Education and Information Technologies (2023) 28:14071–14089
https://doi.org/10.1007/s10639-023-11763-z

The relationship between social media-related factors and student collaborative problem-solving achievement: an HLM analysis of 37 countries

Meishu Wang[1] · **Rushi Yu**[1] · **Jie Hu**[1]

Received: 17 November 2022 / Accepted: 23 March 2023 / Published online: 3 April 2023

Abstract

Knowledge and abilities with social media technologies are perceived as critical premises for human development. Familiarity with different types of social media technologies has become pivotal for collaborative learning and successfully solving problems. This study examined the impact of social media technologies, compartmentalized into social media usage and students' attitudes towards social media usage, on their collaborative problem-solving (CPS) achievement by adopting the sample from the PISA 2015 dataset across 37 countries/regions. A three-level hierarchical linear model (HLM) was adopted to identify the significant factors related to CPS achievement. Results indicated that social media usage had a significant impact on CPS achievement and they are varied in terms of different learning contexts, different social media types (e.g., e-mails, social networking sites), and different purposes of social media use (leisure or academic use). Furthermore, students who had a more positive attitude toward social media were more likely to achieve higher CPS performance.

Keywords Social media · Educational technologies · Collaborative problem-solving · Secondary students · Programme for International Student Assessment (PISA)

Meishu Wang and Rushi Yu should be considered joint first author.

✉ Jie Hu
huj@zju.edu.cn

[1] Department of Linguistics, School of International Studies, Global Competency Center, Institute of Asian Civilizations, Zhejiang University, 866 Yuhangtang Road, Hangzhou City, Zhejiang Province 310058, China

1 Introduction

Considered as a central 21st century skill that is crucial for career development and public integration in society, collaborative problem-solving (CPS) competence has received widespread attention in recent years (e.g., Chang et al., 2017; Herborn et al., 2020; Stadler et al., 2019). CPS, by its nature, is a complicated constructs that encompasses a broad swathe of social collaboration skills and higher cognitive processing skills (OECD, 2017). In CPS tasks, students are able to engage in meaningful interactions, maintain awareness of group dynamics, think ahead, test hypotheses, make judgments about dynamically changing systems, and generate feasible solutions (e.g., Greiff & Neubert, 2014; Rojas et al., 2021; Stadler et al., 2020).

With the continuous evolution of Information Communication Technology (ICT), social media has become ubiquitous in the context of current increasingly globalized and hyperconnected societies (e.g., Erdogdu, 2022; Vosoughi et al., 2018). The effective use of ICT-based social media in teaching and learning is considered as the key enabler to elevate the educational innovation (e.g., Alalwan, 2022; Adam & Tatnall, 2017; Balakrishnan & Lay, 2016; Yu et al., 2023). Broadly defined as "a group of Internet-based applications that build on the ideological and technological foundation of Web 2.0" (Kaplan & Haenlein, 2010, p.60), social media tools include e-mails, instant messaging applications, wikis, blogs, social networking sites (SNS), online games, as well as websites. These various social media platforms provide students with unique opportunities to access information, share perspectives, co-create and solve problems with their peers in a more interactive and virtual environment, advancing the process of collaborative learning and problem-solving (e.g., Alvarez, 2013; Chugh & Ruhi, 2019; Sarwar et al., 2019).

A great deal of research has been devoted to investigate how social media tools are associated with student learning outcomes (e.g., Alalwan, 2022; Hu & Yu, 2021; Reinhardt, 2019; Srijamdee & Pholphirul, 2020). However, previous research have yielded inconsistent findings on the relationship between social media and learning performance. Considering the positive effects of social media, prior studies have suggested that social media platforms provide convenient communication channels regardless of distance (e.g., Gikas & Grant, 2013; Srijamdee, & Pholphirul, 2020), makes it possible for students to effectively engage in direct learning and investigate topics by collecting a wider range of resources, significantly facilitates students' information literacy (e.g., Sarwar et al., 2019) and critical thinking (e.g., Reinhardt, 2019; Vosoughi et al., 2018). Additionally, the use of social media can support teaching and learning effectiveness, making classes more interactive and attractive (e.g., Andersson et al., 2014). A wide variety of authentic games with higher-order scientific reasoning episodes in social media platforms might be conducive for students to deal with complicated learning activities (Unal & Cakir, 2021; Wu & Nian, 2021), and improve students' self-efficacy (e.g., Chen & Hu, 2020; Manca & Ranieri, 2016). However, concerns have been raised that the excessive intensity of the use of social media tools might distract students from learning (e.g., Feng et al., 2019).

Therefore, given the essential role of social media in boosting learning process in this digital age, and the inconsistent findings on their relationship, it is important to develop in-depth analyses of the effects of social media-related factors on stu-

dent collaborative problem-solving performance, and the mechanism underlying this influential pattern (e.g., Li et al., 2020). However, studies investigating the effectiveness of social media have mainly focused on student learning proficiency, such as digital reading literacy (e.g., Hu & Yu, 2021) and math or science achievements (e.g., Zhang & Liu, 2016), limited research attention has been devoted to student CPS performance. Even where CPS is considered, researchers have mainly concerned with the validity of CPS assessment (e.g., Chang et al., 2017; Stadler et al., 2020) or the effects of using technology-supported CPS on student learning achievements (e.g., Alvarezet et al., 2013), with scant attention paid to the social media factors influencing students' CPS achievement. This oversight seems unexpected, given the strong current political and educational acknowledgment of the relevance of CPS performance in this digital age.

The current research investigates the relationship between social media technologies factors and adolescents' CPS achievements. First, this study offers a multidimensional and comprehensive overview of the possible influences of social media-related factors at the student, school, and national levels. Second, this study utilizes a large-scale data set, the first and latest Programme for International Student Assessment (PISA) 2015 CPS assessment data, based on results for 262,358 students from 9,387 schools across 37 countries/regions, to present the evidence of the effects of social media.

2 Literature Review

2.1 Social media usage factors and CPS achievement

Social media usage factors could be classified based on the diversity of places and for varieties of social media usage purposes, including informal or formal use, i.e., outside school or at school, and usage for leisure or schoolwork (Goldhammer et al., 2016).

In studying the relationship between social media usage factors and student CPS achievement, most studies suggested that the use of social media has a positive influence on student CPS achievement. For instance, Kim and Sin (2015) suggested that the positive influence of social media usage, for example, social networking sites, was relatively easily accessible to seek for information. Their study revealed that students who read news online were more open-minded and tended to develop more competency in problem-solving activities than students who did not surf the internet. Li et al. (2020) then examined the relationship between enterprise internet technologies and CPS performance within organizations. Their study indicated that social media can promote emergent practices of knowledge exchange by offering increased visibility of content, and help individuals reach consensus during problem-solving activities. Daniela et al. (2016) compared the effects of the use of Twitter and Skype for chatting, suggesting that all social media platforms could positively affect students' CPS performance, while lower frequency use of social media had no positive influence. With respect to the effects of online games, Shute et al. (2015) elucidated that playing video games and cognitive training games were positively related to stu-

dents' problem-solving outcomes; in contrast, Dindar (2018) claimed that there is no significant practical link between playing video games and student problem solving performance. Moreover, DeWitt et al. (2017) examined relationships among social media use, CPS, and academic achievements, using wikis and SNS as examples of the former; their results indicated that the use of wikis in the CPS module supported students' interactions and was conducive to learning performance. Similarly, Wu (2019) investigated the effects of online discussion environments and found that Facebook-based online learning is beneficial for instruction activities, which helps to improve students' higher cognitive processing and CPS ability.

