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Impact of extracurricular synchronous and asynchronous computer-mediated communication between students and teachers on digital reading performance: Evidence from 53 countries/regions

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Abstract

This study compared the effects of extracurricular synchronous computer-mediated communication (SCMC) and asynchronous computer-mediated communication (ASCMC) between students and teachers on students' digital reading performance at different frequencies. 392,269 samples from 53 countries/regions that participated in the Programme for International Student Assessment 2018 were collected. Multilevel regression analysis showed that SCMC negatively influenced digital reading performance across countries/regions. As the frequency decreased, the negative effect of SCMC diminished. In contrast, ASCMC at a moderately low frequency could facilitate digital reading performance in some countries/regions; however, as frequency increased, the positive effect became negative. These results showed that synchronicity played a role in predicting students' digital reading performance. This study also explored the mediating effect of metacognition with Nelson and Naren's metacognitive control-monitoring model. A multilevel mediation analysis proved that the effects of SCMC and ASCMC on digital reading performance were mediated by students' metacognition of assessing credibility. Practical implications and suggestions for students' self-paced learning were discussed with the purpose of promoting the effective use of extracurricular CMC between students and teachers and improving students' digital reading achievement in the post-COVID-19 pandemic era.

Keywords Computer-mediated communication · Digital reading · Metacognition · PISA reading · Self-paced learning

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1 Introduction

With the rapid development of information and communications technology (ICT), communication between students and teachers has been largely transitioned from the face-to-face mode to the computer-mediated communication (CMC) mode outside of school (e.g., Chen et al., 2021a; Yang, 2009; Yang et al., 2022). In addition, the spread of the coronavirus disease 2019 (COVID-19) pandemic has given further impetus to this shift (Dhawan, 2020). Therefore, it is essential to explore the impact of extracurricular student-teacher CMC and to further develop effective student-teacher communications outside of school in the post-COVID-19 pandemic era. CMC can be categorized as synchronous CMC (SCMC) and asynchronous CMC (ASCMC) (Jonassen et al., 1995) in which SCMC is instant, i.e., in real-time (e.g., Facebook), and ASCMC has a longer interval, i.e., delayed in time (e.g., e-mail). The effects of both SCMC and ASCMC on academic outcomes can be positively predictive (e.g., Junco et al., 2011; Law & Stock, 2019; Shang, 2005) or negatively predictive (e.g., Abrams, 2003; Giesbers et al., 2014; Kirschner & Karpinski, 2010; Paul et al., 2012).

Another notable change in the rapid development of ICT is the shift of reading from print to digital texts (e.g., Xiao et al., 2019; Xiao & Hu, 2019; Yu & Hu, 2022a). With a wealth of information, smaller displays, cluttered screens, and networks of pages, the texts that people read online significantly differ from traditional texts, which calls for the cultivation of digital reading proficiency (OECD, 2019). It has been noted that the additional complexities of hypertexts compared to printed texts require an additional metacognitive process (Coiro & Dobler, 2007) and dynamic adjustment of learning strategies (Hu, 2014). To address the challenges posed by the rich inventories of knowledge created by complex or even contradictory information online (Hahnel et al., 2018), it is essential for learners to metacognitively supervise the process of assessing credibility (e.g., Abendroth & Richter, 2021; Lang et al., 2021; Maier & Richter, 2013; Mason et al., 2010). Therefore, the role of metacognition in assessing credibility in students' reading performance is particularly significant as a topic for further investigation in the digital era.

Based on the controversial role of extracurricular CMC in students' academic reading performance, this study attempted to investigate whether current extracurricular SCMC and ASCMC between students and teachers at different frequencies are effective in facilitating students' digital reading performance from an international perspective. Furthermore, the underlying reasons why extracurricular CMC between students and teachers influences students' digital reading performance were explored from the perspective of the metacognitive process of assessing credibility to provide insights into how to develop effective student-teacher online communication outside of school in the post-COVID-19 pandemic era.

2 Literature review

2.1 SCMC and ASCMC

As SCMC and ASCMC differ in the interval of response, ASCMC has distinct benefits for students' learning compared to SCMC in several respects. Studies found that students took more time to contemplate questions in depth in ASCMC than in SCMC (e.g., AbuSeileek & Qatawneh, 2013; Angeli & Schwartz, 2016; Riordan & Kreuz, 2010). Furthermore, students displayed higher cognitive achievement (e.g., Ogbonna et al., 2019) and provided more accurate (e.g., Giesbers et al., 2014), complex and sophisticated answers (e.g., Oztok et al., 2013) during ASCMC than during SCMC. The majority of the above studies focus on the language skills of speaking (e.g., AbuSeileek & Qatawneh, 2013; Cunningham, 2016; McNeil, 2014; Razagifard, 2013) and writing (e.g., Angeli & Schwartz, 2016). However, research concerning the language skills of reading, particularly digital reading, is noticeably scarce (Christopher et al., 2004; Yu et al., 2022). Additionally, differences in the timing of asynchronous responses convey important information about users' perceptions and expectations of ASCMC (Tyler & Tang, 2003). Comparison of the effects of SCMC and ASCMC, however, has primarily occurred under conditions in which the frequency of the CMC was controlled, such as in settings where SCMC or ASCMC were used once a week (AbuSeileek & Qatawneh, 2013; Pérez, 2003). To the best of our knowledge, however, no research compared the impacts of SCMC and ASCMC on students' academic achievement under varied frequencies. Therefore, the present study was undertaken to remedy the aforementioned two research gaps and explore the differential effects of SCMC and ASCMC between students and teachers on digital reading performance when the frequency of CMC varies.

2.2 Metacognition and digital reading performance

Metacognition refers to the regulation of one's cognitive activities in learning processes (Flavell, 1979). The results of previous studies have consistently proven that high-achieving readers employ appropriate metacognitive strategies in reading (e.g., Dignath et al., 2008; Mokhtari & Reichard, 2002; Thiede et al., 2003), whereas low-achieving readers use fewer metacognitive strategies (e.g., Lau & Chan, 2003). Furthermore, in both printed and electronic formats, metacognitive strategies have been shown to have positive effects on reading performance (e.g., Chang et al., 2019; Wu & Peng, 2017). These positive effects might be explained by several factors related to the frequent use of metacognitive strategies, including reduced anxiety (Melanlioglu, 2014), a positive attitude towards reading texts (e.g., Mijuskovic & Simovic, 2016), and high intrinsic motivation for reading comprehension (e.g., Miyamoto et al., 2019). In addition, metacognition is often found to be a positive variable mediating the relationship between students' digital reading achievement

and different independent variables, e.g., intrinsic motivation (e.g., Miyamoto et al., 2019), teaching methods (e.g., Schünemann et al., 2013), and parent involvement (e.g., Veas et al., 2019). Nevertheless, the impact of extracurricular CMC between students and teachers on students' digital reading performance and the mediating role of metacognition are still understudied.

In the context of PISA, metacognition refers to the ability to think about and control reading and comprehension strategies (OECD, 2019, p. 52). Digital reading, as defined in the PISA context, requires readers to be minimally ICT competent, to search for texts online, to assess information quality and credibility, to corroborate information, and to resolve potential discrepancies and conflicts (OECD, 2019, p. 26). In PISA-related research, metacognition has also been found to enhance digital reading (e.g., Lee & Wu, 2013; Lim & Jung, 2019; Wu, 2014). Concerning the mediating role of metacognition, PISA-related studies have also shown metacognition to be a strong mediator between various independent variables and students' digital reading achievement; for example, metacognition positively mediated the relationship between information-seeking reading activities (e.g., Lee & Wu 2013; Wu, 2014) and students' digital reading performance. Narrowing the discussion to a specific type of metacognition, metacognition of assessing credibility is particularly important for students to navigate the sea of digital information (e.g., Abendroth & Richter, 2021; Lang et al., 2021; Maier & Richter, 2013; Mason et al., 2010). Considering that the particular metacognitive process of assessing credibility was newly added to the latest round of the PISA in 2018, previous PISA-related research on metacognition has not engaged in discussions of this aspect, which provides a research impetus for the current study.

2.3 Conceptual framework of CMC and metacognition

The current study utilized Nelson and Naren's (1990) metacognitive control-monitoring model as the theoretical framework to explore the mechanism of the metacognitive process of assessing credibility during extracurricular SCMC and ASCMC between students and teachers. Nelson and Naren's formulation of the metacognitive system consists of two dominance relations (i.e., control and monitoring). Metacognitive control is interpreted as a change in the current behavior, while metacognitive monitoring refers to the process of obtaining information from what is occurring (Nelson & Narens, 1990). In the ongoing process of acquisition, metacognitive monitoring allows judgment regarding whether the current state of mastery reaches the norm of study, i.e., the desired mastery. If yes, learners exit from the acquisition sequence. In contrast, if not, learners allocate additional self-paced study time to the learning material and implement strategies from their metacognitive library of strategies to attain the desired mastery. The current study extended this model further from the following two aspects. First, the current study extended the discussion to the unexplored aspect of synchronous learning. Second, this study testified a particular metacognitive process of assessing credibility. On this basis, an adapted conceptual framework was developed in this study to illustrate the relationship between the two CMC modes and metacognition during the process of learning (see Fig. 1). The left-hand box

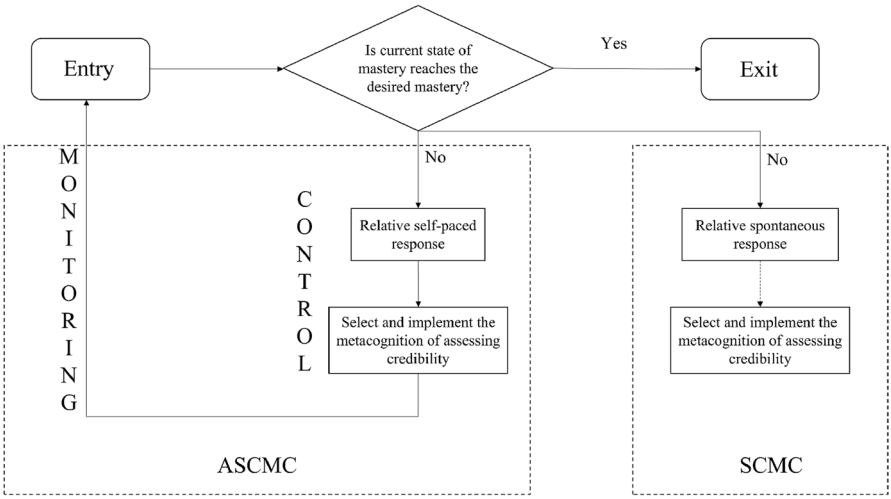

Fig. 1 The adapted conceptual framework of the two CMC modes and metacognition

framed by dotted lines shows the metacognitive process during ASCMC, with the adjustment of selecting strategies from learners' metacognitive library to the particular metacognitive process of assessing credibility. The right-hand box framed by dotted lines displays the presumed metacognitive process during SCMC, which was newly developed in the current study to fulfill the aim of this study.

