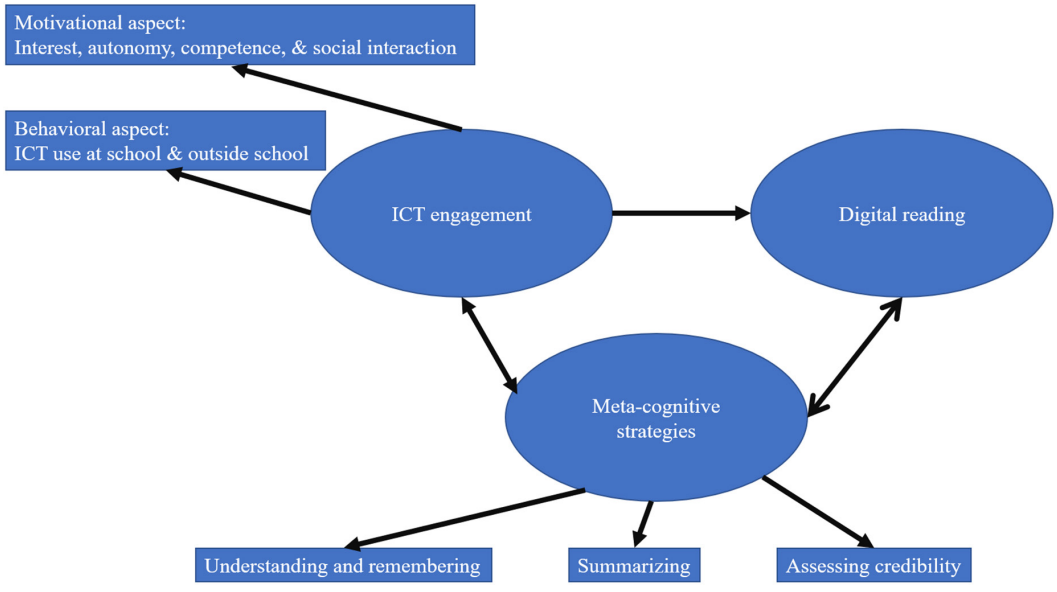



**FIGURE 1** Conceptual framework.

We hypothesized that behavioural aspect of ICT engagement (ICT use at school and outside of school) negatively impacts digital reading achievement (*Hypothesis 1*), while motivational aspect of ICT engagement (ICT interest, ICT competence, autonomy of ICT use and ICT social motivation) positively impacts digital reading achievement (*Hypothesis 2*).

b. What kind of role do meta-cognitive strategies play in the relationship between ICT engagement and digital reading?

We hypothesized that meta-cognitive strategies mediate the relationship between ICT engagement and digital reading (*Hypothesis 3*). In addition, meta-cognitive strategies moderate the relationship between ICT engagement and digital reading (*Hypothesis 4*).

# METHOD

## Sample

For the current study, the latest PISA 2018 data were retrieved (http://www.oecd.org/pisa/data/), which included a total of 612,004 students from 80 countries and regions. The triennial international assessment collected data of 15-year-old students' reading, mathematics and science achievement, as well as information regarding students' background constructs, schooling constructs and noncognitive/meta-cognitive constructs (PISA 2018 Assessment and Analytical Framework, 2019). A total of 26,975 students' data from Finland (5649 students), the United States (4838 students), Singapore (6676 students), Hong Kong (6037 students) and Macau (3775 students) were further selected. They represent five countries and regions, where students performed well in PISA reading, Males and females were almost evenly distributed (50.90% males and 49.10% females) in the sample. The average age of the students was 15.78 years old with a standard deviation of 0.29 years old. Due to different educational systems, the grade level of the sampled students ranged from Grade 7 to Grade 12 (0.50% Grade 7, 5.50% Grade 8, 31.30% Grade 9, 59.30% Grade 10, 3.50% Grade 11 and 0.10% Grade 12).

## Measures and instruments

### ICT engagement

Both aspects of students' ICT engagement, which were its behavioural aspect and motivation aspect, were assessed by the ICT Familiarity Questionnaire for PISA 2018. The behavioural engagement of ICT was measured by two index variables, which solicited students' responses about how often they would use digital devices at school (eg, using email at school, browsing the Internet for schoolwork) and outside of school (eg, using email for communication with other students about schoolwork, browsing the internet for watching YouTube videos for fun). The items were rated on a 5-point Likert scale, ranging from 1 (‘*Never or hardly ever*’) to 5 (‘*Every day*’). The Cronbach's αs for ICT use at school and ICT use out of school were 0.91 and 0.90 respectively.