From all the existing studies above, it can be seen that all of the existing studies on the relationship between social media usage and student CPS achievement has been limited to considering one or two specific types of social media (e.g., blogs, Twitter, Facebook). Therefore, these studies are hard to provide a comprehensive perspective on the effects of social media usage concerning different types and different purposes within different study contexts.

2.2 Student perceived value of social media usage and CPS achievement

Defined as one of the cognitive-motivational factors in ICT engagement, student perceived value of using social media best reflects students' feeling of control over their social media usage and their self-directedness in various relevant activities (Goldhammer et al., 2016). Thus, whether students considered social media as a useful tool can drive their use of social media and subsequently influence their CPS outcomes.

Some recent literature has suggested that student perceived value of social media is an effective mediator between the duration of social media usage and collaborative learning performance (e.g., Balakrishnan & Lay, 2016; Cooke, 2017; Sarwar et al., 2019). For example, Junco (2012) highlighted the effects of students' positive attitudes toward social media with respect to collaborative learning. They found that students' interest in using social media motivated them to engage in more collaborative tasks, driving them to discuss the core concepts embedded in the learning problems and thus enhancing both the learning experience and learning outcomes. In another study, Ertmer et al. (2011) reported that student perceived value for social media had largely determined their frequency of social media usage, which in turn allowed students closely coordinate with each other and integrate different perspectives to solve problems. As a result, student might be engaged in deeper cognitive processing of learning problems that aided their learning performance. Nevertheless, Cooke (2017) contradicted previous researchers, suggesting that students' positive perceptions of social media had little influence on their learning processes.

Based on the existing literature, researchers have emphasized the importance of analysis of students' attitudes towards social media and its effects on collaborative learning processes instead of focusing on specific CPS assessments. Additionally, previous studies have mainly explored this relationship among postsecondary students, scarce empirical research have elucidated the impact of students' perceptions of social media on CPS achievement among 15-year-old students.

2.3 Rationale for the present study

The existing literature elucidates the potentially significant influence of social media on student educational outcomes. Although substantial efforts have been made to explore the correlations between social media and academic achievements, little attention has been attracted to the impact of social media on students' CPS achievement, and mostly have regarded social media as a general use without considering different types of social media, its different purposes and different locations of use. Second, the results are inconclusive and merit renewed scrutiny given the increased importance and universality of social media usage in education. Third, the participants in previous studies were mainly higher education students, few insights have been generated on secondary school students. Fourth, there have been relatively few studies using the international educational large-scale database, i.e., PISA 2015, which is authoritative and representative to investigate adolescents' CPS achievement.

Accordingly, the present study adopts the latest global data set provided by an authoritative international large-scale assessment of CPS performance, PISA 2015, and aims to fill these lacunae by exploring social media usage factors and students' perceived value of using social media tools from a multidimensional perspective by considering student-, school-, and country-level variables. A conceptual framework is established to reflect the relationships between different variables (see Fig. 1).

Based on the previous empirical evidence, we hypothesized as follows,

Hypothesis 1 Social media usage factors are significantly related to student CPS achievement, and varieties of social media tools for leisure or schoolwork usage within different study context, i.e., outside school or at school, might have varied effects.

Hypothesis 2 Students' perceived value of using social media are positively linked to their CPS achievement.

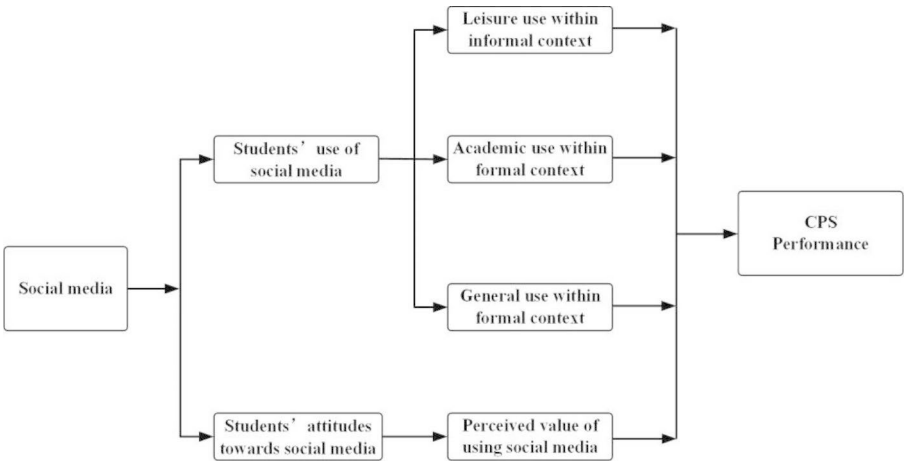

Fig. 1 Framework for the relationship between social media and CPS outcomes

3 Materials and methods

3.1 Data

The data in the current study were obtained from the PISA 2015 database, which is the latest survey measuring CPS performance in the PISA assessment (URL: http://www.oecd.org/pisa/data/2015database/). Conducted by OECD every three years, PISA probably counts as the most influential and authoritative international large-scale assessment, with essential effects on educational policies (e.g., Stadler et al., 2019). Additionally, PISA provides abundant data of student individual factors, family backgrounds, and school contextual factors, which presents strong evidence to measure and monitor the quality of basic education in various countries/regions. It evaluates secondary students' reading, mathematics, and science performance, and began to evaluate students' CPS skills in 2015. In PISA 2015, data were collected from approximately 710,000 secondary students from 72 participating countries/economies, representing over 31 million secondary students in these countries/regions; among the participating countries or regions, 53 implemented the computer-based CPS assessment. During the data preprocessing, the countries whose data were completely missing were entirely eliminated; thus, a total of 262,358 students from 9,387 schools in 37 countries or regions were selected in the current study. Table 1 displays the detailed demographic information for statistics in the PISA 2015 results.

3.2 Variables

Considering that each student was unable to implement all survey items, PISA 2015 computed 10 plausible values (PVs) of CPS scores to estimate student achievement in a stable and unbiased way (OECD, 2017). Therefore, the dependent variable was student CPS achievement in the PISA 2015 assessment, which was represented by 10 PVs of each student.

