



THE EFFECT OF DIGITAL TECHNOLOGY INTEGRATION ON STUDENTS' CREATIVE THINKING SKILLS: PISA EVIDENCE USING PROPENSITY SCORE MATCHING

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Abstract

Identifying elements that enhance student creativity is essential for effective educational design. The rapid adoption of digital educational technologies (DETs) has become a key factor in this process. This study aims to present causal evidence on the impact of teachers' use of digital technology in education on the creative thinking of 15-year-old students in two countries, characterized by contrasting levels of digital technology integration in upper-secondary school. Propensity score analysis was applied to nationally representative PISA 2022 datasets of Singapore (n=6,606 students in 164 schools) and Morocco (n=6,867 students in 178 schools) to obtain causal estimates conditional on specified confounding factors. This causal inference method, which is infrequently employed in educational research, assesses interventions via observational data, considering temporal precedence, yielding less biased estimates by mitigating disparities between treatment and control groups. The findings showed that DET use at schools did not significantly influence students' creative thinking in Singapore, and surprisingly, it significantly decreased Moroccan students' creative thinking. Sensitivity analysis corroborated the robustness of the treatment effect estimates. The generalizability of the results is limited to the genuine educational contexts of the countries. The findings suggest that educational policymakers should be cautious about over-investment and over-reliance on digital technologies without carefully optimizing educational and curricular design for technology-enhanced creativity.

Keywords: digital technology; creative thinking; propensity score matching; comparative analysis

Introduction

Creative thinking skills, as a pronounced 21st century skill, has become a topic of increasing interest among educators and researchers, due to their considerable potential to augment problem-solving capabilities and foster innovation among young learners. Education systems placing this skill at the center and preparing students for the needs of the future constitute one of the cornerstones of both individual and societal progress. Yet students' creative thinking skills are globally low (i.e., students in Organization for Economic Cooperation and Development [OECD] countries scored an average of 33 out of 60 in PISA 2022) (OECD, 2023), and 15-year-old students show lower levels of creativity compared to their 10-year-old peers (OECD, 2021). Despite a misbelief among some educators that creativity is an innate trait (Aljughaiman & Mowrer-Reynolds, 2005), the extant literature has indicated that creative thinking is amenable to instruction across all levels of education and various disciplines (e.g., Beghetto & Kaufman, 2014; McDonald et al., 2020; Pikhart et al., 2024), with the most pronounced advancements occurring at the senior high school level (Yang et al., 2024). For these reasons, it is crucial to identify the factors that influence the creative thinking of 15-year-

old students at this critical age, and the use of digital technology in the classroom has been considered as one of these factors.

Digital educational technologies (DETs) have transitioned from serving as an external tool to teaching and learning process to an unprecedented worldwide adoption and popularity that influence curriculum development, teaching strategies and evaluation techniques (Wang et al., 2024). Yet, recent empirical evidence regarding the effectiveness of digital technologies on creative thinking skills has yielded mixed results. While certain studies underscored the favorable relationship between digital technology use and creative thinking (e.g., Pikhart et al., 2024; Tang et al., 2022), others raised concerns regarding nonsignificant effects (Harianto et al., 2024) or potential disadvantages, such as diminished attention spans and an overreliance on superficial information processing (Rubin, 2012), disruptions on memory (Baron, 2021), and addiction to technology and distraction from learning (Selwyn & Aagaard, 2020). A research study concerning vocational education students revealed that intrinsic motivation, innovative pedagogical approaches, and support from industry stakeholders substantially contribute to the enhancement of creative thinking abilities, accounting for 68.7% of the variability in creative thinking skills; yet, the learning environment did not manifest a statistically significant influence on creative thinking skills (Harianto et al., 2024). A review identified that the most favorable outcomes in fostering creative thinking occurred in science discipline, while the incorporation of technology did not exhibit a significant effect on the efficacy of teaching creative thinking (Yang et al., 2024). This duality in findings suggests that the mere incorporation of technological innovations into educational settings without proper implementation—such as lack of infrastructure, psychological resistance among teachers and students to digital technology (Moorhouse, 2021), or poor digital literacy skills—may prove insufficient in improving students' creative thinking; thus, more emphasis must be placed on the current effectiveness of digital technologies in their natural settings, namely classrooms.

Furthermore, a recent meta-analysis found a high degree of heterogeneity between the studies regarding the effects of various educational technologies on creative thinking (Zaremozhzabieh et al., 2024). In the cited meta-analysis, studies that were conducted on high school students had relatively small sample sizes ($n = 27$ to 118), and in terms of methodological quality, most of these studies were reported to be moderate level of quality based on criteria such as allocation concealment, blinding of main outcome evaluation and attrition information. More importantly, none of those studies used a randomized controlled trial design that could provide strong causal evidence for the generalizability of the results. Propensity score matching (PSM) can be utilized in contexts where randomized experiments are prohibitively expensive or impractical. This methodology, which has been infrequently used in educational research literature, facilitates the estimation of more broadly applicable treatment effects through the creation of balanced samples derived from large observational datasets (Guo & Fraser, 2015). In PSM analyses, the phenomenon of digital technology use in the classroom can be conceptualized as a variable analogous to a treatment condition in a randomized controlled trial (i.e., classrooms that use digital technologies in the classrooms and those that do not), facilitating the delineation of treatment and control groups predicated on exposure to said variable. Given that practitioners disclose their prior experiences of digital technology use during the collection of creative thinking data in PISA, the use of digital technologies in instruction functions as a theoretical intervention that fulfills the requisite criteria of temporal precedence, which is an essential criterion for the identification of causal relationships. Furthermore, in addition to the relationship between the treatment and resultant outcome, in order to eliminate alternative explanations regarding the specified association, the treatment and control groups are meticulously balanced on a comprehensive array of covariates via PSM, and the influence of potential omitted confounders on the specified relationship is scrutinized through sensitivity analysis. Using this methodological approach on nationally representative PISA datasets enables the estimation of nationally generalizable causal relationships within the PSM framework.

