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Integrating Digital Storytelling into STEAM Teaching: Examining Young Language Learners' Development of Self-regulation and English Literacy

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Abstract

As an innovative pedagogical approach, STEAM Education uses science, technology, engineering, the arts, and mathematics to spark students' learning motivation, problem-solving skills, and cognitive development. Despite widespread literature on STEAM pedagogy, evidence on the benefit of integrating STEAM with technology-enhanced language learning at elementary levels is insufficient. This study thus inspects the impact of incorporating digital storytelling (DST) into STEAM teaching on young language learners' development of self-regulation and English literacy. Thirty-three schoolchildren participated in the study as the experimental and control groups. Their English literacy and self-regulation were examined before and after the study. Both groups received STEAM instructional content in English for one semester. The DST group worked with the online platform StoryJumper to make digital books for their projects; meanwhile, the control group prepared their projects by reports and presentations. At the end of the experiment, the DST group's academic self-regulation improved significantly which was the result of their enhanced introjected and external regulation. Also, the DST group outperformed the control group in English literacy. Due to the key role of STEAM education in making students interested in STEAM disciplines at elementary levels, planning and implementing best practices of STEAM pedagogy for schoolchildren is recommended.

Introduction

The 21st century is the age of skill, technology, and entrepreneurship where knowledge creation and transmission need to be fast and fruitful to meet the needs of society by providing an ingenious, inventive, and yet skilled workforce for all careers. The key to this type of education that opens doors to the prosperity of the nation in today's competitive economy is incorporating science and technology into the schooling system. This demands particular attention to STEM (science, technology, engineering, and math) pedagogy and assurance that sufficient numbers of students select STEM domains for their future studies and professional careers (Istrate et al., 2019).

STEM pedagogy is a teaching approach that combines four fields of science, technology, education, and mathematics and functions as a means to prepare today's students to structure the innovative, productive, and responsible citizens of tomorrow's ideal community. The STEM approach was originally introduced into mainstream education by the US National Science Foundation in 2001 to prepare students for STEM-related professions and connect schools, universities, and workplaces through implementing STEM curricula (Britannica, 2023). In persuasion of STEM's best practices and considering the importance of arts in students' creativity and technology literacy, the arts were added to the package and STEM evolved into STEAM to help students "combine the mind of a scientist or technologist with that of an artist or designer" (Meletiou-Mavrotheris, et al., 2022, p. 1). The arts as the core of strengthening emotional growth, creativity, critical thinking, and self-awareness develop students' capacity to become risk-takers, problem solvers, collaborators, and innovators (Bauld, 2022).

Research shows that learners get inspired by STEAM concepts and instructional practices and they can apply their knowledge and skills to real-world situations (Kang, 2019). Learning in the STEAM program results in outputs where the learners must process what they have received and then through inquiry skills, use it to solve a problem or to model a real scientific fact instead of just memorizing some facts of school subjects. To achieve these inquiry skills, 'thinking like a scientist' emerges as a model to follow and understand the cause and effect of STEAM-related concepts (Thuneberg et al., 2018). The objectives of the STEAM curriculum are not only teaching knowledge but also promoting accountability, collaborative effort, and self-regulatory skills (Santillán-Aguirre et al., 2020).

Evidently, STEAM pedagogy impacts students' conceptual understanding of science, technology, engineering, the arts, and mathematics in a positive manner and it can remarkably foster understanding of scientific concepts through a learner-centered approach (Ozkan & Topsakal, 2021). Considering the loss of students' interest in STEAM topics across the curriculum (Innes, 2020), improving the way the STEAM concepts are learned to capture students' attention and interest in STEAM disciplines and careers is a priority (Guenaga et al., 2017). One novel aspect of STEAM education is functional literacy which deals with "not merely the knowledge acquired on an individual subject but rather the ability to creatively utilize it in an ever-changing economic or social environment" (Marmon, 2019, p. 109). To attain such a goal, integrating different types of technologies into STEAM education to address young generations' learning needs and preferences is of significant importance. In this way, both creating and solving a larger number of problems would be possible (Beal & Cohen, 2012) and the students' understanding of the STEAM complex concepts would increase. Additionally, real and genuine use of technologies for contemplating real-world issues can reinforce problem-solving and design thinking (Yang & Chittoori, 2022).