The independent variables can be compartmentalized into social media usage for leisure within informal contexts, social media usage for schoolwork within informal contexts, social media usage in general within formal contexts, and students' perceived value of using social media. Specifically, six kinds of social media usage factors for leisure were included, namely, "use of email for leisure" (RECUSEM), "use of chatting online" (RECUSECO), "use of playing digital games" (RECUSEPG), "use of SNS" (RECUSESN), "use of browsing the Internet" (RECUSEINT), as well as "use of reading news from website" (RECUSERO). In addition, four other variables were categorized as social media usage for schoolwork within informal contexts, namely, "use of email for schoolwork with peers" (ACAUSEMS), "use of email for schoolwork with teachers" (ACAUSEMT), "use of SNS for schoolwork with students" (ACAUSESNS), and "use of SNS for schoolwork with teachers" (ACAUSESNT). Considering the six types of social media usage factors, students provided responses on a five-point Likert scale, including "never or hardly ever", "once or twice a month", "once or twice a week", "almost every day", and "every day". With respect to the variable of students' perceived value of using social media, the responses were based on a four-point Likert scale, ranging from "strongly dis-

Table 1 Demographic information for statistics in the PISA 2015 results

Country/Region	PISA 2015 CPS Assessment	
	N (School)	N (Females)/N (Total students) (percentage)
Australia	697	6,620/13,443 (49.24%)
Belgium	277	4,601/9,308 (49.43%)
Brazil	642	9,587/18,324 (52.32%)
Bulgaria	180	2,823/5,928 (47.62%)
Chile	220	3,412/6,880 (49.59%)
China (B-S-J-G)	268	4,682/9,841 (47.58%)
Colombia	324	5,521/10,366 (53.30%)
Costa Rica	205	3,494/6,866 (50.89%)
Croatia	160	3,013/5,809 (51.87%)
Czech Republic	339	3,345/6,766 (49.44%)
Denmark	275	2,984/5,911 (50.48%)
Estonia	206	2,788/5,587 (49.90%)
Finland	167	2,846/5,846 (48.68%)
France	237	2,948/5,793 (50.89%)
Germany	204	2,546/5,150 (49.44%)
Greece	210	2,703/5,528 (48.90%)
Hong Kong-China	138	2,675/5,359 (49.92%)
Hungary	233	2,721/5,331 (51.04%)
Italy	342	4,162/8,480 (49.08%)
Japan	198	3,309/6,647 (49.78%)
Korea	168	2,669/5,581 (47.82%)
Latvia	248	2,401/4,835 (49.66%)
Lithuania	312	3201/6525 (49.06%)
Luxembourg	44	2,683/5,299 (50.63%)
Macao-China	45	2,230/4,476 (49.82%)
Mexico	275	3,803/7,568 (50.25%)
Netherlands	135	1,941/3,919 (49.53%)
Peru	281	3,460/6,971 (49.63%)
Portugal	242	3,604/7,235 (49.81%)
Russian Federation	210	3,107/6,036 (51.47%)
Singapore	176	2,956/6,082 (48.60%)
Slovak Republic	290	3,035/6,350 (47.80%)
Slovenia	309	2,695/5,963 (45.20%)
Spain	200	3,399/6,726 (50.54%)
Thailand	272	4,629/8,208 (56.40%)
United Kingdom	439	5,578/11,359 (49.11%)
Uruguay	220	3,154/6,062 (52.03%)
Total	9387	131,325/262,358 (50.05%)

Sources: PISA 2015 database (URL: http://www.oecd.org/pisa/data/2015database/)

agree" to "strongly agree". Additionally, students' gender and the index of economic social and cultural status (ESCS) were used as control variables.

Regarding the school-level variables, two variables, namely, "overall social media usage at school" (SCHUSE) as well as "overall students' perceived value in social media usage" (ATTUSE), were derived from the median of the relevant student-level variables (Hu & Yu, 2021). The country-level variable, "the logarithm of national

gross domestic product per capita", was used as the control variable. Specific information regarding the descriptions of the selected variables is presented in supplementary materials (see Table S1).

3.3 Data preprocessing

Focusing on the design of PISA assessment, participants were randomly assorted to testlets rather than implementing all sets of items (Hu & Yu, 2021), thus the missing data occurred at random. The multiple imputation (MI) algorithm, as a useful method for conducting assumption analysis under both missing at random or not (Ratitch, 2014), provides more precise imputations by creating multiple data sets for missing data compared to single imputation or listwise deletion (Enders, 2010). Therefore, MI was used to impute missing values. The data imputation process with MI was performed using the statistical package IBM SPSS Statistics 25.0. Specifically, the process of MI in this current study was based on 10 replications to ensure the quality of the imputation (Schafer & Olsen, 1998). The results indicated an efficiency of 99% for imputing 10% missing data in the PISA 2015 assessment database, which proved that MI was appropriate for this research (Hox, 2010).

Based on this step, the student weight was computed following the instructions of the PISA Data Analysis Manual (OECD, 2017). Afterward, continuous variables were made to be easily comparable by Z-score normalizing. Categorical variables were transformed into dummy variables using R (R Core Team, 2019). Additionally, the correlation matrices of variables for all 37 countries/regions and variance inflation factors are provided, and all of them were in the acceptable range (see Table S2-S5 in supplementary materials).

3.4 Data analysis

In the current study, statistical hierarchical linear modeling, conducted by Hierarchical Linear & Nonlinear Modeling 8.0 (License ID: 1686), was employed to analyze the student-level, school-level, and country-level variables (Raudenbush et al., 2019). Compared to traditional regression models, the hierarchical linear model (HLM) fits better for multilevel data structures because it addresses the dependency correlations among variables from different levels and can simultaneously analyze the influence of these variables on the outcome variables (Raudenbush & Bryk, 2002). Additionally, standard errors can be estimated more robustly, and aggregation bias was avoided with an HLM (Hox, 2010). In the PISA 2015 assessments, the student-level data were clustered within the school-level data, and school-level data were clustered within country-level data. Therefore, HLMs were applied to analyze the relationship among variables from different levels and to account for the variation in the outcome variables, namely, student CPS outcome scores (Field et al., 2012; Hox, 2010; Raudenbush & Bryk, 1992).

The modeling started with the null model was built to partition the variance in the student outcome scores within the student, school, and country levels, contributing to the justification of the use of hierarchical linear modeling analysis. The intraclass correlation coefficient (ICC) was calculated to determine the variance proportion

at each level and to identify the key variances at each level (Hedges, Hedberg, & Kuyper, 2012). In addition, all data were weighed for unbiased estimation when integrating into HLMs.

Model 2 included all control variables that were proven to be significant at the student, school, and country levels (i.e., student gender, student SES, school type, school location, school size and LnGDP), with the aims of identifying the significance of these variables as well as the proportion of additional variance in the student CPS scores. In addition, there is a need of emphasizing that the backward approach was applied to remove the insignificant variables ($p > 0.05$) from this step and the following steps. These steps were repeated until all the variables involved in this model were indicated to be significant (Field, 2009).