Digital Technology and Its Use in Classrooms

Digital technologies are mainly composed of Information and Communication Technologies (ICT), technologies for assessment and feedback, and mobile technologies (Pinto & Leite, 2020). DETs encompass learning materials that employ technology in curriculum-based learning areas, including, by way of illustration, online games, multimedia, cloud computing, 3D printing, and mobile computing (Kumi-Yeboah et al., 2020).

Technology in education has been shown to facilitate lifelong learning by providing students with an individualized virtual world and the freedom to easily access digital information (Haleem et al., 2022). The integration of digital technologies into educational settings increases student engagement, eases the workload of teachers, facilitates understanding of difficult subjects, and accelerates communication and information transmission (Sarkar, 2023). Learners are able to utilize DETs to augment the knowledge imparted by educators within the classroom environment and to acquire supplementary information while navigating the Internet (Prodani et al., 2022). The use of some DETs, such as augmented reality, in learning optimized cognitive load for novice learners (Poupard et al., 2023). Furthermore, digital technologies have been shown to enhance social communication, in addition to enabling the dissemination and storage of information, thereby fostering the development of students both as individuals and as a collective (Kaldırım & Tavşanlı, 2021).

In contrast to the rapid advances witnessed in the field of digital technology, the existing conditions that facilitate the integration of technological resources in educational institutions have remained relatively static (Ng, 2015) until it became an integral part of schooling during the COVID pandemic (Wang et al., 2024). To leverage digital education technologies effectively, both teachers and students require specific competencies. Nonetheless, both cohorts encounter considerable challenges in the effective utilization of these technologies within educational settings (Lamanauskas, 2010; Moorhouse, 2021). The facilitation of efficacious technological utilization by teachers necessitates that they embody a requisite level of digital literacy (Wang et al., 2024) as they play a pivotal role in integrating these technological resources into the classroom (Alberola-Mulet et al., 2021). Several factors that influence teachers' integration of DET into their teaching include their beliefs and attitudes (Johnson, 2016; Kılınç et al., 2016), their self-confidence contingent upon receiving support from training and administrators, and their constant monitoring of student progress to assess effective DET intervention.

It is imperative to acknowledge that the presence of computers equipped with adequate software in the classroom, coupled with substantial professional development for instructors, does not ensure an immediate and consistent enhancement in student grades and engagement (McKnight et al., 2016). This is attributable to the common observation that, while teachers generally acknowledge the merits of educational technologies, they frequently encounter challenges in the seamless integration of novel educational technologies. These challenges encompass a wide range of aspects, from the procurement of new technological equipment to the adaptation of curricula and pedagogical approaches to incorporate these novel educational tools (Johnson, 2016). Consequently, despite their facilitation of learning, digital technology integration has posed significant challenges for educators at all levels of the educational system.

Creative Thinking

In the dynamic environment of the 21st century, individuals need not only to consume existing knowledge but also to generate innovative ideas, adapt to changes, and shape the future. Creative thinking is a competency that enables individuals to develop unconventional solutions and has been recognized as one of the most critical skills of the 21st century (OECD, 2019). Creative thinking can be defined as “the capacity to generate many different kinds of ideas,

manipulate ideas in unusual ways and make unconventional connections in order to outline novel possibilities that have the potential to elegantly meet a given purpose" (Ramalingam et al., 2020, p. 2). OECD (2019) defined creative thinking as "the competence to generate, evaluate, and improve original and diverse ideas," and this definition encompasses not only idea generation but also critical analysis and improvement processes. Creative thinking consists of the combination of multiple cognitive skills, including divergent thinking (OECD, 2019). Torrance (2018) and Guilford (1960) approached this skill in four fundamental dimensions: fluency (generating a large number of relevant ideas), flexibility (thinking across different categories or themes), originality (developing uncommon and new ideas), and elaboration (enriching ideas with substantial details).

Creative thinking, as a crucial component of student development in education, plays a critical role in shaping individuals' cognitive and social skills. It is critically important not only in artistic fields but also in areas such as science, technology, mathematics, and engineering (STEM), helping students develop innovative solutions to complex problems (Beghetto & Kaufman, 2014; OECD, 2022) and it contributes to the development of other 21st-century skills such as critical thinking, problem-solving, and collaboration (Lucas & Spencer, 2017). Therefore, it is of great importance for teachers to support students' creativity by creating effective learning environments (Danesh & Nourdad, 2017; Kim, 2020), especially via student-centered instructional designs (Aytaç & Kula, 2020) to enhance students' future competencies including their academic achievements, self-efficacy, and readiness for the knowledge economy (Lin, 2023).

Creative thinking in education is influenced by various positive and negative factors. Research has indicated that factors such as the flexibility of the learning environment (Davies et al., 2013), teacher support (Kozmus & Kaučič, 2022), access to technological tools (Zaremohzzabieh et al., 2024), and opportunities for autonomous learning (Orakcı, 2025) positively enhanced creative thinking. On the other hand, test-oriented education systems, short class durations, teachers' inadequate training in creative pedagogies, and assessment methods that prioritize individual student performance were among the factors that negatively affected creative thinking (Lucas, 2022).

Overall, developing this skill in education strengthens students' academic achievements and long-term learning motivation while preparing them for their future professional and social lives (Lucas & Spencer, 2017). However, flexible learning environments and encouraging creativity-inducing teaching methods are essential for this potential to emerge.