Based on the literature review and the conceptual framework, the following research questions (RQs) were developed:

RQ 1: What are the effects of extracurricular SCMC and ASCMC between students and teachers on digital reading performance at different frequencies across countries/regions?
RQ 2: Are the effects of extracurricular SCMC and ASCMC between students and teachers on digital reading performance mediated by the metacognitive process of assessing credibility across countries/regions?

Corresponding to the RQs, the following hypotheses were proposed in this study:

Hypothesis 1: As manifested in the literature review, students have more time to contemplate questions during ASCMC than SCMC (e.g., AbuSeileek & Qatawneh, 2013; Angeli & Schwartz, 2016; Riordan & Kreuz, 2010) and therefore display a higher cognitive level (e.g., Ogbonna et al., 2019) and give more accurate answers (e.g., Giesbers et al., 2014). Therefore, this study hypothesized that ASCMC between students and teachers would have a more positive effect on students' digital reading performance than SCMC. In addition, ASCMC differs from SCMC in the interval of response, and as the frequency of ASCMC increases, ASCMC gradually loses the trait of asynchronicity, becoming more synchronous

and verging on SCMC. This study, therefore, hypothesized that the positive effect of ASCMC would diminish as the frequency of ASCMC increased.

Hypothesis 2: According to Nelson and Naren's (1990) control-monitoring model, when students' current state of mastery does not reach the desired level, students learn asynchronously by devoting more study time to items that they perceive as harder and less study time to easier items, and during this process, they choose and implement the required metacognitive strategies. Therefore, this study hypothesized that ASCMC between students and teachers would have a positive effect on the cultivation of students' metacognition, while SCMC would not have a positive effect because of the limited self-paced learning time. In addition, many studies have shown that metacognition could facilitate digital reading and serve as a mediator in the relationship between various independent variables and digital reading performance (e.g., Yu & Hu, 2022b). Thus, this study also hypothesized that the effects of extracurricular SCMC and ASCMC between students and teachers on students' digital reading performance would be mediated by the metacognitive process of assessing credibility.

3 Methods

3.1 Data source

The Programme for International Student Assessment (PISA) is one of the largest international exams, evaluating the knowledge and abilities of 15-year-olds enrolled in compulsory education (Adam & Tatnall, 2017; Srijamdee & Pholphirul, 2020). By establishing standardized examinations to assess students' performance, PISA has proven its reliability (e.g., Hu & Yu, 2021; OECD, 2017) and validity (Artelt & Schneider, 2015; Stadler et al., 2020); and it enables quantification and comparison across countries, regions, and even individual schools (Herborn et al., 2020; Niemann et al., 2017); and so has a substantial influence on educational systems globally (Arpaci et al., 2021; Eickelmann et al., 2017).

Released in December 2019, the latest data from the PISA 2018 was used as the source for this research (URL: http://www.oecd.org/pisa/data/2018database/), which is the seventh cycle of PISA. Seventy-nine countries/regions participated in this cycle, and PISA 2018 foregrounds students' reading performance on both paper-based and computer-based tests. In PISA 2018, the item related to students' metacognitive skill of assessing credibility was measured for the first time in the student questionnaire. In addition, ICT-related items were collected from the ICT Familiarity Questionnaire, among which two items explicitly address the self-reported frequency of extracurricular SCMC and ASCMC usage between students and teachers. For the purpose of this study, 392,269 samples from 53 countries/regions that participated in the digital reading test were selected, and the demographic information of the samples is presented in Table 1 (see https://doi.org/10.6084/m9.figshare.14974299.v5).

Table 1 Demographic information of the samples

Country/Region	N (students)	Female %	N (schools)	SCMC		ASCMC		ICC
				Mean	SD	Mean	SD	
Albania	6,359	49.8	327	2.71	1.40	2.66	1.31	0.2587
Australia	14,273	49.6	763	1.94	1.29	2.68	1.10	0.1808
Austria	6,802	48.8	291	1.77	1.12	2.03	1.08	0.4757
Belgium	8,475	50.4	289	1.71	1.22	1.88	1.05	0.4679
Brazil	1,0691	51.2	598	2.53	1.39	2.16	1.29	0.4286
Brunei Darussalam	6,828	49.5	55	2.15	1.27	1.90	1.09	0.3999
Bulgaria	5,294	47.8	197	2.82	1.21	2.71	1.18	0.5176
Chile	7,621	50.0	254	1.98	1.28	2.15	1.12	0.3821
Chinese Taipei	7,243	50.0	192	1.98	1.17	1.89	1.01	0.3197
Costa Rica	7,221	50.1	205	2.37	1.46	2.19	1.30	0.3128
Croatia	6,609	50.1	183	2.10	1.37	2.15	1.18	0.3972
Czech Republic	7,019	50.1	333	1.85	1.23	2.09	1.03	0.5245
Denmark	7,657	49.8	348	1.96	1.28	2.03	1.13	0.1728
Dominican Republic	5,674	50.9	235	2.41	1.39	2.25	1.32	0.3967
Estonia	5,316	49.9	230	2.17	1.33	2.29	1.12	0.2025
Finland	5,649	49.1	214	1.56	0.99	1.91	0.97	0.0822
France	6,308	48.8	252	1.75	1.25	1.80	1.10	0.5112
Georgia	5,572	48.1	321	2.74	1.29	2.36	1.25	0.2730
Greece	6,403	49.6	242	2.36	1.49	2.29	1.35	0.3717
Hong Kong	6,037	48.9	152	2.08	1.23	2.20	1.14	0.3237
Hungary	5,132	50.8	238	2.51	1.31	2.19	1.14	0.5811
Iceland	3,296	50.2	142	1.82	1.11	2.06	1.04	0.0691
Ireland	5,577	49.8	157	1.46	1.01	1.72	1.00	0.0691
Israel	6,623	53.5	174	2.03	1.17	2.26	1.02	0.4854
Italy	11,785	48.2	542	2.04	1.28	2.15	1.18	0.4439
Japan	6,109	51.1	183	1.36	0.95	1.18	0.63	0.3930
Kazakhstan	19,507	49.1	616	2.76	1.28	2.73	1.24	0.3574
Korea	6,650	48.0	188	2.22	1.24	2.21	1.04	0.2611
Latvia	5,303	50.6	308	2.59	1.32	2.47	1.15	0.2121
Lithuania	6,885	49.0	362	2.40	1.33	2.47	1.25	0.3827
Luxembourg	5,230	49.6	44	1.82	1.24	2.01	1.12	0.2974
Macao	3,775	49.3	45	2.14	1.37	1.97	1.09	0.3249
Malta	3,363	47.9	50	2.54	1.42	2.67	1.20	0.2375
Mexico	7,299	52.4	286	2.70	1.43	2.41	1.20	0.3798
Morocco	6,814	47.9	179	1.98	1.22	1.90	1.16	0.4206
New Zealand	6,173	51.1	192	1.83	1.26	2.46	1.08	0.1654
Panama	6,270	50.6	253	2.45	1.45	1.98	1.22	0.4669
Poland	5,625	50.8	240	2.35	1.39	2.29	1.26	0.1835
Russian Federation	7,608	50.7	263	2.85	1.39	2.60	1.35	0.2805
Serbia	6,609	49.5	187	2.34	1.29	2.29	1.21	0.4152
Singapore	6,676	49.1	166	2.35	1.36	2.31	1.22	0.2924

Table 1 (continued)

Country/Region	N (students)	Female %	N (schools)	SCMC		ASCMC		ICC
				Mean	SD	Mean	SD	
Slovak Republic	5,965	50.3	376	2.45	1.32	2.43	1.15	0.4496
Slovenia	6,401	46.8	345	2.13	1.30	2.33	1.10	0.4844
Spain	35,943	50.0	1,089	1.76	1.22	2.28	1.07	0.1544
Sweden	5,504	50.2	223	1.95	1.33	2.26	1.12	0.1652
Switzerland	5,822	47.9	228	1.86	1.29	1.94	1.10	0.3587
Thailand	8,633	54.4	290	3.37	1.21	3.05	1.16	0.5274
Turkey	6,890	49.3	186	2.28	1.28	2.16	1.20	0.5717
United Kingdom	13,818	50.6	471	1.54	1.03	1.97	0.98	0.1778
United States	4,838	49.1	624	2.00	1.31	2.57	1.21	0.1708
Uruguay	5,263	51.9	189	2.16	1.28	2.29	1.17	0.3898
Moscow Region (RUS)	2,016	48.1	61	2.91	1.40	2.72	1.36	0.1462
Tatarstan (RUS)	5,816	50.0	239	2.99	1.31	2.80	1.29	0.2343

Data were retrieved from the PISA 2018 results (URL: http://www.oecd.org/pisa/data/2018database/)

3.2 Variables

In this study, two independent variables were selected from the PISA 2018 to provide information on the frequency of extracurricular SCMC and ASCMC between students and teachers. The two independent variables were the item IC010Q06NA, *How often do you use social networks for communication with teachers* (*e.g., Facebook, Myspace)*, and the item IC010Q04TA, *How often do you use email for communication with teachers outside of school?* For these two independent variables, students responded to a five-point Likert scale (*never or hardly ever*, *once or twice a month*, *once or twice a week*, *almost every day* and *every day*). Regarding the dependent variable, digital reading scores (item PV1READ) were used. Students' digital reading scores were scored based on their performance in reading passages by navigating the online assessment system. Concerning the mediating variable, the metacognition-related variable is the item METASPAM *assessing credibility*. The metacognitive process of assessing credibility was assessed in a scenario where students were asked to rate strategies from not appropriate to very appropriate in a task of assessing the credibility of uncertain information (OECD, 2017). Consistent with previous PISA studies (e.g., Chen & Hu, 2020; Lee & Wu, 2013), to account for individual variations, gender and ESCS were selected as control variables.