Additionally, all selected variables in this study were added into the following models consecutively. Model 3 was composed of all the remarkable variables at the student-level. Model 4 was formed by merging all the remarkable variables at student and school levels. Finally, the country-level variable was integrated into Model 5, with all above statistically significant variables from the student and school levels, to examine the effects of all the three-level variables simultaneously. The resulting model was constructed with random intercepted and fixed slopes, and it is presented as follows:

$$Y_{ijk} = \gamma_{000} + \pi_{ajk}A_{ijk} + \beta_{0bk}B_{0jk} + \gamma_{00c}C_{00k} + e_{ijk} + r_{0jk} + u_{00k} \quad (1)$$

where.

Y_{ijk} refers to students' CPS achievement.

γ_{000} refers to the intercept;

π_{ajk}, β_{0bk}, and γ_{00c} refer to the fixed slopes of A student-level variables, B school-level variables, and C country-level variables, respectively; and

e_{ijk}, r_{0jk}, and u_{00k} refer to the residual errors of students, schools, and countries, respectively, and the random effects involved in the variances.

For the purpose of ensuring the reliability of the estimates, it is necessary to test the statistical assumptions for HLM and inspect the residual errors for all three levels (Hox, 2010). In particular, scatter plots were provided to check the homoscedasticity at the student level as well as the linearity at all three levels. Histograms and Q-Q plots were provided to detect whether there are abnormalities existed (see Table S11 in supplementary materials).

It is also worth addressing that this study adopted f^2, variance explained, to measure the effect size of the full models, which means how much of the model's unaccounted-for variation was explained by the variables themselves (Hox. 2010). Additionally, the effect size of the models was determined according to Cohen's (1988) rules in which the value 0.02 forecasts a weak influence, 0.15 forecasts a medium influence, and 0.35 forecasts an intense influence.

4 Results

According to the data in the null model (see Table S6 in supplementary materials), it was revealed that the ICC value was 23.65% when students were nested within schools and 16.06% when schools were nested within countries, both of which exceeded 13.8%, indicating a high proportion of variance (Cohen, 1988). Since both school- and country-level variances have explained a remarkable proportion of the total variances, it was confirmed that applying HLMs to conduct further analysis is necessary (Skryabin et al., 2015).

The analysis of Model 2 indicated that all the control variables were significant variables. From a comparison of random effects in Models 1 and 2, the student-level variance explained ranged from 3.44 to 3.50%, the school-level variance explained ranged from 34.36 to 34.69%, and the country-level variance explained ranged from 58.90 to 59.79% (see Table S7 in supplementary materials).

Models 3 and 4 revealed that all selected student- and school-level variables were significantly correlated with student CPS achievement (see Tables S8 and S9), excluding the variable M_ATTUSE in Model 4, which was insignificant ($P > 0.05$). Finally, in Model 5, it was indicated that all variables included in the HLM were significantly related to CPS achievement though with mixed influences ($p < 0.05$) and were divided into four categories: social media usage for leisure within informal context, social media usage for schoolwork within informal context, the general use of social media within formal context, and student perceived value of social media usage. Table 2 presents the descriptive statistics in the final model, namely, Model 5, which was assumed to meet all the model assumptions.

Social media usage for leisure within informal context. Based on the final model, it was revealed that social media usage factors for leisure had a significant interrelation with student CPS outcomes, and the effects are varied in the case of the diversity of social media types. Specifically, using email (variable RECUSEM), browsing the internet (variable RECUSEINT), and reading online news (variable RECUSERN), were all found to have a remarkable positive impact on student CPS outcomes. Additionally, students who spent more time on the use of chatting online (variable RECUSECO) and SNS (variable RECUSESN) for leisure were more likely to achieve higher CPS performance than students with rare usage. For example, students who reported "every day" use tended to achieve higher CPS scores than those who reported "once or twice a month". However, playing digital games online (variable RECUSEPG) was indicated to significantly negatively influence student CPS outcomes.

Social media usage for academic purposes within informal context. Regarding social media usage for schoolwork outside of school, using SNS for peer interactions about schoolwork (variable ACAUSESNS) was proven to have a positive impact on student CPS achievement, whereas using SNS to interact with teachers (variable ACAUSESNT) as well as using email to interact with students and teachers (variables ACAUSEMS and ACAUSEMT) indicated negative effects.

Social media usage in general within formal context. Students' individual general use of social media at school (variables SCHUSECO and SCHUSEM) was found to be negatively correlated with student CPS achievement. Additionally, students' over-

Table 2 Model 5 with all significant variables at the student, school and country levels related to CPS performance

Variable	Coefficient	Standard Error	T-ratio	d.f.	p-value
intercept	461.87	4.62	99.87	35	0.000
Student level					
ESCS	13.65	0.31	44.14	24	0.000
GENDER_2	-15.61	0.44	-35.82	42	0.000
RECUSEM_2	10.36	0.54	19.32	101	0.000
RECUSEM_3	16.10	0.68	23.51	33	0.000
RECUSEM_4	18.47	0.66	27.82	105	0.000
RECUSEM_5	17.23	0.83	20.75	57	0.000
RECUSECO_2	-4.80	0.91	-5.29	38	0.000
RECUSECO_3	-0.83	0.82	-1.02	38	0.316
RECUSECO_4	0.99	0.67	1.47	54	0.148
RECUSECO_5	2.11	0.71	2.96	32	0.006
RECUSESN_2	-4.63	1.19	-3.89	30	0.001
RECUSESN_3	0.002	0.99	-0.002	36	0.999
RECUSESN_4	1.39	0.85	1.64	46	0.108
RECUSESN_5	2.45	0.90	2.71	32	0.011
RECUSEPG_2	-9.31	0.71	-13.04	33	0.000
RECUSEPG_3	-15.11	0.81	-18.76	26	0.000
RECUSEPG_4	-19.21	0.72	-26.83	74	0.000
RECUSEPG_5	-22.58	0.89	-25.25	26	0.000
RECUSEINT_2	5.93	1.16	5.13	45	0.000
RECUSEINT_3	17.42	0.89	19.64	103	0.000
RECUSEINT_4	20.8	0.88	23.75	96	0.000
RECUSEINT_5	24.86	0.90	27.48	77	0.000
RECUSERN_2	7.68	0.67	11.41	66	0.000
RECUSERN_3	13.16	0.80	16.45	23	0.000
RECUSERN_4	13.59	0.62	21.95	93	0.000
RECUSERN_5	13.23	0.74	17.99	47	0.000
ACAUSEMS_2	-7.86	0.59	-13.3	51	0.000
ACAUSEMS_3	-10.95	0.66	-16.65	48	0.000
ACAUSEMS_4	-11.8	0.90	-13.13	33	0.000
ACAUSEMS_5	-14.16	1.05	-13.51	87	0.000
ACAUSEMT_2	5.33	0.55	9.76	55	0.000
ACAUSEMT_3	-1.05	0.59	-1.80	728	0.073
ACAUSEMT_4	-7.87	1.03	-7.66	43	0.000
ACAUSEMT_5	-9.48	1.19	-7.97	146	0.000
ACAUSESNS_2	1.70	0.76	2.24	45	0.030
ACAUSESNS_3	8.32	0.87	9.55	22	0.000
ACAUSESNS_4	8.06	0.71	11.41	60	0.000
ACAUSESNS_5	2.74	0.97	2.82	22	0.010
ACAUSESNT_2	-14.32	0.68	-21.13	43	0.000
ACAUSESNT_3	-24.42	0.67	-36.47	90	0.000
ACAUSESNT_4	-29.32	0.90	-32.74	39	0.000
ACAUSESNT_5	-31.18	0.86	-36.31	73	0.000