Research on the Effect of Digital Technology on Creative Thinking

Digital technologies play a significant role in enhancing students' creative thinking skills by supporting creative problem-solving processes (Göçen et al., 2023; Tang et al., 2022). Multimedia-based instructional methods, particularly in art, design, and digital media, fostered creativity by increasing self-expression and motivation (Al Hashimi et al., 2019), while problem-based learning approaches supported by digital tools enabled students to develop original solution strategies (Wang & Li, 2024). A cross-sectional study found a positive association between digital educational games and student motivation (Li et al., 2024), which is associated with elementary school students' creativity within the framework of self-determination theory (Zhang et al., 2011). Students' creative thinking skills can also be fostered through interactive, tablet-based classroom environments that provide a dynamic learning process (Kim et al., 2016; Tang et al., 2022). In summary, teachers' successful implementation of DET into their teaching practices (Bereczki & Kárpáti, 2021) and effective integration of digital technologies into the curriculum (Yalcinalp & Avci, 2019) were reported to positively influence students' creative thinking skills.

The negative effects of digital technologies on creative thinking are also a notable topic in the literature. Based on increasing evidence in the cognitive neuroscience literature, while the use of digital technologies facilitates the acquisition of specific cognitive skills, certain higher-order cognitive skills, characterized by deep analytical thinking, experience a decline due to changes in neural circuitry in the brain (Cavanaugh et al., 2016). Moreover, Vilarinho-Pereira and Fleith (2021) argued that when technology is misaligned with instructional objectives and used in an unstructured manner, it can lead to distractions in the classroom that hinder students' creative processes. Similarly, Elphick (2018) suggested that the mere presence of digital tools is insufficient, and inappropriate or their excessive use can disrupt students' focus, limiting the development of creative skills. The structural and pedagogical challenges associated with effective DET integration include poorly designed digital integration, which fails to deliver the expected creative benefits, resulting in underdeveloped creative capacities in students (Henriksen et al., 2021; Rubin, 2012).

The influence of digital technology on creative thinking in the classroom is significantly shaped by various contextual factors, particularly the pedagogical strategies employed and the proficiency of teachers in integrating these tools. Interactive and dialogic teaching methods, which, when supported by digital tools, can effectively nurture creativity (Pifarré, 2019; Tusiime et al., 2019). However, these benefits are contingent upon comprehensive teacher training and the alignment of digital technologies with clear pedagogical objectives. The literature underscores that the successful integration of digital technology requires both a strong technological infrastructure and well-trained educators who can effectively utilize these tools (Gangmei & Thomas, 2025). Furthermore, socio-economic factors play a crucial role as disparities in access to digital resources (Micheli, 2015) can limit the creative development opportunities of certain student groups (Kim & Li, 2021). In conclusion, the challenge lies not only in properly incorporating technology into the curriculum to improve students' creative thinking skills but also in ensuring equitable access and contextually appropriate use of these tools, enabling all students to fully benefit from technology-enhanced learning.

Relevant Covariates

To mimic randomized controlled trials, sociodemographic covariates that may have a potential effect on selection into treatment and control groups or those that may impact the outcome variable should be balanced in PSM analyses in order to address the endogeneity problem (Guo & Frazer, 2015). Endogeneity emerges when the treatment variable exhibits an association with confounding factors that simultaneously influence the outcome, resulting in distorted estimates of causal impacts. PSM assists in alleviating endogeneity by minimizing selection bias in observational research.

The treatment variable, digital technology use in schools, was found to be influenced by access to digital technology resources in classrooms and schools (Alotaibi, 2023), school type (Gómez-Fernández & Mediavilla, 2020), and geographical region (Habibi et al., 2023). Furthermore, creative thinking was found to be influenced by student growth mindset (Anderson, 2024), teaching method (Zhong et al., 2024), and school type (Zaremohzzabieh et al., 2024). In a comprehensive meta-analysis, the influence of socioeconomic status (SES) on the creative thinking abilities of students was statistically significant; however, this influence appeared to diminish as students advanced from elementary education to college (Acar et al., 2022). Nevertheless, SES as a 'family cultural capital' influences students' digital technology use and creative thinking skills (Ren et al., 2022), which also influences K-12 teachers' use of digital technology as a 'second-level digital divide' in promoting students' higher-order thinking (Reinhart et al., 2011). While prior research indicated differing creative thinking patterns between genders (Dudek et al., 1993), more recent findings suggested otherwise (e.g.,

Wu et al., 2017). Therefore, controlling for the impact of gender alongside previously mentioned variables is essential to mitigate potential selection bias.

Research Aim

Majority of cited studies employed digital technologies as a medium as a part of a more complex instructional design and they were compared to the conventional instructional designs which did not isolate the effect of DETs from widely established effective constructivist teaching and learning practices such as collaborative or inquiry-based learning practices, enhanced communication, using representations, and making connections among concepts and subjects. In this study, we solely focused on the effect of this medium on student creative thinking regardless of the enacted curriculum. As a leading authority in educational assessment, the Institute of Education Sciences (IES) advocates for research methodologies that produce robust causal evidence, including randomized controlled trials and balanced quasi-experimental designs (IES, 2017). Previous research has yielded mixed results regarding the impact of DETs on individual creativity. Therefore, it is crucial to guide future research with causal evidence regarding these mixed results. Furthermore, despite large investments in equipping schools with digital technologies, there is a lack of generalizable evidence regarding the effectiveness of using DETs in their authentic school settings. Thus, this research seeks to provide evidence to inform future research and further policy decisions.