The motivational aspect of ICT engagement consisted of four subcomponents: ICT interest, ICT competence, autonomy of ICT use and ICT social motivation. There were six items to measure ICT interest (sample item: ‘*I am really excited discovering new digital devices or applications*.’), five items to measure ICT competence (sample item: ‘*When I come across problems with digital devices, I think I can solve them*.’), five items to measure autonomy of

ICT use (sample item: '*If I need a new application, I choose it by myself*'.) and five items to measure ICT social motivation (sample item: '*To learn something new about digital devices, I like to talk about them with my friends*.'). All items were rated on a 4-point Likert scale, ranging from 1 ('*Strongly disagree*') to 4 ('*Strongly agree*'). The Cronbach's $\alpha$s for ICT interest, ICT competence, autonomy of ICT use and ICT social motivation were 0.80, 0.86, 0.83 and 0.86 respectively.

All ICT engagement variables, that is, ICT use at school, ICT use outside of school, ICT interest, ICT competence, autonomy of ICT use and ICT social motivation, were standardized by OECD so that each variable had a mean of zero and standard deviation of one across all students (OECD, n.d.).

### Meta-cognitive strategy

Students' knowledge of meta-cognitive strategies for reading were measured by three index variables, which were understanding and remembering (six items), summarizing (five items) and assessing credibility (five items). The former two variables were implemented in the previous cycles of PISA data, while the latter one was the newly added variable in PISA 2018 (OECD, 2020). '*I concentrate on the parts of the text that are easy to understand*' is a sample item for understanding and remembering. '*I write a summary. Then I check that each paragraph is covered in the summary*' is a sample item for summarizing, while '*Delete the email without clicking on the link*' is a sample item for assessing credibility.

For the six understanding and remembering items, as well as the five summarizing items, students responded on a 6-point Likert scale from 1 ('*Not usefully at all*') to 6 ('*Very useful*'), with higher values indicating more knowledge about meta-cognitive strategies. For the five assessing credibility items, students responded on a 6-point Likert scale from 1 ('*Not appropriate at all*') to 6 ('*Very appropriate*'). The Cronbach $\alpha$s for these three index variables were 0.73, 0.77 and 0.50 respectively.

Like the ICT engagement variables, all three meta-cognitive strategy variables, that is, understanding and remembering, summarizing and assessing credibility, were standardized by OECD so that each variable had a mean of zero and standard deviation of one across all students (OECD, n.d.).

### Digital reading

Digital reading achievement was assessed via computer by a total of 245 items in PISA 2018. The majority of students were tested 35–39 items within the 60-minute period. Ten plausible values were computed as the unbiased estimates of a student' achievement on reading. They were standardized with a mean of 500 and a standard deviation of 100. Please refer to the PISA assessment framework and technical report for more details (OECD, 2019a, 2019b).

## Analyses

Regression analysis was conducted using SPSS 27.0, whereas mediating analysis and moderating analysis were conducted within Mplus 8.3 by using maximum likelihood to estimate the parameters. To reduce the potential bias of using one plausible variable, we conducted separate analysis for each of the 10 plausible digital reading variables, and then averaged out all statistics generated from the 10 runs of analyses (OECD, 2009).

**TABLE 1** Descriptive statistics and zero-order correlations of digital reading achievement, ICT engagement and meta-cognitive strategy use.

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | DRA | 1.00 | | | | | | | | | | | | |
| 2 | USESCH | −0.117** | 1.00 | | | | | | | | | | | |
| 3 | USEOUT | −0.048** | 0.488** | 1.00 | | | | | | | | | | |
| 4 | INTICT | 0.151** | 0.141** | 0.267** | 1.00 | | | | | | | | | |
| 5 | AUTICT | 0.145** | 0.104** | 0.230** | 0.417** | 1.00 | | | | | | | | |
| 6 | COMPICT | 0.074** | 0.185** | 0.281** | 0.476** | 0.590** | 1.00 | | | | | | | |
| 7 | SOIAICT | −0.101** | 0.250** | 0.353** | 0.317** | 0.451** | 0.460** | 1.00 | | | | | | |
| 8 | UNDREM | 0.342** | −0.043** | −0.038** | 0.063** | 0.013* | 0.007 | −0.076** | 1.00 | | | | | |
| 9 | METASUM | 0.392** | −0.028** | −0.061** | 0.056** | 0.009 | 0.006 | −0.105** | 0.476** | 1.00 | | | | |
| 10 | METASPAM | 0.463** | −0.079** | −0.077** | 0.063** | 0.070** | 0.031** | −0.106** | 0.317** | 0.408** | 1.00 | | | |
| 11 | ESCS | 0.266** | 0.137** | 0.094** | 0.069** | 0.073** | 0.110** | 0.012 | 0.142** | 0.206** | 0.188** | 1.00 | | |
| 12 | GENDER[a] | −0.151** | 0.040** | 0.098** | −0.012 | 0.152** | 0.129** | 0.212** | −0.184** | −0.189** | −0.117** | −0.044** | 1.00 | |
| 13 | GRADE | 0.185** | 0.008 | 0.082** | 0.120** | 0.012* | 0.055** | −0.028** | 0.092** | 0.067** | 0.062** | 0.060** | −0.047** | 1.00 |
| 14 | M | 525.939 | 0.107 | 0.080 | 0.096 | 0.111 | −0.029 | 0.111 | −0.136 | −0.144 | 0.028 | −0.083 | 1.509 | 9.597 |
| 15 | SD | 103.585 | 0.910 | 0.763 | 0.913 | 0.908 | 0.858 | 0.888 | 0.992 | 1.013 | 1.017 | 0.991 | 0.500 | 0.674 |