3.3 Modeling

Mediation analysis was used in this research to discover the underlying mechanism through which the independent variable exerted an impact on the dependent variable via intermediate factors. PISA data are hierarchical in nature, with student-level data nested within schools, which are further nested within countries/regions. As a result,

the intraclass correlation coefficient (ICC) was computed to determine if multilevel modeling was warranted. Except for Finland, Iceland, and Ireland, all countries/regions had ICCs greater than 0.1, suggesting the necessity of conducting a multilevel analysis (Snijders & Bosker, 2012). Given the multilevel structure of the data and the categorical characteristics of the independent variables, this research used multilevel mediation analysis with multicategorical independent variables.

Figure 2 shows the model of the multilevel mediation analysis with multicategorical independent variables. In this diagram, X represents the two independent variables, namely, IC010Q06NA and IC010Q04TA. To dummy-code the five categories of frequency, 4 dummy variables (D_1, D_2, D_3 and D_4) were constructed. The arrows pointing from D_1, D_2, D_3, and D_4 to X indicate that they jointly constitute X as a whole. Y represents students' digital reading scores (PV1READ). The relationship between X and Y is mediated by the mediating variable of the metacognitive process of *assessing credibility* (METASPAM), represented as M. C_1 and C_2 represent gender and ESCS, respectively. The categorical variable of gender was converted to a dummy variable. The arrows indicate the direction of the effects or constituting relationships.

3.4 Data preprocessing

Prior to data processing, data were preprocessed and the underlying assumptions were validated. In order to fill in the missing data, imputation using the closest nearest neighbor classification, commonly known as K-nearest neighbors (KNN), was used (Kramer, 2013). KNN imputation was implemented in the present research using the function knnImputation from the DMwR R package (Torgo, 2017). Given the categorical nature of the CMC frequency and the controlled variable of gender, dummy coding was applied to avoid the problem of multicollinearity (Hardy, 1993).

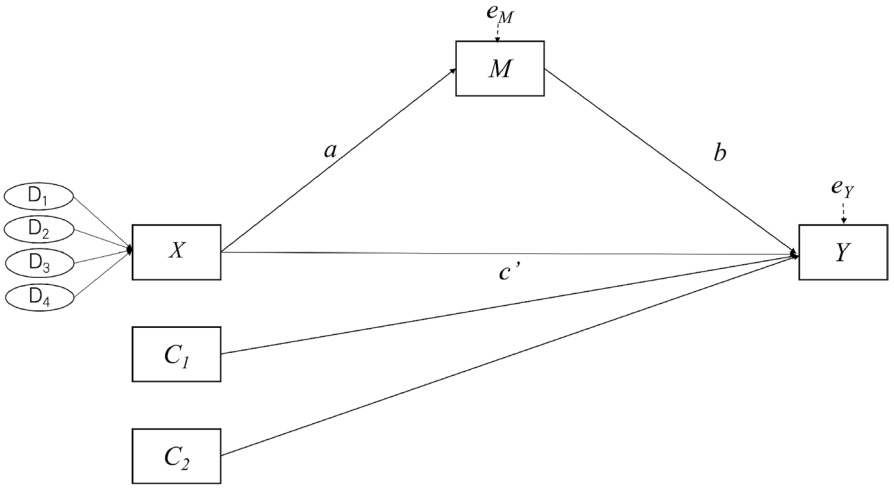

Fig. 2 Conceptual diagram of the multilevel mediation model with multicategorical independent variables

To confirm that the samples were representative of the population, student weights were performed in R (R Core Team, 2019) and unbiased population-level values were obtained. Due to the fact that multilevel mediation analysis with multicategorical independent variables is an extension of conventional least squares regression (Hayes, 2013), the fundamental regression assumptions were evaluated first, and the findings indicated that they were fulfilled. Correlation matrices for six variables were reported in the supplemental materials (see https://doi.org/10.6084/m9.figshare.15050595.v1) for all 53 countries/regions, and the results indicated that all correlations were within an acceptable range.

3.5 Data processing

In mediation analysis, the direct impact is expected to reach the target without the intervention of the mediator; by contrast, the indirect effect is expected to pass via the mediating variable on its way from the independent to the dependent variable. The relative influence of each dummy variable in X on Y follows the same reasoning, indicating the degree to which each dummy variable in X may directly or indirectly explain Y. The sign *c'* indicates the direct influence of each dummy variable in X on Y while all other variables are held constant. The relative indirect impact of each dummy variable of X on Y through the mediator is the percentage of the influence on the dependent variable that may be generated relative to the reference group via the mediator (Hayes & Preacher, 2014). By multiplying a_1, a_2, a_3, and a_4 by b, the proportionate indirect effects of each dummy variable of X on Y via M were calculated. By adding the relative direct and indirect effects of each dummy variable of X on Y, the relative total impact of each dummy variable on Y was obtained. The correlation coefficients of distinct effects are utilized in accordance with Cohen's (1988) study on regression analysis, which evaluates the ratio of variance to the total variance. In mediation analysis, the impact size is determined by comparing the magnitudes of the indirect effect, direct effect, and total effect (Sobel, 1982). Prior to analysis, the relative total direct, direct, and indirect effects were all normalized, and the findings may be interpreted as standardized mean differences comparable to *Cohen's d*. (Hayes & Preacher, 2014). To illustrate these relationships more clearly, the following equations are provided within the context of mediation analysis using a multicategorical independent variable (Hayes & Preacher, 2014):

$$Y = i_1 + c_1 D_1 + c_2 D_2 + c_3 D_3 + c_4 D_4 + e_{Y1} \tag{1}$$

$$M = i_2 + a_1 D_1 + a_2 D_2 + a_3 D_3 + a_4 D_4 + e_M \tag{2}$$

$$Y = i_3 + c'_1 D_1 + c'_2 D_2 + c'_3 D_3 + c'_4 D_4 + bM + e_{Y2} \tag{3}$$

where
i_1, i_2, and i_3 quantify the constants for each regression;
e_M, e_{Y1}, and e_{Y2} quantify the errors in the calculation of M and Y;

c_1, c_2, c_3, and c_4 quantify the relative total effects of X on Y;
c'_1, c'_2, c'_3, *and* c'_4 quantify the relative direct effects of X on Y when the effect of M on Y is controlled;
a_1, a_2, a_3, and a_4 quantify the relative direct effects of X on M; and.
b quantifies the direct effect of the mediator on Y when the other variables are controlled.

The multilevel mediation analysis with multicategorical independent variables was conducted in R (R Core Team, 2019) utilizing the structural equation modeling (SEM) technique in a latent variable analysis (i.e., *lavaan* package) (Rosseel, 2012). Not only is SEM capable of quantifying total, direct, and indirect effects (Hayes, 2009), as necessary in mediation studies (Baron & Kenny, 1986), but it is also appropriate for multicategorical and hierarchical data (Hayes & Preacher, 2014).

4 Results and discussion

4.1 The relative total effects of SCMC and ASCMC on digital reading

To answer the RQ 1, the effect size of extracurricular SCMC and ASCMC between students and teachers on digital reading performance at different frequencies was tested. According to Cohen (1988), the benchmarks for the magnitude of the effect size are 0.10 for a small correlation, 0.30 for a medium correlation, and 0.50 for a large correlation. In this study, the approximate effect size of using SCMC once or twice a month, once or twice a week, almost every day, and every day on students' digital reading performance was −0.5579, -0.7284, -0.7635 and −0.7031, respectively, revealing that large negative effect size that on students' digital reading performance. In addition, the approximate effect size of using ASCMC once or twice a week, almost every day, and every day, was −0.4717, -0.5815 and −0.5697, respectively, revealing that the negative effect size of ASCMC decreased from large to medium as the extent of synchronicity decreased.

The relative total effects of the four frequencies of SCMC and ASCMC on digital reading were reported in the columns labeled $\underline{c}$ in Tables 2 (https://doi.org/10.6084/m9.figshare.14974344.v6) and 3 (see https://doi.org/10.6084/m9.figshare.14974509.v4), respectively, and the results confirmed the first hypothesis. As shown in Table 2, compared to the reference frequency of never or hardly ever, the relative total effects of the other frequencies of SCMC on students' digital reading performance were significantly negative for all countries/regions. In Table 3, the general significantly negative relative total effects of ASCMC between students and teachers on digital reading performance were revealed. Regarding the frequency of having ASCMC once or twice a month, however, diverse relative total effects of ASCMC between students and teachers on digital reading performance were observed. To illustrate, there were both significantly positive and negative relative total effects of ASCMC on digital reading performance in many countries/regions. Particularly, ASCMC were observed to have positive effects on digital reading performance in many countries, and some of them are statistically significant, such as in Australia,