Notably, for both domains, that is STEAM pedagogy and technology-enhanced instruction, a certain degree of self-regulatory skills and strategies is required as self-regulation plays a critical role in tasks that demand interdisciplinary knowledge. Self-regulation is one of the predictors of academic achievement and is viewed as the most frequently utilized cognitive process that assists in successful academic performance (Li et al., 2018). Self-regulation as a mental activity empowers learners to assess their cognition, emotion, and motivation while learning and aids students in adapting themselves to the requirements of a given task (Pintrich, 2000). Evidently, STEAM activities are challenging for students and require assessment of one's weaknesses and strengths, as well as precision, perseverance, and motivation to complete the tasks (Nu'man et al., 2021). Some studies have shown that learning STEAM-related topics and self-regulatory skills are interrelated (e.g., Bene et al., 2021), however, it is unknown if performing STEAM-related activities can impact the development of self-regulatory strategies, particularly in technology-enhanced learning (TEL) environments. Taking into account the above-mentioned points, the current study seeks answers to the following research questions:

1. Does integrating DST into STEAM teaching impact language learners' development of academic self-regulation?
2. Does integrating DST into STEAM teaching impact EFL learners' development of literacy (reading and writing) skills?

Review of Related Literature

Technology-enhanced Learning Environments and STEAM Curriculum

The advancement of technology and its ubiquitous presence in all spheres of human activities have brought about fundamental changes in educational planning and administration. TEL is supported by solid theoretical underpinnings and extensive empirical evidence. Accordingly, any emerging technology quickly finds its way into the classroom and its effectiveness on learning and teaching is evaluated. Contrary to expectations, the result of meta-analyses on the impact of technology on learning outcomes is moderate while variations in effect sizes are attributed to the studied variables such as subject matter, educational context, and types of learners (Chauhan, 2017; Ran et al., 2022). In other words, the incorporation of different types of technologies across different contexts and curricula may yield different results, and STEM pedagogy is not an exception. Practice-grounded findings in this arena shed light on how to choose the right technology and adopt appropriate pedagogical approaches for STEAM teaching.

It is suggested that integrating technology into STEAM makes a connection between theory and practice and prevents the disconnection of the STEAM domains in the curriculum (Vahidy, 2019). Four strategies are proposed for integrating TEL into the STEAM curriculum including supporting authentic learning conditions and web-based quest environments, promoting learning by extended reality (ER), and converting learners to creators rather than consumers of the instruction (Yang & Baldwin, 2020). Certain types of technologies such as online learning, simulation, ER, and gaming are noticed to have pedagogical potential for STEAM education (e.g., Wu & Anderson, 2015; Vahidy, 2019).

Within this scheme, some researchers have examined the benefits of integrating different technologies into the STEAM curriculum, mostly for learning gains of STEAM concepts and STEAM motivation in primary and middle school contexts. Beal and Cohen (2012) examined the impact of a web-based content-authoring and sharing system on middle school students' math and science problem-creation and solving. The result showed that the participants' ability in problem-solving activities exceeded their problem-posing. Further, both students and teachers appeared to have positive perceptions of the activities.

Chiu et al. (2013) described the design and development of WISEngineering, a web-based engineering design platform for improving K-7 students' understanding of mathematical concepts and engineering ideas. The results showed that students' math scores improved as a result of the intervention. Students, teachers, and administrators' perceptions showed that the WISEngineering project was effective in promoting cooperation, tolerance, and the growth of pro-social skills of at-risk youth. Restivo et al. (2014) explored the educational benefits of an augmented reality (AR) application for teaching DC circuit fundamentals among young learners (ages 14-16) to involve the users in the learning process. The result was indicative of students' satisfaction and positive perceptions of the experience supporting the educational value of AR in improving STEM instruction. Kopcha et al. (2017) investigated the effects of robot-assisted learning in the STEM curriculum on K-5 students' development of computational thinking. The results of the study showed that both students and teachers had positive attitudes toward the program and that the proposed curriculum supported students' problem-solving and teacher's instructional practices.