Based on the theoretical and empirical discussion above, the purpose of this study was to fulfill the aforementioned research gaps by providing evidence on the effect of digital technology interventions in 15-year-old students' creative thinking skills in schools' natural settings by analyzing nationally representative PISA 2022 dataset using the PSM method. This study sought to find the extent to which digital technology use in schools improves 15-year-old students' creative thinking skills in Singapore and Morocco. According to PISA 2022 data, Singapore had a higher frequency of technology use in schools, while Morocco had one of the lowest frequencies of technology use in schools. By cross-comparison of high-tech and low-tech countries, it was intended to derive less biased inference when evaluating whether DET improves students' creative thinking skills regardless of the prevalence of digital technology use in the educational context. Based on the previous research indicating conflicting evidence regarding the effect of digital technologies on creative thinking, it is hypothesized that the effect is not significant; however, the treatment effect is hypothesized to be slightly higher for Singapore due to higher prevalence of the implementation of DET at schools that might have improved digital literacy of students and teachers. The findings are intended to inform researchers, policymakers, and school practitioners pertaining to the effectiveness of digital technologies in improving students' creative thinking skills within schools.

Research Methodology

Research Design

This study utilized PISA 2022 data, specifically, the datasets of Singapore and Morocco. The design and data analysis for current study were carried out between December 2024 and February 2025. Creative thinking was the outcome variable, and DET use in upper secondary school was the treatment variable. Several covariates were used to balance the sample characteristics on the treatment variable. PSM analyses were employed to create comparable groups, allowing for a less biased assessment (i.e., by balancing treatment and control groups on specified covariates) of the effect of teachers' educational technology use on students' creative thinking.

Sample

The international PISA 2022 assessment, conducted in 81 participating countries, focused on the performance of 15-year-old students in the core domains of mathematics, science, and reading, as well as in the domain of creative thinking. This assessment used a two-stage stratified sampling design, which includes probabilistic sampling to represent the corresponding population (OECD, 2024a). Two countries were included in the analyses: Singapore ($n = 6,606$ students in 164 schools) and Morocco ($n = 6,867$ students in 178 schools). The selection of these countries was predicated on their disparate levels of DET utilization in educational institutions, which are characterized by high and low prevalence, respectively. In Singapore, 15-year-old students are generally in their first year of upper secondary education (i.e., Secondary 3). In Morocco, they are either in the Tronc Commun (bridge year) or the initial year of the Baccalauréat, both corresponding to upper secondary. Because the objective of this study was to ascertain the effect of the implementation of DET in schools on creative thinking skills, the comparison of the treatment effects across these countries serves to eliminate the potential interpretative bias that may arise from the varying levels of digital technology adoption within educational systems. Furthermore, the utilization of these large datasets of the countries facilitates the accurate evaluation of causal effects in implementing greedy matching techniques, provided that the PSM assumptions are met (Guo & Frazer, 2015). 15-year-old students' and school administrators' responses to student and school questionnaires were used in this study.

Instruments

Treatment Variable: The Use of Digital Educational Technology at School

PSM analysis is a commonly used method for the evaluation of an intervention. In the PISA 2022 assessment framework, 'digital resources' refer to digital devices or hardware (e.g., tablets, computers, smartphones), software (e.g., Apps, educational learning tools), and online platforms (e.g., websites, web portals). This variable was used to estimate the treatment effect on the treated (ATT), namely, the average difference in creative thinking between those who were treated with DET at school and their matched non-users had these non-users been exposed to the treatment. The testing period for the PISA 2022 assessment, excluding a limited number of nations, took place during March and April in the academic calendar (OECD, 2023). Consequently, the experience of the treatment groups with DETs encompassed at least half of the academic year. Given that extant literature has affirmed that creative thinking can be proficiently fostered through instructional techniques at every educational level and throughout various academic disciplines (e.g., Beghetto & Kaufman, 2014; McDonald et al., 2020; Pikhart et al., 2024), this period of intervention should yield valid inferences. The researchers believe that this treatment effect has important implications for policymakers considering overinvestment in DETs.

A binary variable for this hypothetical intervention (i.e., whether or not DETs are implemented at schools) was created using the answers to the item "Educational software, games or Apps, other learning tools" to the stem question of "This school year, how often did you use the following <digital resources> at school?". The 4-point Likert-type response scale options included 1 (*Never or almost never*), 2 (*About once or twice a month*), 3 (*About once or twice a week*), 4 (*Every day or almost every day*), and 5 (*Several times a day*). Table 2 lists the distribution of DET use in the countries using the original data. The binary variable was coded 0 if 'Never or almost never' option was selected and 1 for other responses.

Outcome Variable

The outcome variable is creative thinking. The PISA 2022 creative thinking assessment framework was developed to evaluate students' proficiency in generating, evaluating, and refining ideas across four specific domains of application: written expression, visual expression, social problem-solving, and scientific problem-solving (OECD, 2024a). Rather than providing a single point estimate representing the extent of creative thinking skills, the PISA 2022 employed a nuanced approach by offering multiple proficiency values. Specifically, for countries that have implemented the creative thinking tests, the assessment provides ten imputed plausible values. This methodological decision is noteworthy as it enables a more precise estimation of measurement error, because students respond to a subset of items instead of the entire scale. Pooled estimates obtained from imputed item scores served as a more accurate representation of their actual skills (See PISA 2022 Technical Report [OECD, 2024a] for more information). The scores of the creative thinking scale ranged from 0 to 60 points—a score of 60 indicates a perfect score across 32 test items— and imputed scores reflected estimated performance on a hypothetical comprehensive test of all 32 items (OECD, 2024b).

