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Integrating STEAM activities into teaching reading: Examination of comprehension and cognitive load[1]

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Abstract

This paper reports the findings of an experimental study that probed into the impact of integrating STEAM activities into teaching English as a Foreign Language (EFL) reading on reading comprehension and its associated cognitive load. The sample included 60 high school students who were split into experimental and control groups, with 30 students in each. Before the study, their reading comprehension was assessed by the reading module of the A2 Key test. The associated cognitive load of A2 Key was assessed by the National Aeronautics and Space Administration Task Load Index (NASATLX) before the study as well. For the experimental group,STEAM-based pre-reading activitieswere incorporated into teaching reading while the control group was taught based on the conventional method utilizing the activities of their textbook. The experiment lasted for five months. The reading section of A2 Key and the NASA TLX were used to explore the effect of the intervention on the participants' reading comprehension and its associated cognitive load after the study. The data were analyzed by *t*-test and Multivariate Analysis of Covariance (MANCOVA). According to the findings, STEAM-based warm-up activities significantly impactedthe development of reading comprehension in favor of the experimental group. It was also found that the cognitive load of the experimental group significantly reduced regardingmental demand, physical demand, and frustration in comparison to the control group. The practical implications of the study for education policymakers,curriculum designers, and teachers are understood in terms of integrating STEAM into the EFL curriculum to make students interested in STEAM topics and create a friendly class atmosphere that would lead to developing their reading skills and knowledge acquisition.

Keywords: cognitive load, EFL, reading comprehension, STEAM

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Introduction

STEM (Science, Technology, Engineering, and Mathematics) education was conceived and thrived as a result of concerted efforts of developed countries, mainly the US, to make students interested in the STEM domains and assist them in deciding about their future careers. STEM education arms students with real-world competencies and skills and enables them to join the dexterousworkforce of the 21st-centurydemands in life at large beyond the classroom (Hasanah, 2020).

In this framework, Science, Technology, Engineering, Arts, and Mathematics(STEAM) pedagogy was introduced by adding the arts to STEM as a countervailing force to the decline of arts education that occurred as a result of the over-popularity of STEM pedagogy (Perignat & Katz-Buonincontro, 2019). STEAM education is viewed as "an approach to learning that uses science, technology, engineering, the arts, and mathematics as access points for guiding student inquiry, dialogue, and critical thinking (Thomas & Huffman, 2020, p.285). STEAM enhances students' cognitive development, creativity, and problem-solving skills.

Despite its approval by many pedagogues, STEAM implementation is not without its flaws (Aguilera & Ortiz-Revilla, 2021). Teachers and students may develop negative attitudes towards STEAM across the curriculum and lose their interest in its content (Innes, 2020). One way to maintain the quality of the STEAM program is integrating it into the teaching of other school subjectswhich eventually leads to higher interest in both subject domains. The STEAM approach is an ideal practice for teaching L2 since integrating its components into the curriculum can build an environment that is both language-rich and context-specific (Richards & Rodgers, 2014). Moreover, it provides ample opportunities to acquire STEAM content and academic language simultaneously (Engelbret, 2015). English learning and STEAM education are two requirements in today's world and mastering both domains opens doors to academic and professional success for students. To bring these two together, however, one should pay attention to the relevant standards of both STEAM and EFL education, and their pedagogical models and agendas.

There are certain models where STEAM topics are integrated into teaching the language. One of the most frequently applied ones is content-based language instruction (CBLI) where a second language (L2) is used to teach the content. In this model, contentlearning is the primary goal of the curriculum, and language learning is its byproduct (Richards & Rodgers, 2014). Reading comprehension plays a crucial role in CBLI as reading is a significant predictor of students' academic success (Cooper et al., 2014) in general and their science literacy in particular (Neri et al., 2021). Most often students find reading STEAM passages very difficult because they lack enough familiarity with the topics of STEAM domains or the linguistic characteristics of the texts (Amirinejad & Rahimi, 2023). Therefore, activating students' prior knowledge of the topic and familiarizing them with technical terms play a key role in promoting their comprehension. This is basically done through pre-reading activities in the process through which learners can cognitively develop thinking and problem-solving skills while relating their experiences to real-life situations (Echeverri & McNulty, 2010).