Innes (2020) examined the effects of technology on primary students' (K3-5) interest in STEM education by using three Texas Instruments technologies. The results showed that students were more interested in electronics, STEAM topics, and coding after using the technologies. Also, teachers showed a positive response to the experiment and asserted that they were more ready to use the STEAM approach in their classrooms. In a recent study, Yang and Chittoori (2022) examined the use of technology in engineering design and problem-solving activities and tasks among upper-level elementary students. The results show that technology significantly assisted students in performing tasks and solving engineering design problems. Further, the students believed that using technologies and tools during the design tasks was joyful.

Despite the existence of a trend for integrating state-of-the-art technologies in STEAM education (Meletiou-Mavrotheris et al., 2022), as this succinct review shows, there is a scarcity of empirical studies on technology integration into STEAM education in the primary school context. Further, there is a gap in the literature on how STEAM pedagogy can be combined with the teaching of other subjects such as language to amplify the effectiveness of both on learning gains. The success of such programs requires lots of effort because putting STEAM into practice in an integrated manner demands varying degrees of pedagogical expertise. As for integrating STEAM pedagogy and language curriculum within TEL environments, recognition of the interdisciplinary nature of STEAM teaching, pedagogical practices of foreign language teaching, and theoretical underpinnings of educational technology should be recognized.

STEAM Education and Language Teaching: Transforming STEAM into STREAM?

The integration of STEM/STEAM teaching with language has been originally framed in Content and Language Integrated Learning (CLIL) where content, i.e., science and its related disciplines, is taught through the medium of a second/foreign language, and contrariwise, a second/foreign language is taught through content. CLIL not only puts students in an advantageous position to learn some areas of language better (Llinares, 2023) but also empowers them to effectively "communicate technical and scientific STEM content within global STEM markets" (Crum, 2022, p. 1). As a learner-centered approach, CLIL underscores the role of language as a means of making meaning and constructing knowledge (Paraná et al., 2023) and thus emphasizes the social nature of learning where what students learn in the classroom is linked to the skills and knowledge they need in the real world. There is evidence that CLIL is effective in promoting language learners' listening (Nieto Moreno de Diezmas, 2018), reading (Ruiz de Zarobe & Zenotz, 2018), speaking (Pérez Cañado & Lancaster, 2017), and writing (Lahuerta, 2020). As expected, CLIL is also effective in learning science and math (Jäppinen, 2005) taught in a foreign language. More importantly, CLIL sparks the learners to adopt a more active role in the process of learning both the language and the content by assessing their performance and keeping an eye on their progress and possible reasons for failure (Menegale, 2017). The students' constant monitoring of their actions leads to the development of their self-regulatory skills to overcome the challenges they encounter in CLIL (Campbell et al., 2017). In this framework, there are a few studies that have integrated the STEM/STEAM teaching model with second/foreign language instruction and have reported non-native speakers' development of English literacy (Fuhrman-Petersen, 2013), discipline-specific vocabulary acquisition (Poese, 2014), and language proficiency (Duo-Terron et al., 2022). This interconnectedness between language and science teaching has justified the movement of transferring STEAM into STREAM when Reading and w(R)iting are added to the STEAM teaching.