Covariates

To correctly model the selection into treatment, a rich set of covariates (student, family and school background measures) that may influence digital technology use at schools or creative thinking were selected. Because the inclusion of covariates in the matching process is directly linked to the internal validity of PSM, covariates that are evidenced to be linked to the treatment and outcome variables were selected (See Table 1). The variable 'school type' was answered by school administrators, and other items were answered by students.

In the context of PSM analyses, binary variables were formulated for these dichotomous constructs. For k-levels of a multicategorical variable (i.e., the number of books present in the household), k-1 dummy-coded variables were generated to mitigate the dimensionality problem and to facilitate a more equitable balance between treatment and control cohorts (Guo & Frazer, 2015).

Table 1
Descriptive Information for Covariates

Covariate	PISA Item	Response range	Missing (%)
Female*	Gender	0=Male 1=Female	S: 0.00 M: 0.00
Growth mindset	Growth mindset	S: Min = -3.599 Max = 2.029 M: Min = -3.602 Max = 3.372	S: 0.06 M: 19.71
Other language*	What language do you speak at home most of the time?	0=Language of the test 1=Other language	S: 0.02 M: 0.61
Mother education ^r	What is the <highest level of schooling> completed by your mother?	1=No education 2=Primary education 3=Lower secondary 4=Upper secondary with direct access to tertiary education 5=Upper secondary with no direct access to tertiary education	S: 0.68 M: 3.08
Father education ^r	What is the highest level of schooling completed by your father?	1 = There are no books 2 = 1-25 books 3 = 26-100 books 4 = More than 100 books	S: 0.88 M: 4.06
Books at home*	How many books are there in your home?	0=No 1=Yes	S: 0.03 M: 0.53
Digital education tech at home*	Which of the following are in your home? Educational software of Apps	0=No 1=Yes	S: 0.27 M: 3.18
Computer at home*	Which of the following are in your home? A computer (laptop, desktop, or tablet) that you can use for schoolwork	0=No 1=Yes	S: 0.08 M: 1.91
Internet at home*	Which of the following are in your home? Internet access (e.g., Wi-fi) (excluding through smartphones) at home	0=No 1=Yes	S: 0.09 M: 2.14
ICT availability	ICT resources at school	S: Min = -5.624 Max = 0.406 M: Min = -5.624 Max = 0.406	S: 0.00 M: 0.22
School type	School type	1=Private independent 2=Public	S: 0.00 M: 0.00

Notes. * Variables recoded into binary variables or with less dimension; r: Reverse coded;
S: Singapore; M: Morocco

Data Analysis

PSM analysis performs significantly better when implemented on large datasets (Rubin, 1997), which the use of national datasets offers this advantage. Students who did not specify their treatment or control condition were excluded from the further analyses (141 from the Singapore dataset and 765 from the Morocco datasets). Through PSM analyses, each student in the control group of the respective country (1438 students in Singapore and 3675 students in Morocco) was matched with a student whose school implemented DET (4930 students in Singapore and 2356 students in Morocco) using their propensity scores.

Multivariate outliers possess the potential to distort estimates of population parameters (Leys et al., 2018). For the purpose of identifying multivariate outliers, the 'minimum covariance determinant estimator' (Verardi & Dehon, 2010), which represents a more robust

adaptation of the Mahalanobis distance, was employed. Chen et al. (2023) reported that the characteristics of random responders were being male, possessing a limited number of books at home, and infrequently or never engaging in communication in the test language. In order to mitigate threats to the ecological validity of the nationally representative datasets, only extreme multivariate outliers—with unusual Mahalanobis distances—with at least one of the characteristics of random responders, were excluded from the datasets. In the Singapore and Morocco datasets, respectively, 97 and 71 multivariate outliers were removed. After data management, final sample sizes were 6368 for Singapore and 6031 for Morocco.

Additionally, conducting PSM analyses on covariates with missing data risks compromising the validity of treatment effect estimates (D'Agostino & Rubin, 2000). In the Singapore dataset, all covariates had less than one percent of missing cases. In the Morocco dataset, the growth mindset variable had 19.71% missing cases, and other variables had 4.06% or less missing cases. The analysis of missing value patterns revealed that the missing data mechanism was missing at random. Because variables with missing data consisted of continuous, ordinal, and binary variables, the multivariate imputation by chained equations (MICE) method was employed in Stata software. This methodological approach executes a sequence of univariate models that subsequently leverage the posterior predictive distribution of imputed values on a variable-by-variable basis, thereby obviating the necessity for a multivariate normal distribution (Bouhlila & Sellaouti, 2013) and replacing missing values with corresponding variable type. By applying the MICE method, a total of ten imputed datasets were generated for the datasets of both countries. In each dataset, one of the ten 'plausible values in creative thinking' was retained.

Propensity score analysis, a non-experimental causal inference method, was conducted on these imputed datasets. The performed analyses included the modeling of covariates, calculating propensity scores, checking the assumptions of PSM, and estimating the treatment effects on the treated (ATT). First, a pre-specified set of fixed-effect covariates was identified that could explain alternative explanations for the selection into the treatment and variables affecting the outcome. The evaluation of their inclusion was assessed through formal tests and statistics, including the non-parametric Wilcoxon Rank Sum test, standardized differences between groups, and visual inspection of their distributions across treatment conditions. Through this process, a variety of covariates that showed evidence of imbalanced distribution across the treatment or control groups were delineated (see Table 1) to address the issue of selection bias. Several covariates that are available in the PISA dataset (i.e., parents' immigrant background, students' grade repetition, and school location) did not meet any of these diagnostics for inclusion. Propensity scores for treatment and control groups, conditional on the selected covariates, were calculated. Given the ambiguity concerning the *probability* of receiving treatment in non-experimental designs, these propensity scores are utilized to evaluate the likelihood of assignment to the treatment and control groups based on the observed confounding factors (Rubin, 2001). Before engaging in analyses on balanced samples and deriving causal inferences through caliper matching method using *psmatch2* command in Stata—with caliper size of 0.10 and the imposition of common support region, evidence obtained for the two foundational assumptions of PSM: the strong ignorability of treatment assignment condition and the stable unit treatment value assumption (SUTVA) (Guo & Frazer, 2015). These assumptions were evaluated by examining the balance of covariates between the treatment and control groups before and after the matching process, scrutinizing the common support region of the propensity scores across the groups, and conducting sensitivity analyses (Powell et al., 2019; Rosenbaum & Rubin, 1983). The covariate balance was evaluated via the calculations of the percentages of bias on both unmatched and matched samples with the objective of achieving a bias less than 10% for each covariate and a mean bias under 5%, and adequate overlap in the distributions of propensity scores between the treatment and control