Abbreviations: AUTICT, autonomy of ICT use; COMPICT, ICT competence; DRA, digital reading achievement; ESCS, socio-economic; GENDER, gender; GRADE, grade level; INTICT, ICT interest; METASPAM, assessing credibility; METASUM, summarizing; SOIAICT, ICT social motivation; UNDREM, understanding and remembering; USEOUT, ICT use outside of school; USESCH, ICT use at school.

[a]Gender was binary coded (1—female, 2—male).

**Correlation is significant at the 0.01 level (two-tailed); *Correlation is significant at the 0.05 level (two-tailed).

The percentage of missing values on all of the variables ranged from 2.34% to 8.56%. Missing data were imputed by using missForest package in Python 3.8.8 (Van Rossum & Drake, 2009). This iterative technique, which is based on random forests, is a state-of-art approach for handling missing values on a combination of continuous and categorical variables (Stekhoven & Bühlmann, 2012).

# RESULTS

Correlation matrices of digital reading achievement, meta-cognitive strategies, ICT engagement, socio-economic status, gender, grade level, as well as the means and standard deviations of these variables, are presented in Table 1.

## The impact of ICT engagement on digital reading achievement

A series of regression analysis was conducted to evaluate whether ICT use at school (ICT use outside of school, ICT interest, ICT competence, autonomy of ICT use or ICT social motivation) had significant impacts on digital reading achievement, above and beyond socio-economic status, gender and grade level. The results showed that all ICT engagement variables were significant predictors, all $p$s $<0.001$. ICT use at school ($\beta = -0.15$, $p < 0.001$), ICT use outside of school ($\beta = -0.07$, $p < 0.001$) and ICT social motivation ($\beta = -0.07$, $p < 0.001$) were negative predictors, while ICT interest ($\beta = 0.11$, $p < 0.001$), ICT competence ($\beta = 0.06$, $p < 0.001$) and autonomy of ICT use ($\beta = 0.15$, $p < 0.001$) were positive predictors. However, when all ICT engagement variables were entered as predictors in a model, ICT use outside of school and ICT competence were nonsignificant. Based on that, they were dropped, and the final model (Model 7) included four significant ICT engagement predictors, along with the control variables, and it accounted for approximately 19% of the total variance. ICT use at school ($\beta = -0.14$, $p < 0.001$) and ICT social motivation ($\beta = -0.16$, $p < 0.001$) negatively predicted digital reading, while ICT interest ($\beta = 0.11$, $p < 0.001$) and autonomy of ICT use ($\beta = 0.18$, $p < 0.001$) positively predicted digital reading. All estimated parameters are presented in Table 2.

## Mediating and moderating effects of meta-cognitive strategies

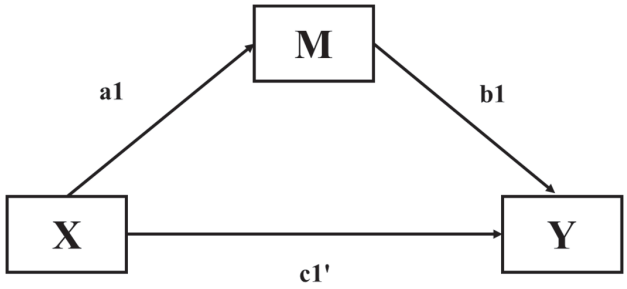
Based on the Sobel method (Hayes, 2009; Sobel, 1986), a series of mediation models were tested with the independent variable being ICT use at school (ICT use outside of school, ICT interest, ICT competence, autonomy of ICT use or ICT social motivation). The dependent variable was digital reading achievement, and the mediators were understanding and remembering (summarizing and assessing credibility) (see Figure 2). All mediation analysis models were saturated models and had a perfect fit with CFI = 1.00, SRMR = 0.00 and RMSEA = 0.00. Estimated parameters are presented in Table 3.