Table 2 (continued)

Variable	Coefficient	Standard Error	T-ratio	d.f.	p-value
SCHUSECO_2	-8.03	0.66	-12.08	71	0.000
SCHUSECO_3	-8.18	0.60	-13.61	127	0.000
SCHUSECO_4	-8.27	0.63	-13.2	77	0.000
SCHUSECO_5	-12.4	0.73	-16.9	54	0.000
SCHUSEM_2	-0.29	0.65	-0.45	31	0.658
SCHUSEM_3	-1.31	0.60	-2.18	124	0.031
SCHUSEM_4	-6.85	1.07	-6.43	26	0.000
SCHUSEM_5	-8.77	1.12	-7.85	52	0.000
ATTUSESN_2	16.95	1.19	14.25	30	0.000
ATTUSESN_3	21.92	1.03	21.33	35	0.000
ATTUSESN_4	19.79	3.74	5.29	35	0.000
School level					
SCHSIZE	8.73	0.56	15.47	569	0.000
SCHLOCA_2	8.02	1.78	4.51	89	0.000
SCHLOCA_3	12.73	1.80	7.08	64	0.000
SCHLOCA_4	18.22	1.77	10.31	147	0.000
SCHLOCA_5	23.61	2.19	10.77	93	0.000
SCHTYPE_2	-14.91	2.32	-6.42	282	0.000
SCHTYPE_3	-20.66	1.89	-10.93	443	0.000
M_SCHUSE_2	-3.70	1.31	-2.82	161	0.006
M_SCHUSE_3	-4.47	1.55	-2.88	256	0.005
M_SCHUSE_4	1.73	3.50	0.50	154	0.621
M_SCHUSE_5	5.17	15.56	0.33	32	0.742
Country level					
LnGDP	25.25	1.02	24.75	48	0.000

Note. The statistics are based on the mean of the 10 multiply imputed datasets with the 10 PVs for PISA 2015; P values exceeding 0.05 are deemed nonsignificant

all general use of social media at school indicated strong correlations with student CPS achievement.

Students' perceived value of social media usage. The results demonstrated that students who hold a positive perception of social media tend to achieve higher CPS outcomes than students who considered social media as little value.

Random Effects. According to the data (see Table S6 and S9 in supplementary materials), compared to the null model, all f^2, variance explained, in student-level was 10.7%, relatively close to medium effect. The f^2 in school-level was 51.18%, and the country-level f^2 was 71.79% respectively, indicating large effect sizes.

5 Discussion

The present study probes into the relationship between student-, school-, and national-level social media factors and student CPS achievement across 37 countries/regions. The results added to the previous empirical evidence in three aspects. First,

according to the effect size estimations of the full models, social media tools had a close relationship with student CPS performance. Second, different types of social media factors showed diverse significant relationships with student CPS achievement and should be considered in terms of the different locations, purposes, and contexts of social media usage, which has been ignored in previous studies. Third, this study elucidated new findings on the positive effects of students' perceived value of using social media on student CPS performance, which has rarely been explored before. A detailed interpretation of the results is discussed below, followed by the policy implications.

5.1 The relationship between social media usage factors and CPS achievement

A closer look at the findings indicates that different types of social media factors have diverse significant impacts on student CPS achievement, adding to the evidence of the existing literature that asserted the influence of social media usage as an integral. Specifically, findings on the positive impact of using email, accessing SNS, chatting online, browsing the Internet, and reading online news for fun, partly consistent with the results of previous research that social media usage was conducive to students' CPS performance (e.g., Wu & Nian, 2021; DeWitt et al., 2015). That is, social media provides a learner-directed platform and creates an ideal condition for free voluntary CPS activities, leading to a stronger mutual engagement in the student community (Balakrishnan & Lay, 2016; Reinhardt, 2019). Furthermore, these online platforms promoted students' broad interactive learning experience online and emergent practices of knowledge collaboration (Arpaci et al., 2021; Hammond, 2020). A vast amount of higher-order scientific reasoning episodes involved in these text-based entertainment platforms contribute to the development of student CPS skills (Unal & Cakir, 2021; Wu & Nian, 2021). Students might be more open-minded to gain an understanding of new concepts and develop a shared plan to solve a problem that constitutes part of the social media usage experience of subjects within which information processing, argumentation skills, and critical thinking skills are required (DeWitt et al., 2015; Zheng et al., 2020).

However, there was a significant negative relationship between playing digital games and student CPS performance, which yielded contradictory results with previous studies that suggested playing digital games was conducive to improving students' problem-solving skills (Shute et al., 2015) and no significant relationship was found between playing games and problem-solving outcomes (Dindar, 2018). The difference in findings between these previous studies and the present study might be the diversity of how the problem-solving skills be measured. A study conducted by Shute et al. (2015) measured the effects of specific digital games and Dindar (2018) focused on the complex problem-solving ability. However, the findings of the present study were based on the international large-scale data of collaborative problem-solving assessment, and were not limited to specific games, which offers a new and wider viewpoint for readers.

The findings on the influences of social media for academic purposes within informal contexts were complex and varied. Four different types of social media usage were revealed to have a significant impact on students' CPS performance, but with

different directions of influence. Both using email for interaction with their peers and teachers showed a negative influence on students' CPS performance, which adds new evidence of previous literature regarding the effects of using email for schoolwork. In contrast, this study found a positive impact of using SNS for schoolwork on CPS performance. Similar findings were obtained by Wu (2019) for the positive influences of Facebook for improving cognitive processing and DeWitt et al. (2017) for the supportive functions of Wikis in science learning, whilst contradicted with some studies mentioned that digital devices might be detrimental to students' educational achievement (Beland & Murphy, 2016; Eickelmann et al., 2017). Considering the key to elaborating the mixed results of the academic use of social media, it might be attributed to the differed nature and quality of interactions in these online platforms (Comi et al., 2017; Meggiolaro, 2018). Compared to the asynchronous nature of email, SNS (e.g., Facebook, Myspace or Skypes) allow synchronous and instant interactions that create a more lighthearted atmosphere to motivate students actively participate in group discussion and collaboration tasks (Manca & Ranieri, 2016; Rutherford, 2010; Wu & Nian, 2021). The ample and attractive resources and activities involved in synchronous platforms enable students to effectively engage in collaborative learning, develop their analytical skills, and facilitate their CPS ability (Petko et al., 2017).