groups. Because caliper matching yields less biased treatment effect estimates than optimal and nearest neighbor matching (Austin, 2013), the estimates were calculated using this method. An additional model was performed to examine the robustness of the results. Because the inclusion of schools' ICT resources may possibly dilute the treatment effect, for example, implementation of DETs may lead to more school ICT resources, an alternative model excluding this covariate in the estimation of propensity scores was analyzed. Consequently, sensitivity analyses using the *sensatt* command (preceded by the estimates obtained using the *attk* command) in Stata were conducted after the execution of PSM analyses in each imputed dataset of each country to determine the simulated impact of unaccounted confounders. The simulated parameters for this confounder U is set at $p_{11} = .40$, $p_{10} = .30$, $p_{01} = .30$ and $p_{00} = .20$. The sensitivity analysis helps in estimating the effect of the treatment condition on the outcome in the presence of the simulated effect of U by assigning these moderate-to-high probabilities to U of being included in treatment and conditions (Nannicini, 2007). Propensity score-weighted estimations with bootstrapped standard errors and sensitivity analyses for each imputed dataset were performed with 500 replications, and they were aggregated for each respective country employing Rubin's formula (Li et al., 1991).

Due to the complex sampling design of the PISA survey, student weights were incorporated into the PSM analysis in order to alleviate biases that may arise from variations in selection and/or response rates. This integration yields a generalizable estimation of a treatment effect (Ridgeway et al., 2015). Additionally, prior to conducting propensity score analyses, the intraclass correlation coefficient (ICC) is calculated through an unconditional ANOVA utilizing random effects, as suggested by Raudenbush and Bryk (2002). Given the substantial ICC values for datasets of both countries (.189 for Singapore and .332 for Morocco), the cluster variable (i.e., school ID variable) in conjunction with the student weight variable was employed in the calculation of propensity scores. All analyses were conducted using Stata 14.1 software.

Research Results

Descriptive Results

Prior to constructing a binary treatment variable, the distribution of digital technology implementation at schools using the raw data is given in Table 2. In all levels of digital technology use at schools, Singapore had a higher frequency compared to Morocco. Pooled average creative thinking score was also higher for Singapore ($M = 41.141$; Linearized $SD = 0.123$) compared to Morocco ($\bar{X}M = 15.822$; Linearized $SD = 0.160$).

Table 2
Distribution of Digital Educational Technology Use at School

Responses	Singapore (%)	Morocco (%)
Never or almost never	19.61	52.56
About once or twice a month	20.00	11.95
About once or twice a week	24.44	10.46
Every day or almost every day	17.57	8.46
Several times a day	14.48	7.75
Nonresponse/Missing	3.90	8.83

Propensity Score Matching Estimates

The results of PSM analysis using caliper matching are given in Table 3. Empirical evidence indicated that digital technology implementation at schools in Singapore, where the frequency of the use of DET is quite high, did not significantly increase 15-year-old students' creative thinking ($\tau=0.947$, $SE = 0.531$, ns). Surprisingly, in Morocco, where the frequency of the use of DET implementation at schools is considerably lower, the use of digital technology use significantly decreased students' creative thinking ability ($\tau = -2.687$, $SE = 0.469$, $p < .001$).

Table 3
Pooled Treatment Effects of Digital Technology Use on Creative Thinking

Countries	Caliper Matching		Alternative Model*	
	ATT	SE	ATT	SE
Singapore	0.947	0.531	1.152	0.571
Morocco	-2.687***	0.469	-2.904***	0.463

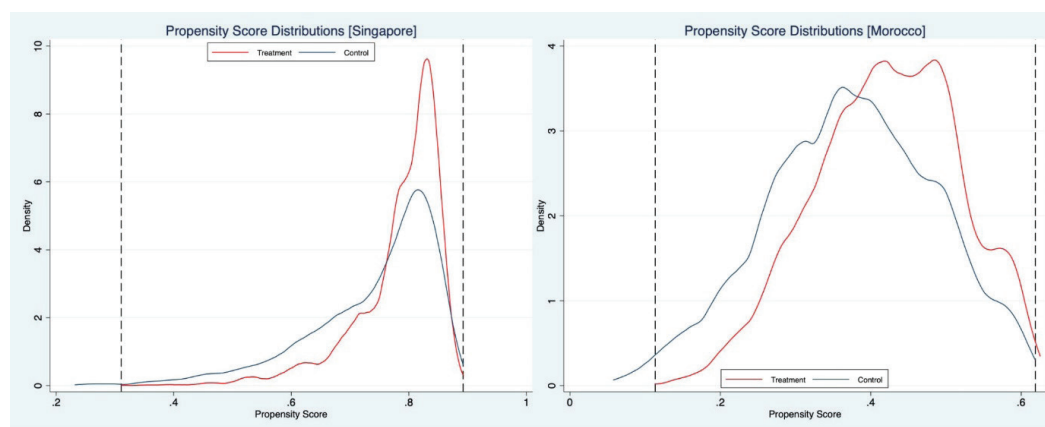
Notes. * Caliper matching estimates without the inclusion of school ICT resources as covariate. Pooled estimates were derived using weighted and clustered propensity scores from 10 imputed datasets.