All indirect effects were significant, all $p$s $<0.05$, except for the following indirect effects: the indirect effect of autonomy of ICT use via understanding and remembering ($\beta = 0.002$, $p = 0.45$), the indirect effect of autonomy of ICT use via summarizing ($\beta = -0.001$, $p = 0.69$), the indirect effect of ICT competence via understanding and remembering ($\beta = 0.003$, $p = 0.36$) and the indirect effect of ICT competence via summarizing ($\beta = -0.001$, $p = 0.84$). ICT use at school, ICT use outside school and ICT social motivation had negative indirect effects on digital reading achievement via understanding and remembering, summarizing and assessing credibility (all $\beta$s $< -0.01$, all $p$s $< 0.001$). In addition, ICT interest had positive

**TABLE 2** Regression models with digital reading achievement as the dependent variable.

| | | | GENDER | | GRADE | | ESCS | | X | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Models** | | $R^2$ | $\beta$ | $p$ | $\beta$ | $p$ | $\beta$ | $p$ | $\beta$ | $p$ |
| Model 1 | USESCH | 0.139 | −0.126 | <0.001 | 0.164 | <0.001 | 0.272 | <0.001 | −0.150 | <0.001 |
| Model 2 | USEOUT | 0.122 | −0.125 | <0.001 | 0.169 | <0.001 | 0.258 | <0.001 | −0.074 | <0.001 |
| Model 3 | INTICT | 0.130 | −0.132 | <0.001 | 0.150 | <0.001 | 0.244 | <0.001 | 0.114 | <0.001 |
| Model 4 | AUTICT | 0.139 | −0.156 | <0.001 | 0.161 | <0.001 | 0.239 | <0.001 | 0.149 | <0.001 |
| Model 5 | COMPICT | 0.120 | −0.140 | <0.001 | 0.160 | <0.001 | 0.245 | <0.001 | 0.057 | <0.001 |
| Model 6 | SOIAICT | 0.122 | −0.117 | <0.001 | 0.162 | <0.001 | 0.253 | <0.001 | −0.074 | <0.001 |
| Model 7 | USESCH | 0.188 | −0.122 | <0.001 | 0.145 | <0.001 | 0.242 | <0.001 | −0.143 | <0.001 |
| | USEOUT | | | | | | | | / | |
| | INTICT | | | | | | | | 0.107 | <0.001 |
| | AUTICT | | | | | | | | 0.183 | <0.001 |
| | COMPICT | | | | | | | | / | |
| | SOIAICT | | | | | | | | −0.155 | <0.001 |

Abbreviations: AUTICT, autonomy of ICT use; COMPICT, ICT competence; ESCS, economic; social and cultural status; GENDER, gender; GRADE, grade level; INTICT, ICT interest; SOIAICT, ICT social motivation; USEOUT, ICT use outside of school; USESCH, ICT use at school.




X: ICT use at school (ICT use outside of school, ICT interest, perceived ICT competence, perceived autonomy of ICT use, or ICT as a topic in social interaction.

Y: digital reading achievement.

M: understanding and remembering, summarizing, or assessing credibility.

**FIGURE 2** Mediation model. X: ICT use at school (ICT use outside of school, ICT interest, perceived ICT competence, perceived autonomy of ICT use or ICT as a topic in social interaction. Y: digital reading achievement. M: understanding and remembering, summarizing or assessing credibility.

indirect effects on digital reading achievement via the three variables of the meta-cognitive strategies (all $\beta$s $> 0.01$, all $p$s $< 0.001$). Finally, autonomy of ICT use had a positive indirect effect on digital reading achievement only via assessing credibility ($\beta = 0.03$, $p < 0.001$), while ICT competence had a positive indirect effect via assessing credibility ($\beta = 0.01$, $p = 0.01$).

To examine the moderating role of meta-cognitive strategies, we created a predictor–moderator interaction. Specifically, ICT use at school (ICT use outside of school, ICT interest, ICT competence, autonomy of ICT use or ICT social motivation) was multiplied by understanding and remembering (summarizing or assessing credibility). A series of regression analysis was conducted, with each regression model including a predictor (eg, ICT use at school), a moderator (eg, understanding and remembering) and an interaction. When there was a significant interaction, simple slopes were further examined at three specific values of a moderator, which was one standard deviation below the mean, at the mean and one standard deviation above the mean (Cohen et al., 2002). All moderation models were saturated models and had a perfect fit with CFI = 1.00, SRMR = 0.00 and RMSEA = 0.00. Estimated parameters are presented in Table 4.