In this study, the academic use of SNS for peer interactions was positively associated with students' CPS performance, whereas a negative relationship was revealed between using SNS for interaction with teachers and their CPS performance, these two completely reverse effects had received less attention from the literature. One possible reason for the positive impact of using SNS for peer interactions can be attributed to the benefits of online peer-assisted learning (e.g., Yu & Hu, 2021; Wu, 2019). It is believed that learner-learner interactions occurring in computer-supported synchronous CPS contexts entails the dialogical processes between peers, engendering the development of critical thinking and knowledge integration processes (e.g., Herborn et al., 2020; Wu & Nian, 2021). Explicitly, the effects of learner-learner interactions in social media may over the effects of faculty-student interactions (e.g., Smith, 2016; Vaughan, 2010), and such interactions could enable students to think, synthesize different perspectives from their peers and achieve a shared knowledge for solving the problems (Chang et al., 2017). On the other hand, students are more likely to engage in online collaborative learning in an unimpeded manner since such peer discussion provides students with necessary emotional and practical support in countless ways (Wang & Hu, 2022; Yu et al., 2023).

This study also revealed that two types of social media (i.e., chatting online, using e-mail) for general use within formal contexts were significantly negatively related to student CPS achievement. In other words, more frequently using social media at school was inextricably linked to students' lower CPS achievement. These findings were congruent with some of the previous literature (e.g., Mora et al., 2018). Lambic (2016) also demonstrated that no significant correlations between the use of Facebook for general purposes and student academic performance. Given the fact that students generally engaged in the improper use of social media platforms, a higher frequency of chatting online and using emails at school may occupy students' regular learning time and distract students from classes. From another perspective, it was found that teachers were more inclined to use computers for a narrow set of

pedagogical purposes without innovations (e.g., Hew & Brush, 2007). Therefore, in this situation, a higher frequency use of social media might hamper students' critical thinking abilities, problem-solving skills and fail to enhance their CPS performance.

5.2 The relationship between students' perception of social media and CPS achievement

The present study examined the influence of student perceived value of social media usage on CPS achievement in multiple dimensions, at the student level and school level. Students who reported that social media was useful presented a higher CPS performance. These results were partly in agreement with previous literature (e.g., Cooke, 2017), which indicated that positive attitudes toward social media help improve students' problem-solving abilities in the collaborative learning process. As Lin, Zhang, and Zheng (2017) explained, students' attitudes and motivation were considered as determining factors in how effective online learning environments will be in their academic achievements. Similarly, also found that positive attitudes toward digital devices might lead to more frequent use of digital devices and higher grades in collaborative learning tasks. Accordingly, one of the possible reasons for this impact might be that students' positive attitudes toward social media can arouse their potential interest and provokes students' initiative to engage in more group discussion activities, to construct solutions to a problem (Rutherford, 2010). By contrast, there is no significant correlation between the aggregation effects of school mean student attitudes toward social media and student CPS achievement. Given the different influential patterns of students' perceived value of social media at the student- and school-level, the findings in this current study suggested the necessity of considering the multidimensional factors.

Although previous studies have explored the effects of students' attitudinal factors toward social media on students' collaborative learning process, the mediating effect of student-perceived value of social media, social media usage and adolescents' CPS performance is unknown, and further exploration clarifying this issue is still needed. Considering the significant contribution of perceived value of social media usage on CPS performance, schools are supposed to be the focal points for raising adolescents' awareness of using social media by introducing varieties of online activities.

6 Conclusion

The present study examined the effects of various types of social media technologies for leisure and academic usage within different contexts, i.e., informal and formal contexts, as well as student perceived value of social media on adolescents' CPS achievement at the student-, school-, and national-level across 37 countries/regions. To the best of our knowledge, this is the first study in the field of education and linguistics to probe into the effects of social media tools on adolescents' collaborative problem-solving performance using an international large-scale data set. This study adds to the literature in multiple ways. (1) It provides a multidimensional and comprehensive overview of the effects of social media-related factors at the student, school, and

national levels based on the previous literature. (2) It offers new viewpoints regarding the varied influences of social media on student CPS achievement and reveals that the analysis of influences should consider various types of social media factors (e.g., using emails, SNS) for leisure or academic usage within different contexts (i.e., informal or formal context). (3) It used an international large-scale data set, the first and latest PISA 2015 CPS assessment data of 262,358 students from 9,387 schools across 37 countries/regions, to investigate the relationship between social media and student CPS performance. Results indicated that most of social media use factors for leisure purposes and student perceived value of using social media have significant positive influences on student CPS performance, whereas some types of social media factors for academic purposes have negative influences. These results shed light on the pedagogical and administrative implications for technology-supported teaching and learning, which are crucial to educators, researchers and policy makers. On the one hand, the integration of social media in education provides alternative solutions and multiple paths to puzzling learning problems; on the other hand, the use of social media should be treated in optimized ways to enhance its quality and efficiency.

The current study is not without limitations. First, considering the data variation, if possible, future studies could expand the scale of the data set, conducting longitudinal experimental research on the same groups of participants over the years to examine the cause-and-effect interrelationship. The second limitation related to the PISA assessment questionnaire is that since most of the surveys were self-reported by students, the endogeneity of variables needs cautious treatment. Third, the interrelations between social media usage and student perceived value of using social media have not been examined due to the complexity of the multilevel model building. For the purpose of identifying the interrelations between the use of social media and student perceived value of using social media, further mediation analyses are needed to probe these effects in depth.

Funding This research was supported by the Zhejiang Provincial Philosophy and Social Sciences Programme of Leading Talents Cultivation Project for Distinguished Young Scholars, China "A study on the influencing factors and mechanism of digital reading literacy in the digital intelligence era" (grant number 23QNYC04ZD).

Declarations

Conflict of interest None.

References

Adam, T., & Tatnall, A. (2017). The value of using ICT in the education of school students with learning difficulties. *Education and Information Technologies*, *22*(6), 2711–2726. https://doi.org/10.1007/s10639-017-9605-2

Alalwan, N. (2022). Actual use of social media for engagement to enhance students' learning. *Education and Information Technologies*, *27*(7), 9767–9789. https://doi.org/10.1007/s10639-022-11014-7

Alvarez, C., Salavati, S., Nussbaum, M., & Milrad, M. (2013). Collboard: Fostering new media literacies in the classroom through collaborative problem solving supported by digital pens and interactive whiteboards. *Computers & Education*, *63*, 368–379. https://doi.org/10.1016/j.compedu.2012.12.019

Alvarez, C., Salavati, S., Nussbaum, M., & Milrad, M. (2013). Collboard: Fostering new media literacies in the classroom through collaborative problem solving supported by digital pens and interactive whiteboards. *Computers & Education*, *63*(4), 368–379. https://doi.org/10.1016/j.compedu.2012.12.019