STREAM education underscores a holistic curriculum (Nuangchalerm et al., 2020) to teaching content and language literacy skills to arm students with "communication skills to tackle crucial challenges" (Sucheta, 2022, p. 16) they have with STEAM topics. STREAM approach contributes more significantly to language and cognition development as well as knowledge and skill acquisition. Integrating reading and writing into STEM/STEAM lets students develop their science literacy and be able to read and write more critically about the STEAM topics they learned rather than just memorizing the concepts and notions (Norris & Phillips, 2003). The proponents of STREAM believe that integrating reading and writing into STEAM makes it more approachable and inclusive to a wider range of learners regardless of their earlier differences (Trachta, 2018). Despite its theoretical popularity, there are very few empirical studies on the STREAM approach and its merits for promoting science and language literacies (e.g., Nuangchalerm et al., 2020; Sucheta, 2022).

Digital Storytelling (DST) and STEAM Pedagogy

DST or the art of narrating stories with digital media is one of the recent forms of storytelling. DST lets people use a wide range of technologies to share their personal stories with the audience. Literature shows that DST has a broad scope of influence and its positive outcome on attitudes, thinking skills, knowledge acquisition, academic performance, IT literacy, language skills, identity, and social skills is evident (Wu & Chen, 2020). DST is among the technologies that have been suggested to be valuable for communicating complex technical information in STEM pedagogy (Hill & Grinnell, 2014).

The multimedia nature of DST is proven to make learning easier in comparison to single-medium content (Mayer, 2014). Cognitively, multimedia learning lowers mental struggle and discomfort by increasing the capacity of working memory and thus decreases task complexity and anxiety (Sweller et al., 2011). Pedagogically, combining image, narration, graphics, and movement help understand complex scientific notions (Mayer, 2014) and help students understand even abstract concepts and procedure more easily (Shirazi & Rahimi, 2023) by paying attention to displays (Higgin et al., 2018) and contextual examples (Pace & Jones, 2009). Empirical studies show that DST affects science learning (Bilen et al., 2019) and can impact students' attitudes and satisfaction in science classes (Saritepeci, 2021). DST encourages the incorporation of art into the STEM curriculum to "help learners and adult professionals imagine new ideas in STEM education; to shift from "what is" to new possibilities of "what might be" (Anastasiadis, 2018, p. 85).

Despite the proposed value of DST for STEAM pedagogy, very few studies have examined the role of DST in STEAM curricula (e.g., Restivo et al., 2014; Hill & Grinnell, 2014; Anastasiadis et al., 2018). It is arguable that utilizing DST in an integrated STEAM, where content and language teaching are interwoven, promotes young language learners' development of reading and writing skills and their self-regulatory strategies. Research shows that integrating STEAM into other school subjects where suitable technology is exploited makes students more interested in selecting STEAM-related fields of study and STEAM careers in the future (Restivo et al., 2014). This is critically important for countries like Iran where the selection rate of STEAM-related disciplines in secondary and tertiary education is disappointingly low.

Method

Participants

The participants included 33 schoolchildren who were studying in a primary bilingual school in Tehran. The participants were assigned to the experimental (n=16) and control (n=17) groups randomly. As the participants were minors, their parents' consent was gained in the Parent-Teacher Association's (PTA) meeting by explaining the procedure of the experiment. The parents were involved in the intervention throughout the study.

Instrumentation

Cambridge Movers Test

The Cambridge Young Learners English (YLE) Test is the second of the three Cambridge English tests to assess the general knowledge of young learners around familiar topics. These standard tests focus on four main skills that every young learner needs to communicate effectively in English. YLE Exams are intended to support three levels: Starters (CEFR pre-A1 level); Movers (CEFR A1 level), and Flyers (CEFR A2 level). YLE tests include listening, reading and writing, and speaking parts. The assessment aims to give children a good evaluation for language learning, as well as inform their parents and teachers how they are doing in English (Cambridge English Movers, 2014). For this study, the reading and writing section of the Movers Test was used as the pre-test and post-test to examine the effect of the intervention on the participants' English literacy development. The reading/writing section has 40 questions and lasts 30 minutes. The reliability of Movers was estimated to be .90 for the pre-test and .93 for the post-test, respectively.