When regressing digital reading achievement on ICT use at school with understanding and remembering, summarizing or assessing credibility as the potential moderator, the results showed a significant moderation effect of understanding and remembering ($\beta = 0.03$, $p = 0.001$), indicating that for every one standardized unit increase in understanding and remembering, the impact of ICT use at school on digital reading achievement increased 0.03 standardized unit.

The moderating effect of summarizing on the regression of digital reading achievement on ICT use outside of school ($\beta = -0.02$, $p = 0.002$) was also significant. That means, for every one standardized unit increase in summarizing, the above-mentioned regression slope decreased 0.02 standardized unit.

In addition, the moderating effect of understanding and remembering on the regression of digital reading achievement on ICT competence was also significant ($\beta = -0.02$, $p = 0.03$), indicating that for every one standardized unit increase in understanding and remembering, the regression slope between digital reading and ICT competence decreased 0.02 standardized unit.

**TABLE 3** Estimated parameters in the mediation analysis.

| | | | $a_1$ [a] | | $b_1$ [b] | | $c_1$ [c] | | $a_1 \times b_1$ [d] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | X | Mediator | $\beta$ | $p$ | $\beta$ | $p$ | $\beta$ | $p$ | $\beta$ | $p$ |
| Behavioural aspect of engagement | USESCH | UNDREM | **−0.043** | **<0.001** | **0.331** | **<0.001** | **−0.103** | **<0.001** | **−0.014** | **<0.001** |
| | | METASUM | **−0.029** | **<0.001** | **0.385** | **<0.001** | **−0.106** | **<0.001** | **−0.011** | **<0.001** |
| | | METASPAM | **−0.079** | **<0.001** | **0.456** | **<0.001** | **−0.084** | **<0.001** | **−0.038** | **<0.001** |
| | USEOUT | UNDREM | **−0.041** | **<0.001** | **0.334** | **<0.001** | **−0.038** | **<0.001** | **−0.014** | **<0.001** |
| | | METASUM | **−0.067** | **<0.001** | **0.387** | **<0.001** | **−0.026** | **<0.001** | **−0.026** | **<0.001** |
| | | METASPAM | **−0.081** | **<0.001** | **0.461** | **<0.001** | −0.015 | 0.061 | **−0.037** | **<0.001** |
| Motivational aspect of engagement | INTICT | UNDREM | **0.056** | **<0.001** | **0.329** | **<0.001** | **0.124** | **<0.001** | **0.018** | **<0.001** |
| | | METASUM | **0.051** | **<0.001** | **0.382** | **<0.001** | **0.122** | **<0.001** | **0.020** | **<0.001** |
| | | METASPAM | **0.053** | **<0.001** | **0.456** | **<0.001** | **0.118** | **<0.001** | **0.024** | **<0.001** |
| | AUTICT | UNDREM | 0.006 | 0.450 | **0.335** | **<0.001** | **0.131** | **<0.001** | 0.002 | 0.450 |
| | | METASUM | −0.003 | 0.689 | **0.389** | **<0.001** | **0.135** | **<0.001** | −0.001 | 0.689 |
| | | METASPAM | **0.058** | **<0.001** | **0.456** | **<0.001** | **0.107** | **<0.001** | **0.026** | **<0.001** |
| | COMPICT | UNDREM | 0.008 | 0.360 | **0.335** | **<0.001** | **0.062** | **<0.001** | 0.003 | 0.360 |
| | | METASUM | −0.002 | 0.835 | **0.388** | **<0.001** | **0.066** | **<0.001** | −0.001 | 0.835 |
| | | METASPAM | **0.021** | **0.012** | **0.461** | **<0.001** | **0.055** | **<0.001** | **0.010** | **0.012** |
| | SOIAICT | UNDREM | **−0.081** | **<0.001** | **0.329** | **<0.001** | **−0.080** | **<0.001** | **−0.027** | **<0.001** |
| | | METASUM | **−0.113** | **<0.001** | **0.381** | **<0.001** | **−0.064** | **<0.001** | **−0.043** | **<0.001** |
| | | METASPAM | **−0.114** | **<0.001** | **0.456** | **<0.001** | **−0.054** | **<0.001** | **−0.052** | **<0.001** |

*Note*: Significant results are highlighted in bold.

Abbreviations: AUTICT, autonomy of ICT use; COMPICT, ICT competence; INTICT, ICT interest; METASPAM, assessing credibility; METASUM, summarizing; SOIAICT, ICT social motivation; UNDREM, understanding and remembering; USEOUT, ICT use outside of school; USESCH, ICT use at school; X, independent variable.