Andersson, A., Hatakka, M., Gronlund, A., & Wiklund, M. (2014). Reclaiming the students-coping with social media in 1:1 schools. *Learning Media and Technology*, *39*(1), 37–52. https://doi.org/10.1080/17439884.2012.756518

Arpaci, S., Mercan, F. A., & Arkan, S. (2021). The differential relationships between PISA 2015 science performance and, ICT availability, ICT use and attitudes toward ICT across regions: Evidence from 35 countries. *Education and Information Technologies*, *26*(5), 6299–6318. https://doi.org/10.1007/s10639-021-10576-2

Balakrishnan, V., & Lay, G. C. (2016). Students' learning styles and their effects on the use of social media technology for learning. *Telematics and Informatics*, *33*(3), 808–821. https://doi.org/10.1016/j.tele.2015.12.004

Beland, L. P., & Murphy, R. (2016). Ill communication: Technology, distraction & student performance. *Labour Economics*, *41*, 61–76. https://doi.org/10.1016/j.labeco.2016.04.004

Chang, C. J., Chang, M. H., Chiu, B. C., Liu, C. C., Chiang, S. H. F., Wen, C. T., et al. (2017). An analysis of student collaborative problem solving activities mediated by collaborative simulations. *Computers & Education*, *114*(11), 222–235. https://doi.org/10.1016/j.compedu.2017.07.008

Chen, X., & Hu, J. (2020). ICT-related behavioral factors mediate the relationship between adolescents' ICT interest and their ICT self-efficacy: Evidence from 30 countries. *Computers & Education*, *159*, Article No. 104004. https://doi.org/10.1016/j.compedu.2020.104004

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Eribaum.

Comi, S. L., Argentin, G., Gui, M., Origo, F., & Pagani, L. (2017). Is it the way they use it? Teachers, ICT and student achievement. *Economics of Education Review*, *56*, 24–39. https://doi.org/10.1016/j.econedurev.2016.11.007

Cooke, S. (2017). Social teaching: Student perspectives on the inclusion of social media in higher education. *Education and Information Technologies*, *22*(1), 255–269. https://doi.org/10.1007/s10639-015-9444-y

DeWitt, D., Alias, N., & Siraj, S. (2015). *Transforming learning: Collaborative mLearning for a problem-centered approach*. Kuala Lumpur, Malaysia: University of Malaya Press.

DeWitt, D., Alias, N., Siraj, S., & Spector, J. M. (2017). Wikis for a collaborative problem-solving (CPS) module for secondary school science. *Educational Technology & Society, 20*(1), 144–155. Retrieved from https://www.proquest.com/docview/1874035105?accountid=15198&pq-origsite=360link

Dindar, M. (2018). An empirical study on gender, video game play, academic success and complex problem solving skills. *Computers & Education*, *125*(10), 39–52. https://doi.org/10.1016/j.compedu.2018.05.018

Eickelmann, B., Gerick, J., & Koop, C. (2017). ICT use in mathematics lessons and the mathematics achievement of secondary school students by international comparison: Which role do school level factors play? *Education & Information Technologies*, *22*(4), 1–25. https://doi.org/10.1007/s10639-016-9498-5

Enders, C. K. (2010). *Applied missing data analysis*. New York, NY, US: Guilford Press.

Erdogdu, F. (2022). ICT, learning environment and student characteristics as potential cross-country predictors of academic achievement. *Education and Information Technologies*, *27*(5), 7135–7159. https://doi.org/10.1007/s10639-021-10848-x

Ertmer, P. A., Newby, T. J., Liu, W., Tomory, A., Yu, J. H., & Lee, Y. M. (2011). Students' confidence and perceived value for participating in cross-cultural wiki-based collaborations. *Educational Technology Research and Development*, *59*, 213–228. https://doi.org/10.1007/s11423-011-9187-4

Feng, S. H., Wong, Y. K., Wong, L. Y., & Hossain, L. (2019). The internet and Facebook usage on academic distraction of college students. *Computers & Education*, *134*, 41–49. https://doi.org/10.1016/j.compedu.2019.02.005

Field, A. (2009). *Discovering statistics using SPSS* (3rd ed.). Thousand Oaks, CA, US: Sage publications.

Gikas, J., & Grant, M. M. (2013). Mobile computing devices in higher education: Student perspectives on learning with cellphones, smartphones & social media. *Internet and Higher Education Mobile*, *19*, 18–26. https://doi.org/10.1016/j.iheduc.2013.06.002

Goldhammer, F., Gniewosz, G., & Zylka, J. (2016). ICT engagement in learning environments. In S. Kuger, E. Klieme, N. Jude, & D. Kaplan (Eds.), *Assessing contexts of learning: An international perspective* (pp. 331–351). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-45357-6_13

Greiff, S., & Neubert, J. C. (2014). On the relation of complex problem solving, personality, fluid intelligence, and academic achievement. *Learning & Individual Differences*, *36*, 37–48. https://doi.org/10.1016/j.lindif.2014.08.003

Hammond, M. (2020). What is an ecological approach and how can it assist in understanding ICT take-up? *British Journal of Educational Technology*, *51*(3), 853–866. https://doi.org/10.1111/bjet.12889

Herborn, K., Stadler, M., Mustafić, M., & Greiff, S. (2020). The assessment of collaborative problem solving in PISA 2015: Can computer agents replace humans? *Computers in Human Behavior*, *104*, Article No.105624. https://doi.org/10.1016/j.chb.2018.07.035

Hew, K. F., & Brush, T. (2007). Integrating technology into K-12 teaching and learning: Current knowledge gaps and recommendations for future research. *Educational Technology Research & Development*, *55*(3), 223–252. https://doi.org/10.1007/s11423-006-9022-5

Hox, J. J. (2010). *Multilevel analysis: Techniques and applications* (2nd ed.). New York, NY, US: Routledge.

Hu, J., & Yu, R. (2021). The effects of ICT-based social media on adolescents' digital reading performance: A longitudinal study of PISA 2009, PISA 2012, PISA 2015 and PISA 2018. *Computers & Education, 175*, Article No. 104342. https://doi.org/10.1016/j.compedu.2021.104342

Junco, R. (2012). The relationship between frequency of Facebook use, participation in Facebook activities, and student engagement. *Computers & Education*, *58*(1), 162–171. https://doi.org/10.1016/j.compedu.2011.08.004

Kaplan, A. M., & Haenlein, M. (2010). Users of the world, unite! the challenges and opportunities of social media. *Business Horizons*, *53*(1), 59–68. https://doi.org/10.1016/j.bushor.2009.09.003

Lambic, D. (2016). Correlation between Facebook use for educational purposes and academic performance of students. *Computers in Human Behavior*, *61*, 313–320. https://doi.org/10.1016/j.chb.2016.03.052

Li, K., Huang, L., & Song, Z. (2020). Understanding the emergence of collaborative problem-solving practices in enterprise social media: The roles of social factors. *Ieee Access : Practical Innovations, Open Solutions*, *8*, 210066–210080. https://doi.org/10.1109/ACCESS.2020.3039239