Academic Self-Regulation Questionnaire (SRQ-A)

The academic self-regulation questionnaire (SRQ-A) is a self-report scale structured in self-determination theory (Deci & Ryan, 1985) that is used to assess students' self-regulatory skills in studying and doing their homework. SRQ-A has been developed for young learners above 8 years old. SRQ-A consists of 26 items anchored on a 5-

Likert scale (1 = not at all true to 5 = very true). The scale assesses four regulatory styles including identified regulation (7 items), introjected regulation (6 items), intrinsic motivation (6 items), and external regulation (7 items). The reliability of SRQ-A was found to be .89 for the pre-test and .92 for the post-test, respectively.

Digital Stories

StoryJumper was used by the DST group to prepare their projects based on the STEAM-domain topics the students worked on in the classroom. StoryJumper is a DST tool that assists students in creating digital books with their own photos or artworks, texts, narration, and effects. This tool is used as an important source of teaching reading and creative writing to young learners (Rahimi & Yadollahi, 2017). StoryJumper is a free online DST platform and learners of all ages can use it to improve their writing skills and publish their own stories.

Procedure

The Research Procedure

In pursuit of the purposes of this study, multiple steps were taken. First, 33 schoolchildren were randomly selected and assigned to be the experimental and control groups. Both groups participated in the Movers Test and SRQ-A before the study. Then the teacher used the principles of CLIL to present the topics of the STEAM in teaching English as explained in the following section. The experiment lasted one semester (around five months) and both groups took part in the Movers Test and SRQ-A at the end of the study. The data then were inserted into SPSS 24 and analyzed utilizing parametric data analysis techniques.

The Instructional Procedure

The following steps were taken to teach English and STEAM topics in both classes (Richards & Rodgers, 2014):

(a) Warm up to introduce the topic: The teacher chose a topic of interest from the STEAM-domain topics and activated students' background knowledge. Both general information and linguistic forms were worked on at this stage to make the students ready for the main lesson.

(b) Presenting the content in the context of the language: The STEAM topic was introduced through a variety of tools such as reading passages, video clips, recorded conversations, and tasks.

(c) Content and language-related exercises: To back up what had been presented in the previous phase, the students were asked to do both content and language-related exercises. Examples of content-related activities are hands-on tasks, diagram completion, question-and-answer activities, and concept maps. Examples of language-related activities are vocabulary exercises, summary writing, and audio-transcript analysis.

(d) Group work and projects: The students of both groups were expected to prepare their projects after the presentation of STEAM topics. The difference between the instruction of the DST and the control group was in this stage. The DST group members used the StoryJumper platform to make digital storybooks for their project; while the control group prepared their project by conventional methods of reports and presentations.

Results

Descriptive statistics of the Movers Test and SRQ-A and its components are shown in Table 1. As Table 1 shows, the DST group's mean scores of the Movers and SRQ-A post-tests are higher than those of the control group. Also, the DST group's post-test mean values exceed those of the control group in all components of SRQ-A.

Table 1. Descriptive Statistics of the Movers and SRQ-A Post-test Scores

Variables	**Experimental group**		**Control group**		**Total**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Movers	29.250	5.848	24.882	4.385	27.00	5.528
SRQ-A	4.074	.185	3.823	.391	3.945	.330
Identified regulation	4.633	.270	4.333	.650	4.502	.512
Introjected regulation	4.687	.242	4.333	.565	4.505	.468
Intrinsic motivation	3.697	.400	3.676	.587	3.686	.497
External regulation	3.312	.455	2.958	.418	3.129	.466

The Effect of DST on Self-regulation

To examine the effect of the experiment on the development of academic self-regulation, a one-way Multivariate Analysis of Variance (MANOVA) was run on SRQ-A post-test scores. The results primarily showed a significant difference between the general post-test scores of the two groups [Wilks' Lambda=.661; F (4, 28) =6.30; *p*=.018; ηp^2=.339]. Further analysis (see Table 2) indicated that the scores of the two groups in two components of SRQ-A, that is introjected regulation [F (1, 31) =5.348, *p* =.028, ηp^2=.147] and external regulation [F (1, 31) =5.427, *p* =.027., ηp^2=.149], were significantly different.