[a]Direct effect of X on a mediator.

[b]Direct effect of a mediator on digital reading achievement.

[c]Direct effect of X on digital reading achievement.

[d]Indirect effect of X on digital reading achievement.

**TABLE 4** Estimated parameters in the moderation analysis.

| | | | X×M | | M | | X | | β When M=Mean−1SD | β When M=Mean | β When M=Mean+1SD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | M | β | p | β | p | β | p | | | |
| Behavioural aspect of engagement | USESCH | UNDREM | **0.027** | **0.001** | **0.331** | **<0.001** | **−0.097** | **<0.001** | −0.140 | −0.090 | −0.022 |
| | | METASUM | 0.003 | 0.760 | **0.385** | **<0.001** | **−0.105** | **<0.001** | | | |
| | | METASPAM | 0.008 | 0.245 | **0.456** | **<0.001** | **−0.077** | **<0.001** | | | |
| | USEOUT | UNDREM | −0.002 | 0.830 | **0.334** | **<0.001** | **−0.039** | **<0.001** | | | |
| | | METASUM | **−0.020** | **0.002** | **0.388** | **<0.001** | **−0.035** | **<0.001** | −0.019 | −0.037 | −0.055 |
| | | METASPAM | −0.015 | 0.068 | **0.461** | **<0.001** | **−0.021** | **0.016** | | | |
| Motivational aspect of engagement | INTICT | UNDREM | −0.010 | 0.388 | **0.329** | **<0.001** | **0.122** | **<0.001** | | | |
| | | METASUM | 0.011 | 0.154 | **0.382** | **<0.001** | **0.124** | **<0.001** | | | |
| | | METASPAM | −0.001 | 0.868 | **0.456** | **<0.001** | **0.118** | **<0.001** | | | |
| | AUTICT | UNDREM | −0.003 | 0.738 | **0.335** | **<0.001** | **0.131** | **<0.001** | | | |
| | | METASUM | 0.010 | 0.176 | **0.389** | **<0.001** | **0.135** | **<0.001** | | | |
| | | METASPAM | 0.010 | 0.134 | **0.456** | **<0.001** | **0.107** | **<0.001** | | | |
| | COMPICT | UNDREM | **−0.018** | **0.025** | **0.335** | **<0.001** | **0.061** | **<0.001** | 0.098 | 0.076 | 0.039 |
| | | METASUM | −0.001 | 0.806 | **0.388** | **<0.001** | **0.070** | **<0.001** | | | |
| | | METASPAM | 0.003 | 0.713 | **0.461** | **<0.001** | **0.055** | **<0.001** | | | |
| | SOIAICT | UNDREM | **−0.016** | **0.027** | **0.329** | **<0.001** | **−0.081** | **<0.001** | −0.067 | −0.080 | −0.122 |
| | | METASUM | **−0.039** | **<0.001** | **0.382** | **<0.001** | **−0.067** | **<0.001** | −0.077 | −0.081 | −0.115 |
| | | METASPAM | **−0.032** | **<0.001** | **0.457** | **<0.001** | **−0.056** | **<0.001** | −0.064 | −0.084 | −134 |

*Note*: Significant results are highlighted in bold.

Abbreviations: AUTICT, autonomy of ICT use; COMPICT, ICT competence; INTICT, ICT interest; M, moderator; METASPAM, assessing credibility; METASUM, summarizing; SOIAICT, ICT social motivation; UNDREM, understanding and remembering; USEOUT, ICT use outside of school; USESCH, ICT use at school; X, independent variable.

Finally, understanding and remembering ($\beta = -0.02$, $p = 0.03$), summarizing ($\beta = -0.04$, $p < 0.001$) and assessing credibility ($\beta = -0.03$, $p < 0.001$) moderated the relationship between digital reading achievement and ICT social motivation. The negative beta values indicated that for every one standardized unit increase in understanding and remembering, summarizing and assessing credibility, the impact of ICT social motivation on digital reading achievement decreased 0.02 standardized unit, 0.04 standardized unit and 0.03 standardized unit respectively.

For the above significant moderation effects, simple slopes were further examined when a moderator was at one standard deviation below its mean, at its mean and one standard deviation above its mean. The results are presented in Table 4.

## DISCUSSION AND CONCLUSION

The purpose of the study was to examine the relationships among ICT engagement, meta-cognitive strategies and digital reading. Our analysis of PISA 2018 data has revealed several major findings. First, behavioural aspect of ICT engagement negatively impacted digital reading, whereas motivational aspect of ICT engagement, except ICT social motivation, positively impacted digital reading. Second, the behavioural aspect of ICT engagement, as well as ICT social motivation, had significant negative indirect effects on digital reading achievement through all meta-cognitive strategies, whereas all other motivational aspect ICT engagement were differentially mediated by the meta-cognitive strategies. Third, the impact of ICT social motivation on ICT engagement was mediated and moderated by meta-cognitive strategies. These findings are discussed below.