Table 2 The coefficients of the mediation analysis for SCMC

Country/Region	b path	Once or twice a month			Once or twice a week			Almost every day			Every day		
	b	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*
Albania	**0.1259***	**-0.0983**	**-0.0124**	**-0.3408**	-0.0724	-0.0091	**-0.3252**	**-0.1763**	**-0.0222**	**-0.3608**	**-0.2402**	**-0.0303**	**-0.3289**
Australia	**0.3782***	**-0.5127**	**-0.1939**	**-0.6756**	**-0.7046**	**-0.2665**	**-0.8947**	**-0.6086**	**-0.2302**	**-0.7669**	**-0.5824**	**-0.2203**	**-0.6307**
Austria	**0.4049***	**-0.4377**	**-0.1772**	**-0.6002**	**-0.6443**	**-0.2609**	**-0.8200**	**-0.6136**	**-0.2484**	**-0.9052**	**-0.7565**	**-0.3063**	**-0.8405**
Belgium	**0.3489***	**-0.3866**	**-0.1349**	**-0.5702**	**-0.5158**	**-0.1800**	**-0.9088**	**-0.4585**	**-0.1600**	**-0.7816**	**-0.7439**	**-0.2595**	**-0.7830**
Brazil	**0.3601***	**-0.1126**	**-0.0406**	**-0.3539**	**-0.1513**	**-0.0545**	**-0.4114**	**-0.2365**	**-0.0852**	**-0.4333**	**-0.3075**	**-0.1107**	**-0.3935**
Brunei Darussalam	**0.3075***	**-0.1114**	**-0.0342**	**-0.4274**	**-0.2250**	**-0.0692**	**-0.3785**	**-0.2184**	**-0.0672**	**-0.4035**	**-0.1332**	**-0.0410**	**-0.3752**
Bulgaria	**0.2423***	**-0.2093**	**-0.0507**	**-0.4121**	**-0.1901**	**-0.0461**	**-0.4309**	**-0.3510**	**-0.0850**	**-0.4156**	**-0.3544**	**-0.0859**	**-0.2297**
Chile	**0.3246***	**-0.2988**	**-0.0970**	**-0.4414**	**-0.4027**	**-0.1307**	**-0.5834**	**-0.4838**	**-0.1571**	**-0.6444**	**-0.5235**	**-0.1699**	**-0.6907**
Chinese Taipei	**0.4010***	**-0.2400**	**-0.0963**	**-0.2680**	**-0.3060**	**-0.1230**	**-0.3310**	**-0.3920**	**-0.1570**	**-0.5300**	**-0.4490**	**-0.1800**	**-0.5310**
Costa Rica	**0.3588***	**-0.2397**	**-0.0860**	**-0.3488**	**-0.3419**	**-0.1227**	**-0.5039**	**-0.3341**	**-0.1199**	**-0.6578**	**-0.3533**	**-0.1268**	**-0.5130**
Croatia	**0.3567***	**-0.3541**	**-0.1263**	**-0.4760**	**-0.4669**	**-0.1666**	**-0.6209**	**-0.5114**	**-0.1824**	**-0.7141**	**-0.5222**	**-0.1863**	**-0.5870**
Czech Republic	**0.3537***	**-0.3685**	**-0.1303**	**-0.4618**	**-0.5012**	**-0.1773**	**-0.5503**	**-0.4521**	**-0.1599**	**-0.6486**	**-0.5281**	**-0.1868**	**-0.5927**
Denmark	**0.4062***	**-0.3397**	**-0.1380**	**-0.4453**	**-0.6132**	**-0.2491**	**-0.7453**	**-0.6676**	**-0.2711**	**-0.8652**	**-0.7571**	**-0.3075**	**-0.7073**
Dominican Republic	**0.2348***	**-0.1291**	**-0.0303**	**-0.5812**	**-0.0827**	**-0.0194**	**-0.3894**	**-0.2828**	**-0.0664**	**-0.5377**	**-0.3176**	**-0.0746**	**-0.3891**
Estonia	**0.3833***	**-0.2414**	**-0.0925**	**-0.3771**	**-0.4506**	**-0.1727**	**-0.6055**	**-0.4819**	**-0.1847**	**-0.6592**	**-0.4733**	**-0.1814**	**-0.6270**
Finland	**0.4125***	**-0.4878**	**-0.2013**	**-0.6180**	**-0.6813**	**-0.2811**	**-0.8346**	**-0.8262**	**-0.3409**	**-0.8434**	**-0.5914**	**-0.2440**	**-0.7772**
France	**0.3396***	**-0.3173**	**-0.1078**	**-0.6073**	**-0.4208**	**-0.1429**	**-0.7492**	**-0.4896**	**-0.1663**	**-0.7522**	**-0.5606**	**-0.1904**	**-0.6811**
Georgia	**0.1828***	-0.0310	-0.0057	**-0.2234**	0.0232*	0.0042*	**-0.3072**	0.0519*	0.0095*	**-0.3262**	-0.0589	-0.0108	**-0.1808**
Greece	**0.2993***	**-0.3900**	**-0.1167**	**-0.6796**	**-0.4178**	**-0.1251**	**-0.8060**	**-0.5042**	**-0.1509**	**-0.7409**	**-0.5948**	**-0.1780**	**-0.6747**
Hong Kong	**0.4144***	**-0.2058**	**-0.0853**	**-0.2898**	**-0.3649**	**-0.1512**	**-0.3970**	**-0.4795**	**-0.1987**	**-0.5764**	**-0.5821**	**-0.2412**	**-0.6844**
Hungary	**0.2747***	-0.0423	-0.0116	**-0.1165**	**-0.1953**	**-0.0537**	**-0.4019**	**-0.2443**	**-0.0671**	**-0.5699**	**-0.3486**	**-0.0958**	**-0.5362**
Iceland	**0.3445***	**-0.3509**	**-0.1209**	**-0.5330**	**-0.5319**	**-0.1832**	**-0.7679**	**-0.5059**	**-0.1743**	**-0.8200**	**-0.6637**	**-0.2287**	**-0.9203**
Ireland	**0.3729***	**-0.4140**	**-0.1544**	**-0.6812**	**-0.4831**	**-0.1801**	**-0.7160**	**-0.5778**	**-0.2154**	**-0.8552**	**-0.7226**	**-0.2694**	**-0.9428**

Table 2 (continued)

Country/Region	b path	Once or twice a month			Once or twice a week			Almost every day			Every day		
	b	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*
Israel	**0.3086***	**-0.4445**	**-0.1372**	**-0.6526**	**-0.4151**	**-0.1281**	**-0.8745**	**-0.4830**	**-0.1491**	**-0.7015**	**-0.6145**	**-0.1897**	**-0.7150**
Italy	**0.3187***	**-0.3034**	**-0.0967**	**-0.5268**	**-0.3948**	**-0.1258**	**-0.6976**	**-0.3725**	**-0.1187**	**-0.7045**	**-0.4835**	**-0.1541**	**-0.6336**
Japan	**0.4983***	**-0.3051**	**-0.1520**	**-0.3283**	**-0.4680**	**-0.2332**	**-0.4655**	**-0.6515**	**-0.3246**	**-0.8045**	**-0.5862**	**-0.2921**	**-0.7396**
Kazakhstan	**0.3560***	**-0.1710**	**-0.0609**	**-0.4231**	**-0.2153**	**-0.0766**	**-0.3713**	**-0.1993**	**-0.0710**	**-0.3066**	**-0.1814**	**-0.0646**	**-0.2495**
Korea	**0.4272***	**-0.1237**	**-0.0529**	**-0.1729**	**-0.3364**	**-0.1437**	**-0.3901**	**-0.4035**	**-0.1724**	**-0.4286**	**-0.4526**	**-0.1934**	**-0.4616**
Latvia	**0.3575***	**-0.1352**	**-0.0483**	**-0.3360**	**-0.3421**	**-0.1223**	**-0.6637**	**-0.3485**	**-0.1246**	**-0.6655**	**-0.3108**	**-0.1111**	**-0.5493**
Lithuania	**0.3074***	**-0.2897**	**-0.0891**	**-0.4424**	**-0.5126**	**-0.1576**	**-0.6972**	**-0.5453**	**-0.1676**	**-0.7293**	**-0.5661**	**-0.1740**	**-0.6933**
Luxembourg	**0.3473***	**-0.3885**	**-0.1349**	**-0.6176**	**-0.6581**	**-0.2286**	**-0.9086**	**-0.5804**	**-0.2016**	**-0.9862**	**-0.7384**	**-0.2564**	**-0.8964**
Macao	**0.3468***	-0.0814	-0.0282	**-0.2439**	**-0.3363**	**-0.1166**	**-0.4988**	**-0.2745**	**-0.0952**	**-0.4407**	**-0.2993**	**-0.1038**	**-0.5266**
Malta	**0.3285***	**-0.2798**	**-0.0919**	**-0.4998**	**-0.4924**	**-0.1618**	**-0.8634**	**-0.5382**	**-0.1768**	**-0.8978**	**-0.5700**	**-0.1873**	**-0.6205**
Mexico	**0.3204***	**-0.0935**	**-0.0300**	**-0.3254**	**-0.1352**	**-0.0433**	**-0.2883**	**-0.2394**	**-0.0767**	**-0.3755**	**-0.2063**	**-0.0661**	**-0.3251**
Morocco	**0.1448***	-0.0198	-0.0029	**-0.5041**	0.0181*	0.0026*	**-0.4275**	0.0395*	0.0057*	**-0.4530**	**-0.1215**	**-0.0176**	**-0.3113**
New Zealand	**0.3733***	**-0.4309**	**-0.1608**	**-0.5892**	**-0.6084**	**-0.2271**	**-0.8597**	**-0.6455**	**-0.2409**	**-0.8844**	**-0.5798**	**-0.2164**	**-0.7673**
Panama	**0.2803***	**-0.1003**	**-0.0281**	**-0.4612**	**-0.0867**	**-0.0243**	**-0.4530**	**-0.1960**	**-0.0549**	**-0.5306**	**-0.2356**	**-0.0660**	**-0.4082**
Poland	**0.2936***	**-0.2881**	**-0.0846**	**-0.4789**	**-0.3933**	**-0.1155**	**-0.6607**	**-0.4998**	**-0.1467**	**-0.7443**	**-0.5131**	**-0.1506**	**-0.6211**
Russian Federation	**0.3740***	**-0.1848**	**-0.0691**	**-0.3255**	**-0.3536**	**-0.1323**	**-0.5392**	**-0.3805**	**-0.1423**	**-0.5856**	**-0.4274**	**-0.1599**	**-0.5229**
Serbia	**0.3126***	**-0.3482**	**-0.1088**	**-0.5490**	**-0.4143**	**-0.1295**	**-0.5498**	**-0.3619**	**-0.1131**	**-0.4554**	**-0.4783**	**-0.1495**	**-0.4167**
Singapore	**0.4515***	**-0.1440**	**-0.0650**	**-0.1980**	**-0.2612**	**-0.1179**	**-0.3221**	**-0.4172**	**-0.1884**	**-0.4158**	**-0.3113**	**-0.1406**	**-0.3274**
Slovak Republic	**0.2700***	**-0.3670**	**-0.0991**	**-0.5813**	**-0.4055**	**-0.1095**	**-0.6371**	**-0.4051**	**-0.1094**	**-0.6369**	**-0.5114**	**-0.1381**	**-0.6060**
Slovenia	**0.3059***	**-0.3614**	**-0.1105**	**-0.5265**	**-0.4928**	**-0.1507**	**-0.7318**	**-0.4769**	**-0.1459**	**-0.8087**	**-0.4476**	**-0.1369**	**-0.6116**
Spain	**0.3283***	**-0.3954**	**-0.1298**	**-0.6534**	**-0.5451**	**-0.1790**	**-0.7706**	**-0.5796**	**-0.1903**	**-0.8519**	**-0.6381**	**-0.2095**	**-0.7668**
Sweden	**0.4042***	**-0.4234**	**-0.1711**	**-0.5262**	**-0.6652**	**-0.2689**	**-0.7955**	**-0.7630**	**-0.3084**	**-0.9700**	**-0.7302**	**-0.2952**	**-0.7809**
Switzerland	**0.3767***	**-0.2755**	**-0.1038**	**-0.5120**	**-0.5552**	**-0.2092**	**-0.7677**	**-0.5706**	**-0.2150**	**-0.7540**	**-0.5303**	**-0.1998**	**-0.7226**