The results of the alternative model, where the school's ICT resources were excluded from the balanced covariates, the treatment effect increased in Singapore ($\tau=1.152$, $SE = 0.571$, ns) while the effect decreased in Morocco ($\tau=-2.904$, $SE = 0.463$, $p<.001$).

Balance Diagnostics

The validity of ATT estimates is contingent on the satisfaction of the PSM. Figure 1 shows a high degree of overlap between the propensity scores of the treatment and control groups in both countries.

Figure 1
Propensity Score Distributions in Singapore and Morocco



Notes. The graphs were derived using the first imputed datasets of respective countries. The graphs of other imputed datasets were almost identical.

In addition, the quality of the matching process in PSM analysis was gauged by the statistics of observations within the common support region (See Table 4). More than 99% of cases were on common support region for both countries, which ensured the comparability of the treatment and control groups.

Table 4
On Support vs. Off Support Cases in the Matching Process

Country	Treatment assignment	Off support	On support	Total
SGP	Untreated	6	1432	1438
	Treated	0	4930	4930
	Total	6	6362	6368
MOR	Untreated	36	3639	3675
	Treated	2	2354	2356
	Total	38	5993	6031

The results on covariate balance showed that the bias in each covariate is significantly removed as a result of the caliper matching process. After the matching, the standardized mean differences of each covariate for unmatched and matched samples were less than 0.10. After matching the Singapore datasets, the pseudo R^2 values decreased from .038 to .003, and the mean bias decreased from 13.63% to 2.14%. Similarly, for Morocco, the pseudo R^2 values decreased from .039 to .002, and the mean bias dropped from 13.17% to 2.26% as a result of the covariate matching process. In other words, the PSM method removed approximately 84% and 83% of the bias due to covariate imbalance, respectively.

Sensitivity Analysis

The findings indicated that ATT estimates exhibited robustness against unmeasured confounding variables, as demonstrated through sensitivity analysis in Table 5. The sensitivity analysis showed that the estimated ATT exhibited minimal sensitivity to unobserved variables, as evidenced by the relatively small changes in treatment effect estimates, thereby reinforcing the causal interpretation of the results obtained. The estimated selection effect of 1.74 for Singapore (and 1.72 for Morocco) signifies that, in the presence of an unobserved confounder U , the odds of a student attending a school that implemented DET would be augmented by a factor of 1.74 (or 1.72 for Morocco). Likewise, the outcome effect of 1.67 for Singapore (or 1.571 for Morocco) implies that U would amplify the odds of students exhibiting elevated levels of creative thinking by 1.67 times (or 1.57 times for Morocco). The minimal variation in ATT (9.4% in Singapore and 8.7% in Morocco) indicated that, even in the hypothetical presence of such a confounder with a moderate-to-high levels of selection and outcome effects, the estimated treatment effects remain largely unaffected.

Table 5
Sensitivity Analysis Results

	Singapore	Morocco
ΔATT (%)	9.4	8.7
Γ	1.741	1.723
Λ	1.669	1.571

Notes. ΔATT (%) = $100 * (\tau_{\text{baseline}} - \tau_{\text{simulated}}) / (\tau_{\text{baseline}})$;

Γ : Selection effect; Λ : Outcome effect

Discussion

This study partially provided empirical evidence for the research hypothesis. Using nationally representative PISA 2022 datasets, we found that DET use at schools did not significantly influence students' creative thinking skills in Singapore, and the treatment effect was higher compared to that of Morocco. The unexpected result was the negative effect of DET use on students' creative thinking skills in Morocco. While some studies underlined the positive relationship between the use of digital technology in the classroom and creative thinking (Bereczki & Kárpáti, 2021; Göçen et al., 2023; Naharia et al., 2024; Tang et al., 2022; Wang & Li, 2024; Yalcinalp & Avci, 2019), other studies reported non-significant effects (Harianto et al., 2024; Moorhouse, 2021) or expressed concerns about its detrimental effects (Cavanaugh et al., 2016; Elphick, 2018; Rubin, 2012; Vilarinho-Pereira & Fleith, 2021). Our results provided causal evidence for a non-significant effect for Singapore and a negative effect for Morocco. Henriksen et al. (2021) posited that the utilization of suboptimal or inadequately designed digital learning environments falls short of delivering the anticipated creative benefits to students. This situation is more evident in the case of Morocco, as the use of digital educational technologies resulted in an undesired negative effect on students' creative thinking skills. The extant literature highlights that the successful integration of digital technology requires both a robust technological infrastructure and well-trained educators who can effectively utilize these tools (Gangmei & Thomas, 2025). In this respect, it can be said that the use of digital technology in the classroom environment depends significantly on different factors in terms of increasing students' creative thinking skills.