### The mediating role of meta-cognitive strategies

Based on the theory of engagement (Fredricks et al., 2004) and the theory of motivation (Deci & Ryan, 2012), we distinguished ICT engagement into behavioural aspect (ICT use at school and outside of school) and motivational aspect (ICT interest, ICT competence, autonomy of ICT use and ICT social motivation). Our analysis showed that, overall, the behavioural aspect of ICT engagement negatively impacted digital reading, whereas motivational aspect of ICT engagement positively impacted digital reading, which supports Hypothesis 1 and Hypothesis 2. In particular, no matter whether students were at school or outside of school, frequent use of ICT prevented achieving high scores on digital reading, which is consistent with some existing findings (eg, Gubbels et al., 2020; Kong et al., 2022) but different from the findings revealed from Mullis et al. (2017).

These inconclusive results could be due to the existence of potential mediators, which has been demonstrated by the current study's findings. Specifically, students' knowledge about meta-cognitive strategies mediated the relationship between digital reading achievement and the behavioural aspect of ICT engagement. We used PISA 2018 assessment, which included three meta-cognitive strategy variables—understanding and remembering, summarizing and assessing credibility. Our analysis indicated that the behavioural aspect of ICT engagement had significant negative indirect effects on digital reading achievement through all three meta-cognitive strategy variables, which partially supports Hypothesis 3. These results highlight the importance of guiding students to wisely use ICT for learning. If they apply strategies that aim to improve rote learning, such as memorizing the content, or summarizing the content by copy and paste, utilizing ICT does not seem to lead to improved learning. Therefore, appropriate training of strategy use is needed (Azevedo & Cromley, 2004).

It is worth noting that assessing credibility was added in PISA 2018, a meta-cognitive variable that was not assessed in the previous PISA cycles. Our results showed that, like the other two meta-cognitive strategies, assessing credibility played a significant role as a mediator between digital reading achievement and the behavioural aspect of ICT engagement. This could be interpreted as the importance of students assessing the credibility of information. If students frequently use ICT without evaluating the information delivered via ICT, this kind of ICT use hurts learning. This result echoes with the recent literature that emphasizes the evaluation of scientific information (Brennan et al., 2020; Sinatra & Lombardi, 2020).

In addition to the behavioural aspect of ICT engagement, the motivational aspect of ICT engagement, except ICT social motivation, positively impacted digital reading achievement. Overall, more motivated to use ICT, higher digital reading achievement. This result is consistent with some existing research (Hu et al., 2018; Tømte & Hatlevik, 2011). What the current study adds to the existing literature is that students' knowledge about meta-cognitive strategies mediated some of the relationships between digital reading achievement and the motivational aspect of ICT engagement, which partially supports Hypothesis 3. In particular, ICT interest had positive indirect effects on digital reading achievement via all three meta-cognitive strategies. Furthermore, autonomy of ICT use had a positive indirect effect on digital reading achievement via assessing credibility, while ICT competence had a positive indirect effect via assessing credibility. Our interpretation of the results is that students with a high level of interest and a sense of autonomy and competence may be able to process information delivered via ICT in an active manner with more strategies applied to select information, organize it into coherent structures and integrate it with their prior knowledge (Fiorella & Mayer, 2016). This active information processing, if it occurs, positively impacts their reading achievement. This provides empirical evidence to support the incorporation of motivation into existing learning theories (Mayer, 2014).

However, our analysis also indicated that not all meta-cognitive strategies played a significant mediating role. Summarizing, as well as understanding and remembering, was not a significant mediator for a couple of motivational ICT engagement variables (ie, autonomy of ICT use and ICT competence). More research is needed to clarify these relationships. It could be due to the quality of students' generated summaries, an issue that has been noted in the contemporary engagement theories (Chi & Wylie, 2014). It is also possible that the effect of the memorization strategy has differential cultural impacts (Xu et al., 2023). Future research could utilize survey data and experimental data, along with process data, to generate a more nuanced understanding of the effectiveness of certain strategies, such as summarizing and remembering.