Table 2 (continued)

Country/Region	b path	Once or twice a month			Once or twice a week			Almost every day			Every day		
	b	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*
Thailand	**0.1826***	**-0.0970**	**-0.0177**	**-0.1682**	**-0.1700**	**-0.0311**	**-0.1270**	**-0.2519**	**-0.0460**	**-0.2111**	**-0.3105**	**-0.0567**	**-0.1061**
Turkey	**0.3490***	**-0.1292**	**-0.0451**	**-0.2778**	**-0.2877**	**-0.1004**	**-0.4287**	**-0.2663**	**-0.0929**	**-0.4687**	**-0.4244**	**-0.1481**	**-0.4235**
United Kingdom	**0.3988***	**-0.6076**	**-0.2423**	**-0.7842**	**-0.7488**	**-0.2986**	**-0.7192**	**-0.7308**	**-0.2914**	**-0.6560**	**-0.8257**	**-0.3293**	**-0.7740**
United States	**0.3760***	**-0.3962**	**-0.1490**	**-0.6470**	**-0.4824**	**-0.1814**	**-0.7050**	**-0.5879**	**-0.2210**	**-0.7769**	**-0.6376**	**-0.2397**	**-0.8283**
Uruguay	**0.3286***	**-0.3189**	**-0.1048**	**-0.5689**	**-0.2937**	**-0.0965**	**-0.6360**	**-0.4707**	**-0.1547**	**-0.6883**	**-0.4666**	**-0.1533**	**-0.6016**
Moscow Region (RUS)	**0.3924***	-0.0843	-0.0331	**-0.3223**	**-0.3447**	**-0.1352**	**-0.4477**	**-0.2768**	**-0.1086**	**-0.4517**	**-0.3836**	**-0.1505**	**-0.5118**
Tatarstan (RUS)	**0.3480***	**-0.2951**	**-0.1027**	**-0.4622**	**-0.3806**	**-0.1324**	**-0.5150**	**-0.4202**	**-0.1462**	**-0.5173**	**-0.3991**	**-0.1389**	**-0.4694**

Statistically significant results are highlighted in bold, indicating that zero does not fall within the 95% bootstrap CI (the specific value of the 95% bootstrap CI can be found in the supplementary materials), and an "*" is attached to the value above zero

Table 3 The coefficients of the mediation analysis for ASCMC

Country/Region	b path	Once or twice a month			Once or twice a week			Almost every day			Every day		
	b	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*
Albania	**0.1294***	-0.0093	-0.0012	**-0.1902**	**-0.0871**	**-0.0113**	**-0.2281**	**-0.1632**	**-0.0211**	**-0.2634**	**-0.2624**	**-0.0340**	**-0.2674**
Australia	**0.4577***	**0.1022***	**0.0468***	**0.1444***	**-0.0963**	**-0.0441**	**-0.1353**	**-0.1796**	**-0.0822**	**-0.2074**	**-0.2341**	**-0.1071**	**-0.1665**
Austria	**0.4471***	**-0.0914**	**-0.0409**	**-0.1279**	**-0.4235**	**-0.1894**	**-0.5111**	**-0.4388**	**-0.1962**	**-0.6981**	**-0.7197**	**-0.3218**	**-0.7630**
Belgium	**0.3854***	**0.0461***	**0.0178***	**0.0642***	**-0.2946**	**-0.1135**	**-0.4151**	**-0.4336**	**-0.1671**	**-0.6712**	**-0.6702**	**-0.2583**	**-0.7140**
Brazil	**0.3494***	**-0.1889**	**-0.0660**	**-0.3733**	**-0.2498**	**-0.0873**	**-0.4840**	**-0.2667**	**-0.0932**	**-0.5193**	**-0.4010**	**-0.1401**	**-0.5136**
Brunei Darussalam	**0.3128***	-0.0422	-0.0132	**-0.2902**	**-0.1639**	**-0.0513**	**-0.3724**	**-0.2206**	**-0.0690**	**-0.4801**	-0.0132	-0.0041	**-0.4512**
Bulgaria	**0.2409***	**-0.1241**	**-0.0299**	**-0.2504**	**-0.1894**	**-0.0456**	**-0.3995**	**-0.2833**	**-0.0682**	**-0.4108**	**-0.2634**	**-0.0635**	**-0.2467**
Chile	**0.3539***	-0.0080	-0.0028	-0.0474	**-0.2222**	**-0.0786**	**-0.3291**	**-0.3625**	**-0.1283**	**-0.4428**	**-0.4099**	**-0.1451**	**-0.6180**
Chinese Taipei	**0.4085***	**-0.0907**	**-0.0370**	**-0.0756**	**-0.2838**	**-0.1159**	**-0.2643**	**-0.3983**	**-0.1627**	**-0.5202**	**-0.5088**	**-0.2078**	**-0.5501**
Costa Rica	**0.3810***	-0.0456	-0.0174	**-0.1262**	**-0.1604**	**-0.0611**	**-0.2271**	**-0.1949**	**-0.0743**	**-0.4717**	**-0.3109**	**-0.1185**	**-0.4298**
Croatia	**0.3851***	**-0.0978**	**-0.0377**	**-0.0541**	**-0.2402**	**-0.0925**	**-0.3444**	**-0.4389**	**-0.1691**	**-0.5831**	**-0.5099**	**-0.1964**	**-0.5006**
Czech Republic	**0.4250***	**0.0280***	**0.0108***	-0.0067	**-0.2067**	**-0.0796**	**-0.1703**	**-0.2952**	**-0.1137**	**-0.4507**	**-0.5093**	**-0.1961**	**-0.5170**
Denmark	**0.4250***	**-0.1342**	**-0.0570**	**-0.1724**	**-0.4881**	**-0.2075**	**-0.6596**	**-0.6067**	**-0.2579**	**-0.7722**	**-0.8722**	**-0.3707**	**-0.7452**
Dominican Republic	**0.2470***	-0.0343	-0.0085	**-0.3784**	-0.0278	-0.0069	**-0.2676**	**-0.2138**	**-0.0528**	**-0.4705**	**-0.2773**	**-0.0685**	**-0.2939**
Estonia	**0.3937***	0.0245*	0.0096*	0.0309*	**-0.3391**	**-0.1335**	**-0.4091**	**-0.4756**	**-0.1873**	**-0.5609**	**-0.4241**	**-0.1670**	**-0.5954**
Finland	**0.4530***	-0.0334	-0.0151	-0.0546	**-0.4120**	**-0.1867**	**-0.4806**	**-0.6082**	**-0.2755**	**-0.6431**	**-0.5505**	**-0.2494**	**-0.6455**
France	**0.3632***	-0.0398	-0.0144	**-0.0769**	**-0.3254**	**-0.1182**	**-0.4830**	**-0.5501**	**-0.1998**	**-0.7465**	**-0.5965**	**-0.2167**	**-0.6129**
Georgia	**0.1710***	**-0.0927**	**-0.0159**	**-0.3284**	-0.0500	-0.0086	**-0.4163**	**-0.1428**	**-0.0244**	**-0.5227**	**-0.2173**	**-0.0372**	**-0.3852**
Greece	**0.3278***	**-0.1856**	**-0.0609**	**-0.4340**	**-0.2931**	**-0.0961**	**-0.6046**	**-0.4307**	**-0.1412**	**-0.6364**	**-0.6122**	**-0.2007**	**-0.6664**
Hong Kong	**0.4257***	-0.0157	-0.0067	**-0.0593**	**-0.2670**	**-0.1137**	**-0.2806**	**-0.4922**	**-0.2095**	**-0.4600**	**-0.6241**	**-0.2657**	**-0.5931**
Hungary	**0.2616***	-0.0602	-0.0158	-0.0237	**-0.2636**	**-0.0690**	**-0.4154**	**-0.3735**	**-0.0977**	**-0.6982**	**-0.5480**	**-0.1433**	**-0.7917**
Iceland	**0.3868***	-0.0165	-0.0064	**-0.1594**	**-0.2930**	**-0.1133**	**-0.5227**	**-0.2186**	**-0.0846**	**-0.5936**	**-0.4997**	**-0.1933**	**-0.7469**
Ireland	**0.3990***	**-0.0609**	**-0.0243**	**-0.0754**	**-0.2361**	**-0.0942**	**-0.3768**	**-0.5781**	**-0.2307**	**-0.7369**	**-0.6995**	**-0.2791**	**-0.8994**

Table 3 (continued)