As can be seen in Table 2, the effect size for the intervention (ηp^2=.339> .14) was large. Similarly, the effect sizes for introjected regulation (ηp^2=.147> .14) and external regulation (ηp^2=.149> .14) were large (Cohen, 1988). Based on descriptive statistics (see Table 1), the DST group's introjected regulation (Mean=4.687, SD=.242) and external regulation (Mean=3.312, SD=.455) developed significantly in comparison to the introjected regulation (Mean=4.333, SD=.565) and external regulation (Mean=2.958, SD=.418) of the control group.

Table 2. Tests of Between-Subjects Effects

Source	**Dependent Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Groups	Identified regulation	26.423	1	26.423	2.123	.155	.064
	Introjected regulation	37.220	1	37.220	5.348	.028*	.147
	Intrinsic motivation	.136	1	.136	.015	.904	.000
	External regulation	50.760	1	50.760	5.427	.027*	.149
Error	Identified regulation	385.820	31	12.446			
	Introjected regulation	215.750	31	6.960			

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
	Intrinsic motivation	285.379	31	9.206			
	External regulation	289.967	31	9.354			
Total	Identified regulation	33188.000	33				
	Introjected regulation	24364.000	33				
	Intrinsic motivation	16434.000	33				
	External regulation	16181.000	33				
Corrected	Identified regulation	412.242	32				
Total	Introjected regulation	252.970	32				
	Intrinsic motivation	285.515	32				
	External regulation	340.727	32				

The Effect of DST on English Literacy

To examine the effect of the experiment on the development of reading and writing skills, an independent samples t-test was run on the Movers post-test scores (see Table 3). As Table 3 demonstrates, the difference between the means of the two groups in post-test scores [t (1, 31) =-2.437, *p*=.021<.05] is significant. Descriptive statistics (see Table 1) shows that the DST group's literacy skills (Mean=29.250, SD=5.848) improved significantly in comparison to those of the control group (Mean=24.882, SD=4.385) after the experiment.

Table 3. The Results of Independent Samples T-test on the Movers Post-test Scores

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig.	Mean Difference	Std. Error Difference	Lower	Upper
Equal variances assumed	3.583	.068	-2.437	31	.021*	-4.367	1.792	-8.022	-.712
Equal variances not assumed			-2.416	27.785	.023	-4.367	1.808	-8.072	-.662

Discussion

The current study was carried out to examine the effects of digital storytelling on schoolchildren's development of self-regulation and EFL literacy in STEAM teaching. The findings of the study primarily confirm the positive effect of the DST-integrated STEAM course on the growth of the participant's academic self-regulation. The DST group worked with StoryJumper, a tool that empowered students with a variety of choices to make their own stories and to get inspired by the materials and the concepts of STEAM. In this way, they could find their own favorite subjects and make their own stories related to the key concepts of science, technology, engineering, the arts, or math.

The improvement of introjected and external regulation of the DST group at the end of the experiment makes it logical to attribute the promotion of their self-regulatory skills to their intrinsic motivation and self-esteem as well as the fearless atmosphere of the class created by the external authority-the teacher (Rayan & Connell, 1989). Each student in this group had a voice and idea to talk about, that reflects the highest level of mind skills growth among young learners. All participants were invited to the specified STEAM groups on the online platform and they were provided with links, videos, and tools for producing their reports based on what they were exposed to during the teaching phase. These tools and training resources helped all participants put what they learned into practice by producing projects that were planned and monitored by them and their teammates, and evaluated by the teacher and their peers in a relaxed and fear-free environment. Collaboration and cooperation facilitated scientific inquiry while all were accountable for overcoming their weaknesses and attaining their goals (Campbell et al., 2017).