Lin, C. H., Zhang, Y., & Zheng, B. (2017). The roles of learning strategies and motivation in online language learning: A structural equation modeling analysis. *Computers & Education*, *113*, 75–85. https://doi.org/10.1016/j.compedu.2017.05.014

Manca, S., & Ranieri, M. (2016). Is Facebook still a suitable technology-enhanced learning environment? An updated critical review of the literature from 2012 to 2015. *Journal of Computer Assisted Learning*, *32*(6), 503–528. https://doi.org/10.1111/jcal.12154

Meggiolaro, S. (2018). Information and communication technologies use, gender and mathematics achievement: Evidence from Italy. *Social Psychology of Education*, *21*(2), 497–516. https://doi.org/10.1007/s11218-017-9425-7

Mora, T., Escardíbul, J. O., & Di Pietro, G. (2018). Computers and students' achievement: An analysis of the one laptop per child program in Catalonia. *International Journal of Educational Research*, *92*, 145–157. https://doi.org/10.1016/j.ijer.2018.09.013

OECD. (2017). *PISA 2015 results (volume V)*. Paris: OECD Publishing. https://doi.org/10.1787/19963777

Petko, D., Cantieni, A., & Prasse, D. (2017). Perceived quality of educational technology matters: A secondary analysis of students' ICT use, ICT-related attitudes, and PISA 2012 scores. *Journal of Educational Computing Research*, *54*(8), 1070–1091. https://doi.org/10.1177/0735633116649373

Ratitch, B. (2014). *Multiple imputation*. John Wiley & Sons, Ltd.

Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical linear models*. Sage.

Raudenbush, S. W., Bryk, A. S., Cheong, Y. F., & Congdon, R. (2019). *HLM 8 for Windows [Computer software]*. Skokie, IL: Scientific Software International, Inc.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available online at https://www.R-project.org/

Reinhardt, J. (2019). Social media in second and foreign language teaching and learning: Blogs, wikis, and social networking. *Language Teaching*, *52*(1), 1–39. https://doi.org/10.1017/s0261444818000356

Rojas, M., Nussbaum, M., Chiuminatto, P., Guerrero, O., Greiff, S., Kriegerc, F., & Westhuizenc, L. V. D. (2021). Assessing collaborative problem-solving skills among elementary school students. *Computers & Education*. https://doi.org/10.1016/j.compedu.2021.104313., 175, Article No. 104313.

Rutherford, C. (2010). Using online social media to support preservice student engagement. *MERLOT Journal of Online Learning and Teaching, 6*(4), 703–711. Retrieved from http://jolt.merlot.org/vol6no4/rutherford_1210.pdf

Sarwar, B., Zulfiqar, S., Aziz, S., & Ejaz Chandia, K. (2019). Usage of social media tools for collaborative learning: The effect on learning success with the moderating role of cyberbullying. *Journal of Educational Computing Research*, *57*(1), 246–279. https://doi.org/10.1177/0735633117748415

Schafer, J. L., & Olsen, M. K. (1998). Multiple imputation for multivariate missing-data problems: A data analyst's perspective. *Multivariate Behavioral Research*, *33*(4), 545–571. https://doi.org/10.1207/s15327906mbr3304_5

Shute, V. J., Ventura, M., & Ke, F. F. (2015). The power of play: The effects of Portal 2 and lumosity on cognitive and noncognitive skills. *Computers & Education*, *80*, 58–67. https://doi.org/10.1016/j.compedu.2014.08.013

Skryabin, M., Zhang, J., Liu, L., & Zhang, D. (2015). How the ICT development level and usage influence student achievement in reading, mathematics, and science. *Computers & Education*, *85*, 49–58. https://doi.org/10.1016/j.compedu.2015.02.004

Smith, E. E. (2016). A real double-edged sword": Undergraduate perceptions of social media in their learning. *Computers & Education*, *103*, 44–58. https://doi.org/10.1016/j.compedu.2016.09.009

Srijamdee, K., & Pholphirul, P. (2020). Does ICT familiarity always help promote educational outcomes? Empirical evidence from PISA-Thailand. *Education and Information Technologies*, *25*(6), 1–38. https://doi.org/10.1007/s10639-019-10089-z

Stadler, M., Herborn, K., Mustafi, M., & Greiff, S. (2019). Computer-based collaborative problem solving in PISA 2015 and the role of personality. *Journal of intelligence*, *7*(3), https://doi.org/10.3390/jintelligence7030015. Article No.15.

Stadler, M., Herborn, K., Mustafi, M., & Greiff, S. (2020). The assessment of collaborative problem solving in PISA 2015: An investigation of the validity of the PISA 2015 CPS tasks. *Computers & Education*, *157*(2), 103964. https://doi.org/10.1016/j.compedu.2020.103964

Unal, E., & Cakir, H. (2021). The effect of technology-supported collaborative problem solving method on students' achievement and engagement. *Education and Information Technologies*, *26*(4), 4127–4150. https://doi.org/10.1007/s10639-021-10463-w

Vaughan, N. D. (2010). A blended community of inquiry approach: Linking student engagement and course redesign. *The Internet and Higher Education*, *13*, 60–65. https://doi.org/10.1016/j.iheduc.2009.10.007

Vosoughi, S., Roy, D., & Aral, S. (2018). The spread of true and false news online. *Science*, *359*(6380), 1146–1151. https://doi.org/10.1126/science.aap9559

Wang, M., & Hu, J. (2022). Perceived teacher autonomy support for adolescents' reading achievement: The mediation roles of control-value appraisals and emotions. *Frontiers in Psychology*, *13*, 959461. https://doi.org/10.3389/fpsyg.2022.959461

Wu, J. Y., & Nian, M. W. (2021). The dynamics of an online learning community in a hybrid statistics classroom over time: Implications for the question-oriented problem-solving course design with the social network analysis approach. *Computers & Education, 166*, Article No. 104120. https://doi.org/10.1016/j.compedu.2020.104120

Wu, S. Y. (2019). Incorporation of collaborative problem solving and cognitive tools to improve higher cognitive processing in online discussion environments. *Journal of Educational Computing Research*, *58*(1), 249–272. https://doi.org/10.1177/0735633119828044

Yu, R., Wang, M., & Hu, J. (2023). The relationship between ICT perceived competence and adolescents' digital reading performance: A multilevel mediation study. *Journal of Educational Computing Research*. Advance online publication. https://doi.org/10.1177/07356331221137107

Zhang, D., & Liu, L. (2016). How does ICT use influence students' achievements in math and science over time? Evidence from PISA 2000 to 2012. *Eurasia Journal of Mathematics Science and Technology Education*, *12*(9), 2431–2449. https://doi.org/10.12973/eurasia.2016.1297a

Zheng, Y., Bao, H., Shen, J., & Zhai, X. (2020). Investigating sequence patterns of collaborative problem-solving behavior in online collaborative discussion activity. *Sustainability*, *12*(20), 8522. https://doi.org/10.3390/su1220852