Country/Region	b path	Once or twice a month			Once or twice a week			Almost every day			Every day		
	b	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*
Israel	**0.3660***	0.0197*	0.0072*	**-0.1418**	**-0.1621**	**-0.0593**	**-0.4498**	**-0.3118**	**-0.1141**	**-0.4422**	**-0.5083**	**-0.1860**	**-0.5870**
Italy	**0.3494***	-0.0043	-0.0015	**-0.0861**	**-0.2033**	**-0.0710**	**-0.4340**	**-0.2365**	**-0.0826**	**-0.4618**	**-0.4208**	**-0.1471**	**-0.5873**
Japan	**0.5002***	**-0.3443**	**-0.1722**	**-0.4116**	**-0.6727**	**-0.3364**	**-0.7355**	**-0.8787**	**-0.4395**	**-0.9789**	**-0.9169**	**-0.4586**	**-0.9135**
Kazakhstan	**0.3620***	**-0.0927**	**-0.0336**	**-0.3310**	**-0.0887**	**-0.0321**	**-0.2300**	**-0.0636**	**-0.0230**	**-0.1280**	**-0.0676**	**-0.0245**	**-0.0887**
Korea	**0.4349***	**0.1073***	**0.0467***	**0.2138***	**-0.1353**	**-0.0589**	**-0.1101**	**-0.1961**	**-0.0853**	**-0.1596**	**-0.4099**	**-0.1783**	**-0.2521**
Latvia	**0.3623***	**-0.0950**	**-0.0344**	**-0.1390**	**-0.2705**	**-0.0980**	**-0.5469**	**-0.3840**	**-0.1391**	**-0.6117**	**-0.3630**	**-0.1315**	**-0.6433**
Lithuania	**0.3294***	**-0.1971**	**-0.0649**	**-0.2318**	**-0.3870**	**-0.1275**	**-0.5882**	**-0.4432**	**-0.1460**	**-0.5830**	**-0.5973**	**-0.1967**	**-0.6281**
Luxembourg	**0.4024***	-0.0154	-0.0062	-0.0331	**-0.3501**	**-0.1409**	**-0.4754**	**-0.4289**	**-0.1726**	**-0.7396**	**-0.6800**	**-0.2736**	**-0.8551**
Macao	**0.3576***	0.0498*	0.0178*	-0.0125	**-0.2007**	**-0.0718**	**-0.3178**	**-0.2587**	**-0.0925**	**-0.3937**	**-0.3202**	**-0.1145**	**-0.4638**
Malta	**0.3692***	0.0503*	0.0186*	**-0.1587**	**-0.2803**	**-0.1035**	**-0.5359**	**-0.4121**	**-0.1521**	**-0.6004**	**-0.4726**	**-0.1745**	**-0.4404**
Mexico	**0.3255***	**0.0770***	**0.0251***	0.0198*	-0.0054	-0.0018	-0.0237	**-0.1588**	**-0.0517**	**-0.2471**	**-0.1916**	**-0.0624**	**-0.2191**
Morocco	**0.1488***	0.0503*	0.0075*	**-0.5478**	0.0021*	0.0003*	**-0.4563**	0.0400*	0.0060*	**-0.4254**	-0.1117	-0.0166	**-0.3825**
New Zealand	**0.4406***	**0.1229***	**0.0542***	**0.1204***	**-0.0650**	-0.0286	**-0.1629**	**-0.1599**	**-0.0705**	**-0.3040**	**-0.3082**	**-0.1358**	**-0.3682**
Panama	**0.2854***	-0.0212	-0.0060	**-0.2774**	**-0.1690**	**-0.0482**	**-0.3742**	**-0.1132**	**-0.0323**	**-0.5243**	**-0.2598**	**-0.0742**	**-0.4946**
Poland	**0.3036***	**-0.1599**	**-0.0486**	**-0.2932**	**-0.3723**	**-0.1130**	**-0.5861**	**-0.4991**	**-0.1516**	**-0.7306**	**-0.5724**	**-0.1738**	**-0.6339**
Russian Federation	**0.3700***	**-0.1977**	**-0.0732**	**-0.3685**	**-0.3639**	**-0.1346**	**-0.5477**	**-0.3948**	**-0.1461**	**-0.5451**	**-0.5063**	**-0.1873**	**-0.6047**
Serbia	**0.3253***	**-0.2578**	**-0.0839**	**-0.3380**	**-0.4083**	**-0.1328**	**-0.4789**	**-0.3100**	**-0.1008**	**-0.4020**	**-0.4865**	**-0.1583**	**-0.3618**
Singapore	**0.4615***	-0.0275	-0.0127	0.0008*	**-0.2028**	**-0.0936**	**-0.1780**	**-0.2863**	**-0.1321**	**-0.2226**	**-0.2763**	**-0.1275**	**-0.1729**
Slovak Republic	**0.3034***	**-0.0936**	**-0.0284**	**-0.1984**	**-0.1912**	**-0.0580**	**-0.3256**	**-0.2770**	**-0.0840**	**-0.4642**	**-0.3894**	**-0.1181**	**-0.4568**
Slovenia	**0.3463***	0.0487*	0.0169*	0.0156*	**-0.1503**	**-0.0520**	**-0.3417**	**-0.2489**	**-0.0862**	**-0.5342**	**-0.3550**	**-0.1229**	**-0.5102**
Spain	**0.3806***	**0.0262***	**0.0100***	**0.0487***	**-0.2001**	**-0.0762**	**-0.2187**	**-0.2937**	**-0.1118**	**-0.4182**	**-0.5325**	**-0.2027**	**-0.4974**
Sweden	**0.4482***	0.0400*	0.0179*	-0.0443	**-0.3026**	**-0.1356**	**-0.4040**	**-0.5410**	**-0.2425**	**-0.7766**	**-0.6221**	**-0.2789**	**-0.7831**
Switzerland	**0.4092***	0.0421*	0.0172*	0.0439*	**-0.2719**	**-0.1113**	**-0.3828**	**-0.4424**	**-0.1811**	**-0.5920**	**-0.5150**	**-0.2107**	**-0.7484**

Table 3 (continued)

Country/Region	b path	Once or twice a month			Once or twice a week			Almost every day			Every day		
	b	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*	*a*	*a*b*	*c*
Thailand	**0.1783***	-0.0013	-0.0002	**-0.0740**	**-0.1077**	**-0.0192**	**-0.1285**	**-0.2460**	**-0.0439**	**-0.2186**	**-0.3175**	**-0.0566**	**-0.1801**
Turkey	**0.3426***	**-0.2072**	**-0.0710**	**-0.2945**	**-0.2677**	**-0.0917**	**-0.4597**	**-0.3582**	**-0.1227**	**-0.5995**	**-0.4562**	**-0.1563**	**-0.5618**
United Kingdom	**0.4400***	-0.0091	-0.0040	**0.0585**	**-0.4259**	**-0.1874**	**-0.3364**	**-0.6016**	**-0.2647**	**-0.4787**	**-0.7994**	**-0.3518**	**-0.5857**
United States	**0.4417***	0.0404*	0.0178*	0.0194*	0.0054*	0.0024*	**-0.0952**	**-0.0985**	**-0.0435**	**-0.2114**	**-0.2598**	**-0.1148**	**-0.3962**
Uruguay	**0.3581***	-0.0371	-0.0133	**-0.1795**	**-0.2234**	**-0.0800**	**-0.4535**	**-0.4324**	**-0.1548**	**-0.5013**	**-0.4948**	**-0.1772**	**-0.4486**
Moscow Region (RUS)	**0.3851***	-0.1131	-0.0436	**-0.2426**	**-0.3786**	**-0.1458**	**-0.4891**	**-0.3281**	**-0.1264**	**-0.5428**	**-0.4026**	**-0.1550**	**-0.5166**
Tatarstan (RUS)	**0.3468***	**-0.2242**	**-0.0777**	**-0.3570**	**-0.3923**	**-0.1361**	**-0.4424**	**-0.4150**	**-0.1439**	**-0.5275**	**-0.4103**	**-0.1423**	**-0.4932**

Statistically significant results are highlighted in bold, indicating that zero does not fall within the 95% bootstrap CI (the specific value of the 95% bootstrap CI can be found in the supplementary materials), and an "*" is attached to the value above zero

Belgium, Korea, New Zealand, and Spain. Additionally, in Estonia, Israel, Macao, Malta, Morocco, Slovenia, Sweden, Switzerland, and United States, although relative indirect effects are non-significant, they are all positive. In the spectrum of frequencies, the degree of synchronicity differs, and the results revealed that as frequency increased, i.e., became more synchronous, the effects of having ASCMC with teachers shifted from positive to negative. Furthermore, subtracting the coefficient c of SCMC from that of ASCMC, the difference in the effect size on digital reading between SCMC and ASCMC was quantified by Δc. The results shown in Table 2 revealed that a positive Δc was present in most countries/regions, and in general, the value of Δc increased as frequency decreased. These results indicate that in most countries/regions, ASCMC could play a more positive role in students' digital reading performance, and that, in general, the more asynchronous the CMC, the more positive the impact that is observed.

By proving that ASCMC between students and teachers has a more positive effect on students' digital reading performance than SCMC, which is consistent with many previous studies (e.g., AbuSeileek & Qatawneh, 2013; Angeli & Schwartz, 2016; Giesbers et al., 2014; Ogbonna et al., 2019; Riordan & Kreuz, 2010), the results of this study contribute to the existing literature in the context of a quantitative analysis involving a large number of countries/regions. Furthermore, rather than comparing the different effects of SCMC and ASCMC occurring at a fixed frequency, this study discussed a scale of frequencies for both SCMC and ASCMC, revealing that the differential effects on students' digital reading performance occur not only between SCMC and ASCMC but also among the different frequencies of CMC usage, which has not been carefully examined in previous research. The possible reasons for (1) the generally negative effects of both types of CMC, with the exception of ASCMC occurring at a frequency of once or twice a month, (2) the better impact of ASCMC than SCMC on students' digital reading performance, and (3) the distinct effects when the frequencies of CMC differ are discussed in the following section, in which the mediation analysis results related to RQ 2 are interpreted.

4.2 The relative indirect effect of SCMC and ASCMC on digital reading

In answering the RQ 2, the relative indirect effect size of the four frequencies of SCMC and ASCMC on digital reading was tested. According to Sobel (1982), the effect size measurement in the mediation analysis focuses on comparing the magnitudes of the indirect effect, direct effect, and total effect. In the current study, the relative indirect effects were quantified by multiplying the relative direct effect of CMC on metacognition (the results shown in the columns labeled a) by the direct effect of metacognition on students' digital reading performance (the results shown in the column labeled b). As shown in the $a*b$ column in Tables 2 and 3, the average relative indirect effect size of the mediation of metacognition at the frequency of once or twice a month, once or twice a week, almost every day, and every day was −0.1323, -0.1826, -0.1959 and −0.2119 for SCMC and −0.0532, -0.1149, -0.1459 and −0.1840 for ASCMC, indicating a small to medium relative indirect effect size

of SCMC and ASCMC on students' digital reading performance as mediated by metacognition.