These outcomes may be attributable to a number of factors, including the absence of adequate infrastructure and the psychological resistance to digital technology exhibited by teachers and students (Moorhouse, 2021). In order to utilize digital educational technologies in an effective manner, both teachers and students must possess certain competencies. However, both groups face significant challenges in using these technologies effectively in educational settings (Lamanauskas, 2010; Moorhouse, 2021). The effective integration of technology into the educational environment by educators, hinges upon their possession of the requisite level of digital literacy (Wang et al., 2024). Although three-quarters of students are confident in using DETs at school (OECD, 2023), only 17-21% of teachers were found to be 'versatile users' of DETs (Lee, 2024). Teachers, in particular, assume a pivotal role in the integration of technological resources within the classroom setting (Alberola-Mulet et al., 2021). Students' creative thinking skills can be enhanced by teachers' implementation of instructional methods that can nurture students' creative thinking and creativity-inducing learning environments (Aytaç & Kula, 2020; Kim, 2020). For example, various studies have found that project-based learning (Chen et al., 2022) and STEAM (science technology, engineering, art, and mathematics) education (Erol et al., 2023) contribute to the development of students' creativity. Combined together, positive effects of digital technologies on students' creative thinking depend on pedagogically and

digitally competent teachers who can harness the affordances of subject-appropriate digital technologies with effective instructional designs.

In order to assess the robustness of the causal links for the respective countries, an alternative model was performed in which the treatment and control groups were not matched in terms of school ICT resources. This analysis found that matching students without similar levels of school ICT resources had slightly spurious effects on the DETs' effect on students' creative thinking skills in Singapore. However, the inflated effect was also not statistically significant. By controlling for school ICT resources, a portion of the explained variance in creative thinking through this confounder was eliminated. Consequently, failure to account for school ICT resources leads to an overestimation of the effect of DET on the creative thinking skills of Singaporean students. This change may occur if schools that implement higher levels of creative learning environments in schools with more ICT resources, which may concomitantly manifest heightened levels of creative thinking, are disproportionately represented within the treatment cohort. Once a balanced distribution of school ICT resources is achieved, the treatment effect is more precisely estimated without this confounder. Nevertheless, it was beyond the scope of this study to determine the association of school ICT resources with either or both DET use and creative thinking skills, as well as the direction of the association.

Conversely, in Morocco, the confounding mechanism of school ICT resources is different. The failure to account for the effect of school ICT resources in treatment and control cohorts led to an exacerbation of the negative effect. The decline in the treatment effect can be attributed to the imbalance in the distribution of schools that implement DETs without incorporating creative activities and an environment within the treatment group. This misalignment points to a critical issue in education: the integration of digital technology into the curriculum may not always align with the current infrastructure, impeding student creativity. Insufficient ICT support may also cause frustration among teachers and learners, leading to disengagement and lower learning outcomes. This underlines the need for comprehensive training programs for teachers to enable them to use resources effectively and promote a creative learning environment. In summary, the investigation of school ICT resources reveals a multifaceted relationship with the utilization of DETs in Singapore and Morocco. It is imperative to acknowledge this confounder to ensure the accuracy of estimates regarding the impact of teachers' use of DETs on students' creative thinking skills. Further investigation is necessary regarding the direct and indirect effects of school ICT resources on students' creative thinking skills and DET use more comprehensively.

Limitations

In addition to the possibility of self-report bias, one of the limitations inherent in the study was the lack of control over the prior levels of creative thinking exhibited by students. The PISA 2022 dataset did not include that variable. Nevertheless, given that creative thinking is susceptible to pedagogical intervention (McDonald et al., 2020; Yang et al., 2024), which may be enhanced contingent upon the influence of the use of DETs, and considering that the outcomes of the sensitivity analysis, with a hypothetical moderate-to-high level of confounder, did not drastically alter the estimates of the treatment effects, it can be posited that the impact of this variable is less likely to change the interpretation of the results. While the engagement in creative thinking activities outside schools may also serve as an extraneous variable influencing the results, the extent to which these activities could pertain to school-related assignments remains ambiguous. Consequently, this particular variable was not included as a covariate. Furthermore, neither the proficiency levels of teachers in implementing DETs nor the digital literacy competencies of students were delineated within the selection criteria, which may account for a portion of the variance regarding the disparate results compared to prior research that presupposes optimal conditions. Thus, the findings can only be generalized to the authentic educational contexts within these nations.

Conclusions and Implications

A rapid and widespread adoption of digital technologies is occurring in educational settings around the world. Yet the evidence proverbially showed that policymakers are 'putting the cart before the horse'. This study revealed causal evidence that the widespread implementation of digital educational technologies was not only ineffective in enhancing Singaporean students' creative thinking skills, but it also exerted a detrimental impact on Moroccan students' respective skills. Therefore, it is advisable to adopt a cautious approach towards perceiving DETs as a panacea for educational objectives. It is recommended that educational policymakers exercise caution in over-investment in digital technologies and over-reliance on their implementation without carefully optimizing instructional and curricular design, along with improving the digital literacy of teachers and students for technology-enhanced creative learning environments. The implementation of student-centered teaching methods can be encouraged to foster creative thinking in students. Additionally, it is imperative that professional development programs are implemented to enhance teachers' proficiency in the utilization of digital technologies, given that insufficient digital literacy among teachers and a deficit in technological support within schools may hinder the potential benefits of DET use on creative thinking from being realized. Further empirical research is needed to explore and guide the development of educational policies that transition the *efficacy* of the research regarding the use of digital technology in enhancing students' creative thinking skills into nationwide *effectiveness* while alleviating its challenges, ultimately fostering a rich learning environment conducive to creativity and innovation.

Declaration of Interest

The authors declare no competing interest.

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Received: March 20, 2025

Revised: May 05, 2025

Accepted: June 02, 2025

Cite as: Kaplan, O., Kara, M., & Kaçar, T. (2025). The effect of digital technology integration on students' creative thinking skills: PISA evidence using propensity score matching. *Problems of Education in the 21st Century*, 83(3), 403–423. <https://doi.org/10.33225/pec/25.83.403>

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