ICT social motivation, categorized as the motivational aspect of ICT engagement, negatively impacted digital reading achievement. In addition, the indirect effect of meta-cognitive strategies on the relationship between ICT social motivation and digital reading achievement was also negative. Together with other research that has revealed similar findings (eg, Chen, et al., 2021), we argue that social engagement that involves more than one student is more complex than individual engagement in digital environments. Considering the emphasis on the social element in contemporary motivation and engagement theories (Chi & Wylie, 2014; King & McInerney, 2014; Xie et al., 2022), there might be a need for more empirical research to look into the complex interactions among students when they are in ICT-supported learning environments.

## The moderating role of meta-cognitive strategies

In addition to the mediating effect, we also tested the potential moderating effect of meta-cognitive strategies that impact the relationship between ICT engagement and digital

reading achievement, which has rarely been addressed by researchers. Overall, our analysis indicated that the summarizing strategy moderated the impact of behavioural aspect of ICT engagement on digital reading achievement, which provides partial evidence to support Hypothesis 4. Specifically, with the better knowledge and use of summarizing, the negative impact of ICT use outside of school on digital reading became less strong. Based on that, we argue that appropriate use of the summarizing strategy, for example soliciting learners to make inferences from the reading material, can help engage students in learning in ICT-supported environments, which optimizes their learning outcomes. Moreover, these findings echo the existing research, most of which reports experimental studies conducted with a convenient sample (eg, Zuo & Lin, 2022). What the current study adds is that the positive effect of summarizing may be a general effect, as not only has it been found in experimental research, but also large-scale survey research, such as the PISA 2018 data.

In addition to the summarizing strategy, understanding and remembering strategy also moderated the negative impact of ICT use at school, as well as the positive impact of ICT competence, on digital reading achievement. It is a double-edged sword by mitigating the negative impact of ICT use at school on digital reading while reducing the positive impact of ICT competence. This is an interesting finding, because strategies like memorizing and remembering have been considered a rote learning approach (Chi & Wylie, 2014). Moreover, previous research has indicated that this rote learning strategy has different impacts in various cultures (Xu et al., 2023). What the current study adds is that rote learning strategies, such as remembering, may be still useful in the contexts where ICT use does not facilitate learning. But this benefit of rote learning also comes with a cost on students' motivation, perceived competence in particular.

In addition to the mediating effect of the three meta-cognitive strategies, we also found a moderating effect between ICT social motivation and meta-cognitive strategies on digital reading achievement. Specifically, the negative impact of ICT social motivation on digital reading achievement was mitigated by meta-cognitive strategies. This, along with the findings regarding ICT use behaviours, highlights the importance of utilizing meta-cognitive strategies in ICT-supported learning environments because it can ameliorate the negative effect of the motivational ICT engagement (ie, ICT social motivation), as well as ICT use behaviours, on achievement, while amplifying the positive effect of the motivational ICT engagement. Existing theories and research (Fiorella & Mayer, 2016) have already shed some light on the potential of strategy use. Future research could focus more on how different strategy uses lead to different levels of engagement, which in turn results in different learning outcomes (Chi & Wylie, 2014).

## Educational implications

The findings of the current study have important educational implications. First, it emphasizes the need to take motivation into account. Contemporary theories, such as the cognitive theory of multimedia learning (Mayer, 2014), cognitive load theory (Sweller et al., 2011) and the theory of engagement (Chi & Wylie, 2014), typically put a heavy emphasis on cognition and rely on experimental evidence. The findings of the current study, based on a large-scale survey data (ie, PISA data), provide empirical evidence for including motivation in the existing theoretical framework. Second, educational researchers and practitioners need to be aware that using ICT for learning should not be the focus in modern times. Instead, it should be about how to utilize ICT by applying appropriate strategies. It is obvious that inordinate use of ICT reduces students' engagement and prevents learning. Third, students' knowledge about and use of meta-cognitive strategies cannot be ignored because these strategies play positive roles even in the contexts when rote learning activities are in play. Teachers should

consider incorporating strategy trainings in their classroom teaching to ensure students' quality use of these strategies.

## Limitations and future directions

The current study has several limitations that could be addressed in future research. First, as discussed above, the PISA data and analysis are unable to reveal how meta-cognitive strategies impact engagement and achievement. The quality of students' meta-cognitive strategy use remains unknown. Future research could either specifically or systematically investigate the effect of a strategy using experimental design (eg, Zuo and Lin, 2022), or uncover the black box by collecting and analysing process data (eg, Jiang et al., 2021). Second, PISA data may suffer from some inherent problems, such as sampling issues, biased assessment and lack of representation of lower income countries (Zhao, 2020). More methodological research is needed to enhance the credibility of the data.

### CONFLICT OF INTEREST STATEMENT

There is no potential conflict of interest.

### DATA AVAILABILITY STATEMENT

Data used in this study can be accessed through website: http://www.oecd.org/pisa/data.

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