As indicated by the bold value marked with "*" in the columns labeled *b* in Tables 2 and 3, significantly positive effects of metacognition on digital reading were observed in all countries/regions, and these results are consistent with those of previous studies (e.g., Chang et al., 2019; Lee & Wu, 2013; Lim & Jung, 2019; Wu, 2014; Wu & Peng, 2017). Furthermore, as hypothesized, the statistically significant results of the relative indirect effects of SCMC and ASCMC on students' digital reading performance (the columns labeled *a*b*) corroborated that metacognition plays a significant mediating role in the relationship between the independent variables and digital reading performance, which is consistent with the results of many previous studies (e.g., Lee & Wu, 2013; Miyamoto et al., 2019; Schünemann et al., 2013; Veas et al., 2019; Wu, 2014). However, different results for SCMC and ASCMC were observed. Regarding the relative indirect effects of SCMC (shown in the *a*b* columns in Table 2), the results of each frequency were almost all bold with no "*", indicating that regardless of the frequency, there were significantly negative relative indirect effects of SCMC between students and teachers on students' digital reading performance mediated by metacognition. Regarding the relative indirect effects of ASCMC (shown in the *a*b* columns in Table 3), for the frequencies of once or twice a week, almost every day and every day, almost all results were highlighted in bold with no "*", indicating significantly negative relative indirect effects of ASCMC between students and teachers on digital reading performance mediated by metacognition. For the frequency of once or twice a month, however, there were both significantly positive and negative relative indirect effects of ASCMC on digital reading performance mediated by metacognition. Furthermore, to examine the different effects of SCMC and ASCMC on metacognition, this study subtracted the coefficient *a* of SCMC from that of ASCMC. The difference in the effect size between SCMC and ASCMC was quantified by Δa, in Table 4 entitled "The coefficients of the difference between the SCMC and the ASCMC, and the effects of control variables for the SCMC and the ASCMC", (see https://doi.org/10.6084/m9.figshare.14974509.v4). The results shown in Table 4 illustrate that a positive Δa value could be found in most countries/regions and that the value of Δa increased as the frequency decreased. The interpretation of the above findings of the relative indirect effects could be unfolded along with the answers to the remaining three questions in the discussion of the results of the relative total effects of SCMC and ASCMC on students' digital reading performance. To answer the first question regarding why there were generally negative effects of both types of CMC, with the exception of ASCMC occurring at a frequency of once or twice a month, the statistically significant mediating role of metacognition and the control-monitoring model proposed by Nelson and Naren (1990) could provide a plausible rationale. To illustrate, in the control-monitoring model, when students' current state of mastery does not reach the desired level, they devote more study time to items that they perceive as more difficult, during which process they cultivate metacognitive strategies. In this sense, sufficient time for self-paced learning is considered the prerequisite for the development of metacognitive skills. As suggested by the significant positive impact of metacognition on students' digital reading performance in this study and

Table 4 The coefficients of the difference between SCMC and ASCMC and the effects of the control variables on SCMC and ASCMC

Country/Region	Once or twice a month		Once or twice a week		Almost every day		Every day		Control variables (SCMC)		Control variables (ASCMC)	
	Δa	Δc	Δa	Δc	Δa	Δc	Δa	Δc	Gender	ESCS	Gender	ESCS
Albania	**0.0890***	**0.1506***	**-0.0147**	**0.0971***	**0.0131***	**0.0974***	**-0.0222**	**0.0615***	**-0.4142**	**0.2905***	**-0.4381**	**0.2900***
Australia	**0.6149***	**0.8200***	**0.6083***	**0.7594***	**0.4290***	**0.5595***	**0.3483***	**0.4642***	**-0.0974**	**0.2415***	**-0.1559**	**0.2563***
Austria	**0.3463***	**0.4723***	**0.2208***	**0.3089***	**0.1748***	**0.2071***	**0.0368***	**0.0775***	**-0.1029**	**0.2453***	**-0.1502**	**0.2536***
Belgium	**0.4327***	**0.6344***	**0.2212***	**0.4937***	**0.0249***	**0.1104***	**0.0737***	**0.0690***	**-0.1217**	**0.3061***	**-0.1541**	**0.3216***
Brazil	**-0.0763**	**-0.0194**	**-0.0985**	**-0.0726**	**-0.0302**	**-0.0860**	**-0.0935**	**-0.1201**	**-0.2130**	**0.3091***	**-0.1794**	**0.3167***
Brunei Darussalam	**0.0692***	**0.1372***	**0.0611***	**0.0061***	**-0.0022**	**-0.0766**	**0.1200***	**-0.0760**	**-0.2423**	**0.3401***	**-0.2330**	**0.3542***
Bulgaria	**0.0852***	**0.1617***	**0.0007***	**0.0314***	**0.0677***	**0.0048***	**0.0910***	**-0.0170**	**-0.3553**	**0.3646***	**-0.3546**	**0.3729***
Chile	**0.2908***	**0.3940***	**0.1805***	**0.2543***	**0.1213***	**0.2016***	**0.1136***	**0.0727***	**-0.1195**	**0.3340***	**-0.1602**	**0.3565***
Chinese Taipei	**0.1493***	**0.1924***	**0.0222***	**0.0670***	**-0.0063**	**0.0098***	**-0.0598**	**-0.0191**	**-0.1490**	**0.2890***	**-0.1479**	**0.2910***
Costa Rica	**0.1941***	**0.2226***	**0.1815***	**0.2768***	**0.1392***	**0.1861***	**0.0424***	**0.0832***	**-0.1502**	**0.3008***	**-0.1536**	**0.3060***
Croatia	**0.2563***	**0.4219***	**0.2267***	**0.2765***	**0.0725***	**0.1310***	**0.0123***	**0.0864***	**-0.2380**	**0.2228***	**-0.2685**	**0.2237***
Czech Republic	**0.3965***	**0.4551***	**0.2945***	**0.3800***	**0.1569***	**0.1979***	**0.0188***	**0.0757***	**-0.1563**	**0.3382***	**-0.1809**	**0.3546***
Denmark	**0.2055***	**0.2159***	**0.1251***	**0.0857***	**0.0609***	**0.0930***	**-0.1151**	**-0.0379**	**-0.1284**	**0.2384***	**-0.1551**	**0.2394***
Dominican Republic	**0.0948***	**0.2028***	**0.0549***	**0.1218***	**0.0690***	**0.0672***	**0.0403***	**0.0952***	**-0.3306**	**0.2792***	**-0.3432**	**0.2853***
Estonia	**0.2659***	**0.4080***	**0.1115***	**0.1964***	**0.0063***	**0.0983***	**0.0492***	**0.0316***	**-0.2125**	**0.2152***	**-0.2216**	**0.2188***
Finland	**0.4544***	**0.5634***	**0.2693***	**0.3540***	**0.2180***	**0.2003***	**0.0409***	**0.1317***	**-0.2487**	**0.2360***	**-0.2821**	**0.2408***
France	**0.2775***	**0.5304***	**0.0954***	**0.2662***	**-0.0605**	**0.0057***	**-0.0359**	**0.0682***	**-0.1107**	**0.3435***	**-0.1442**	**0.3654***
Georgia	**-0.0617**	**-0.1050**	**-0.0732**	**-0.1091**	**-0.1947**	**-0.1965**	**-0.1584**	**-0.2044**	**-0.4288**	**0.3096***	**-0.3889**	**0.3099***
Greece	**0.2044***	**0.2456***	**0.1247***	**0.2014***	**0.0735***	**0.1045***	**-0.0174**	**0.0083***	**-0.2158**	**0.2429***	**-0.2271**	**0.2617***
Hong Kong	**0.1901***	**0.2305***	**0.0979***	**0.1164***	**-0.0127**	**0.1164***	**-0.0420**	**0.0913***	**-0.1480**	**0.1614***	**-0.1598**	**0.1637***
Hungary	**-0.0179**	**0.0928***	**-0.0683**	**-0.0135**	**-0.1292**	**-0.1283**	**-0.1994**	**-0.2555**	**-0.2163**	**0.3870***	**-0.1832**	**0.3850***
Iceland	**0.3344***	**0.3736***	**0.2389***	**0.2452***	**0.2873***	**0.2264***	**0.1640***	**0.1734***	**-0.2027**	**0.1913***	**-0.2422**	**0.2027***

Table 4 (continued)