The results of the study corroborate the findings of previous works that DST is a valuable communication tool to be used in integrated STEAM programs because of its essential focus on information, science, and knowledge transfer between the audience and the writers (Hill & Grinnell, 2014). DST facilitates the coordination among four student-centered learning strategies including engagement, reflection, project-based learning, and TEL (Barrett, 2006; Sadik, 2008). Project-based learning and problem-based learning fulfil the students' needs and meet the goals of the STEAM program by expanding students' basic knowledge of STEAM themes and topics (Ozkan & Topsakal, 2021). This enables students to find smart ideas and practical solutions for presenting real-life facts and applying them in their presentations through DST tools and affordances.

It was also found that young learners' reading and writing skills were influenced by integrating DST into STEAM teaching. The effects of literature in general and stories in specific on children's development of literacy skills in both first and second language is evident (Isbell et al., 2004; Omidbakhsh, 2021). Storytelling has a positive impact on the development of language skills, language learning motivation, and social interaction (Lucarevschi, 2016). Storytelling makes a "natural connection between events and concepts" (Barzaq, 2009, p. 9), promotes meaningful communication (Wallace, 2000), boosts visual memory (Katsuhiko, 2002), and makes learning joyful and engaging (Rahimi & Soleymani, 2015). In addition to that, DST is a valuable tool for STEAM programs because DST can promote students' creativity and critical thinking (Pavlou, 2020), engagement in writing practices (Stewart & Ivala, 2017), content generation and motivation (Sevilla-Pavón & Nicolaou, 2017), reading and writing skills (González Mesa, 2020), and action-based learning (Gearty, 2015). All these variables have either direct or indirect associations with students' performance and successful learning in STEAM classes.

The findings are in favor of those pedagogical practices that encourage the integration of the STEAM curriculum into language teaching, including CBI, task-based language teaching, and inquiry-based instruction (Hatami, 2022). These instructional practices provide ample opportunities for students to learn STEAM content and academic language simultaneously (Engelbret, 2015). More specifically, the findings of this study give credence to STREAM pedagogy, at least in the EFL setting, to make STEAM teaching more intriguing for elementary students by helping them read and write about STEAM notions and topics. This type of education opens the professional and academic horizons of these students and guides them to have a more proactive role in their own future and the prosperity of their country.

Conclusion

The current study illustrates that TEL environments can be effectively integrated with the STEAM program and lead to increased self-regulatory strategies as well as the development of literacy skills among schoolchildren. The study contributes to the literature in two ways. First, it shows the importance of integrating the STEAM program into language education and its effect on young learners' development of language skills. Second, it displays the role of suitable technologies in promoting STEAM motivation and making schoolchildren more self-regulated and autonomous learners.

The current study has three practical implications for MOE, higher education administrators, and workforce policymakers. First, due to the importance of STEAM education in making students interested in STEAM disciplines, particularly at primary levels, careful attention to planning and implementing best practices of STEAM pedagogy by MOE and its bureaus is recommended. Second, close cooperation between universities and schools is required for the fruitful implementation of STEAM curricula in mainstream education. This is of particular interest in countries like Iran where students' interest in science, technology, math, and engineering fields of studies and careers is critically low both in secondary and tertiary education. Third, the governmental and private sectors should collaborate tightly in workforce planning and implementation to educate and hire the right people with the right knowledge and skills in STEAM-related jobs and careers.

The findings of this work are interpretable by considering the limitations the researchers had in the process of performing the study. First, the sample of the study was small as locating bilingual primary schools in Tehran is not an easy job. Second, due to practicality issues, boys' schools were not included in the design of the study, and data were just gathered from female students. Last, as the participants were schoolchildren, gathering qualitative data and conducting interviews with them was not possible.

Follow-up studies considering the integration of STEAM pedagogy and DST into other school subjects such as social sciences are recommended. Also, a cross-comparison of the effects of DST and other technologies such as AR and VR in integrated STEAM programs would be enlightening. Further survey on the prospect of transforming STEAM into STREAM via the integration of reading and writing into STEAM teaching in other EFL settings is suggested.

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