Country/Region	Once or twice a month		Once or twice a week		Almost every day		Every day		Control variables (SCMC)		Control variables (ASCMC)	
	Δa	*Δc*	*Δa*	*Δc*	*Δa*	*Δc*	*Δa*	*Δc*	Gender	ESCS	Gender	ESCS
Ireland	**0.3531***	**0.6058***	**0.2470***	**0.3392***	**-0.0003**	**0.1183***	**0.0231***	**0.0434***	**-0.1068**	**0.2621***	**-0.1511**	**0.2702***
Israel	**0.4642***	**0.5108***	**0.2530***	**0.4247***	**0.1712***	**0.2593***	**0.1062***	**0.1280***	**-0.2433**	**0.3114***	**-0.3046**	**0.3230***
Italy	**0.2991***	**0.4407***	**0.1915***	**0.2636***	**0.1360***	**0.2427***	**0.0627***	**0.0463***	**-0.1826**	**0.2259***	**-0.2177**	**0.2401***
Japan	**-0.0392**	**-0.0833**	**-0.2047**	**-0.2700**	**-0.2272**	**-0.1744**	**-0.3307**	**-0.1739**	**-0.0163**	**0.2017***	**-0.0149**	**0.2080***
Kazakhstan	**0.0783***	**0.0921***	**0.1266***	**0.1413***	**0.1357***	**0.1786***	**0.1138***	**0.1608***	**-0.2500**	**0.2541***	**-0.2560**	**0.2550***
Korea	**0.2310***	**0.3867***	**0.2011***	**0.2800***	**0.2074***	**0.2690***	**0.0427***	**0.2095***	**-0.0685**	**0.2213***	**-0.0680**	**0.2205***
Latvia	**0.0402***	**0.1970***	**0.0716***	**0.1168***	**-0.0355**	**0.0538***	**-0.0522**	**-0.0940**	**-0.2953**	**0.2031***	**-0.2876**	**0.2069***
Lithuania	**0.0926***	**0.2106***	**0.1256***	**0.1090***	**0.1021***	**0.1463***	**-0.0312**	**0.0652***	**-0.2641**	**0.2942***	**-0.2751**	**0.3038***
Luxembourg	**0.3731***	**0.5845***	**0.3080***	**0.4332***	**0.1515***	**0.2466***	**0.0584***	**0.0413***	**-0.1280**	**0.3085***	**-0.1549**	**0.3274***
Macao	**0.1312***	**0.2314***	**0.1356***	**0.1810***	**0.0158***	**0.0470***	**-0.0209**	**0.0628***	**-0.1621**	**0.1277***	**-0.1582**	**0.1203***
Malta	**0.3301***	**0.3411***	**0.2121***	**0.7113***	**0.1261***	**0.7233***	**0.0974***	**0.1801***	**-0.2544**	**0.2163***	**-0.3540**	**0.2358***
Mexico	**0.1705***	**0.3452***	**0.1298***	**0.2646***	**0.0806***	**0.1284***	**0.0147***	**0.1060***	**-0.1029**	**0.3372***	**-0.1138**	**0.3404***
Morocco	**0.0701***	**-0.0437**	**-0.0160**	**-0.0288**	**0.0005***	**0.0276***	**0.0098***	**-0.0712**	**-0.2603**	**0.2877***	**-0.2666**	**0.2925***
New Zealand	**0.5538***	**0.7096***	**0.5434***	**0.6968***	**0.4856***	**0.5804***	**0.2716***	**0.3991***	**-0.1365**	**0.2547***	**-0.1968**	**0.2655***
Panama	**0.0791***	**0.1838***	**-0.0823**	**0.0788***	**0.0828***	**0.0063***	**-0.0242**	**-0.0864**	**-0.1628**	**0.3432***	**-0.1445**	**0.3731***
Poland	**0.1282***	**0.1857***	**0.0210***	**0.0746***	**0.0007***	**0.0137***	**-0.0593**	**-0.0128**	**-0.2034**	**0.2599***	**-0.2032**	**0.2723***
Russian Federation	**-0.0129**	**-0.0430**	**-0.0103**	**-0.0085**	**-0.0143**	**0.0405***	**-0.0789**	**-0.0818**	**-0.1928**	**0.2356***	**-0.1911**	**0.2373***
Serbia	**0.0904***	**0.2110***	**0.0060***	**0.0709***	**0.0519***	**0.0534***	**-0.0082**	**0.0549***	**-0.2752**	**0.2607***	**-0.2794**	**0.2652***
Singapore	**0.1165***	**0.1988***	**0.0584***	**0.1441***	**0.1309***	**0.1932***	**0.0350***	**0.1545***	**-0.0408**	**0.2626***	**-0.0563**	**0.2685***
Slovak Republic	**0.2734***	**0.3829***	**0.2143***	**0.3115***	**0.1281***	**0.1727***	**0.1220***	**0.1492***	**-0.2363**	**0.3383***	**-0.2651**	**0.3671***
Slovenia	**0.4101***	**0.5421***	**0.3425***	**0.3901***	**0.2280***	**0.2745***	**0.0926***	**0.1014***	**-0.2680**	**0.2574***	**-0.3380**	**0.2755***
Spain	**0.4216***	**0.7021***	**0.3450***	**0.5519***	**0.2859***	**0.4337***	**0.1056***	**0.2694***	**-0.1264**	**0.2384***	**-0.2114**	**0.2474***

Table 4 (continued)

Country/Region	Once or twice a month		Once or twice a week		Almost every day		Every day		Control variables (SCMC)		Control variables (ASCMC)	
	Δa	*Δc*	*Δa*	*Δc*	*Δa*	*Δc*	*Δa*	*Δc*	Gender	ESCS	Gender	ESCS
Sweden	**0.4634***	**0.4819***	**0.3626***	**0.3915***	**0.2220***	**0.1934***	**0.1081***	**-0.0022**	**-0.1356**	**0.2240***	**-0.1677**	**0.2390***
Switzerland	**0.3176***	**0.5559***	**0.2833***	**0.3849***	**0.1282***	**0.1620***	**0.0153***	**-0.0258**	**-0.1377**	**0.2664***	**-0.1690**	**0.2736***
Thailand	**0.0957***	**0.0942***	**0.0623***	**-0.0015**	**0.0059***	**-0.0075**	**-0.0070**	**-0.0740**	**-0.4013**	**0.4443***	**-0.4040**	**0.4506***
Turkey	**-0.0780**	**-0.0167**	**0.0200***	**-0.0310**	**-0.0919**	**-0.1308**	**-0.0318**	**-0.1383**	**-0.2037**	**0.3011***	**-0.1881**	**0.3010***
United Kingdom	**0.5985***	**0.8427***	**0.3229***	**0.3828***	**0.1292***	**0.1773***	**0.0263***	**0.1883***	**-0.1035**	**0.2131***	**-0.1392**	**0.2140***
United States	**0.4366***	**0.6664***	**0.4878***	**0.6098***	**0.4894***	**0.5655***	**0.3778***	**0.4321***	**-0.1416**	**0.2445***	**-0.1827**	**0.2494***
Uruguay	**0.2818***	**0.3894***	**0.0703***	**0.1825***	**0.0383***	**0.1870***	**-0.0282**	**0.1530***	**-0.1434**	**0.3613***	**-0.1837**	**0.3615***
Moscow Region (RUS)	**-0.0288**	**0.0797***	**-0.0339**	**-0.0414**	**-0.0513**	**-0.0911**	**-0.0190**	**-0.0048**	**-0.2432**	**0.1569***	**-0.2253**	**0.1640***
Tatarstan (RUS)	**0.0709***	**0.1052***	**-0.0117**	**0.0726***	**0.0052***	**-0.0102**	**-0.0112**	**-0.0238**	**-0.2278**	**0.1931***	**-0.2212**	**0.1947***

Statistically significant results are highlighted in bold, indicating that zero does not fall within the 95% bootstrap CI (the specific value of the 95% bootstrap CI can be found in the supplementary materials), and an "*" is attached to the value above zero

many previous studies, sufficient time allocated for self-paced learning can also further predict students' digital reading performance through the mediation of metacognition. Since SCMC and ASCMC at high frequencies might not provide students with adequate time for self-paced learning, generally negative effects were observed in the current study. For the second question, one possible reason why there was a relatively better impact of ASCMC than SCMC on students' digital reading performance may be related to time allocation for self-paced learning. Compared to during SCMC, during ASCMC, students have more time to implement their metacognitive skills, and therefore achieve a higher metacognitive level. Regarding the third question, the time allocated to self-paced learning can also explain the finding that having ASCMC with teachers at a moderately low frequency facilitates digital reading performance in some countries/regions, but as frequency increases, the positive effect becomes negative. A possible reason might be that when the frequency of ASMC increases, it becomes less asynchronous, and therefore, the time allocated to self-paced learning might not be sufficient to complete the cycle of self-paced learning and metacognitive development. Based on the above analyses, it is tentative to conclude that to cultivate students with higher metacognitive levels and therefore facilitate students' digital reading performance, more self-paced learning time given to students during CMC between students and teachers is needed.

This study, however, is by no means without limitations. The first limitation lies in the nature of the data source: the CMC frequency information was collected from the self-reports of students, which are relatively subjective (Chen et al., 2021b) and hard to testify its reliability by individual researchers. Even though PISA didn't disclose the reliability of each item, it did report the scale reliability of the derived variable from related item parameters (OECD, 2017). The two frequency variables related to students' CMC use that this study investigated are two of the twelve items attributed to the derived variable of extracurricular use of ICT for school work activities, the reliability of which ranges from 0.873 to 0.967 across participating countries according to Table 16.71 and Table 16.72 of the technical report of PISA (OECD, 2017). This high scale reliability of the derived variable indicated that its constituent items have relatively high internal consistency reliability (Tavakol & Dennick, 2011). Second, the impact of teachers' instruction practices on students' reading performance is susceptible to the cultural background (Chen et al., 2021b; Hu et al., 2022) indicating the need for further analysis of the cross-national discussion of the results. Third, as technology develops, the difference between SCMC and ASCMC is not limited to the response interval but extends to the manifold applications of SCMC, such as video calls, which might introduce undesirable variation.

5 Conclusions

The objectives of the current study are twofold. First, the effects of extracurricular SCMC and ASCMC between students and teachers on digital reading performance at different frequencies were explored. Second, whether the effects of extracurricular SCMC and ASCMC between students and teachers on digital reading performance

were mediated by the metacognitive process of assessing credibility was examined. The major findings were unfolded as follows:

The findings related to RQ 1 testified that compared to those of SCMC, the effects of ASCMC between students and teachers on students' digital reading performance were significantly more positive, which is consistent with previous results (e.g., Giesbers et al., 2014; Ogbonna et al., 2019; Oztok et al., 2013). The new contributions of the findings obtained during the investigation of RQ 1 were as follows: (1) this study indicated the more positive role of ASCMC on digital reading performance by using an international database, enabling comparisons across different countries/regions, and (2) the current study included the factor of different frequencies of CMC in the exploration of the impact of SCMC and ASCMC, revealing that the more asynchronous the CMC, the better digital reading performance could be observed.

The findings obtained in the investigation of RQ 2 provided plausible reasons for the findings related to RQ 1 through the mediation analysis of the metacognitive process of assessing credibility. The statistically significant results for the relative indirect effects of SCMC and ASCMC on students' digital reading performance corroborated that metacognition plays a significant mediating role between independent variables and digital reading performance, which is consistent with many previous studies (e.g., Lee & Wu, 2013; Miyamoto et al., 2019; Schünemann et al., 2013; Veas et al., 2019; Wu, 2014). By extending the limited applications of the control-monitoring model (Nelson & Naren, 1990) to the online communication context, the results related to RQ 2 further emphasized the importance of giving sufficient self-paced learning time for students to develop their metacognitive skills of assessing credibility and therefore improve their digital reading performance.

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Data availability The dataset that this study based on are available in the official website of PISA (URL: http://www.oecd.org/pisa/data/2018database/). All data provided or analyzed in this study are included in this published article (and its supplemental files).

Declarations

Conflict of interest None.

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