Pre-reading activities let readers connect visual scenes to life experiences, make inferences from what is read, andpreview/predict the content. In this way, the students' prior knowledge of the reading topics is activated and as background knowledge plays a key role in top-down processing during reading,understanding of the text takes place more deeply and confidently (Eysenck et al., 2007). As a result, more working memory (WM) capacity can be

allocated to the reading task (Sweller, 2022) and task pressure and cognitive load are lowered.Despite ample studies done on the role of different types of warm-upin reading comprehension (e.g., Alemi & Ebadi, 2010; Al Akremi, 2016; Pellicer-Sánchez et al., 2021), the role of STEAM-based activities in the development of language skills has been sparingly researched. Therefore, this study probes into the effectiveness of STEAM-based pre-reading activities in comparison to the conventional activities of the school textbook on language learners' reading comprehension and its associated cognitive load.

STEAM Education

The STEM approach is a pedagogical model that combines and presents science, technology, engineering, and mathematics in a unified manner. "Unlike traditional education experiences in which subject areas are concentrated on separately, STEM education emphasizes technology and integrates subjects in ways that connect disciplines and relate them to each other" (Britannica, 2023). In this scheme, students learn topics of more than one domain and utilize multi-disciplinary knowledge to develop critical thinking and problem-solving skills (Yang & Baldwin, 2020).

With an increase of attention to STEM education for preparing students for their future careers and education in related fields, STEAM education was conceivedwhen the arts were added to the framework. The focus of arts in the STEAM pedagogy is on "cultivating learners' comprehensive abilities and core literacy, aiming to nurture excellent talent resources to support the development of modern society"(Li et al., 2022, p. 1). Incorporating art into the STEM curriculum helps students develop their artistry, creativity, cognitive abilities, and communication skills (Taylor, 2016).

The advocates of STEAM believe that discipline-oriented approaches that deal with pure scientific domains no longer fulfill the needs of this era's education. In addition to literacy skills and sciences, the students should own 21st-century skills that demand them to be competent in multiple literacies. Today's schools should utilize a curriculum that introduces students to the core of competencies that activate their creativity, critical thinking, and problem-solving skills. This condition is met through the STEAM curriculum as STEAM takes into account the children's characteristics, needs, and interests and directs their curiosity and imagination to improve the quality of life through an integrated curriculum (Williams, 2011).STEAM can be adapted to any curriculum and helps both teachers and students toexpand the boundaries of the curriculum together (Edelson, 2010). STEAM blends the agendas of five domains of science into one core taking into account the association among the fields and the issues they deal with in the real world (Moore et al., 2014).

Researchers have shown equal interest in both STEAM teaching/teacher education and STEAM learning, indicating that STEAM teacher education and preparation are as important as student learning in STEAM-based classes (Li et al., 2020). As for the students, empirical studies on integrating STEAM into the teaching and learning process show that STEAM can impact students' both cognitive and affective learning, while the effect for affective domains is stronger (Kang, 2019). It is known that STEAM impactsstudents' learning gains and achievement (Kelley & Knowles, 2016), attention and interest (Hatami-Nasab, 2023), and critical thinking (Kang, 2019).

STEAM and Foreign Language Education

Integrating the STEAM approach with language curriculum results from logical reasoning to improve the efficiency of both fields viewed from different perspectives. First, despite the popularity of the STEAM approach in recent years, it is evident that as students move along the curriculum they lose their interest in STEM domain-specific topics (Kelly & Knowles, 2016). The combination of STEAM and language curriculums can increase students' enthusiasm for learning both STEAM content and language features (Hatami-Nasab, 2023). In this way,language learners' interest and motivation increase with their involvement in STEAM activities (Lee & Stephens, 2020).Second, the importance of language, particularly literacy skills, in academic success in general and in acquiring knowledge is evident (Cooper et al., 2014).Language is an indispensable part of science, and it is the device for performing and creating scientific studies and exchanging knowledge (Yore et al., 2003). When language and science literacies are targeted within the same program "educational success will come as a result of students learning the subject curriculum and associated language skills and literacies simultaneously" (Creese, 2005, p. 188).Third, learning a language through STEAM topics would make the learning tasks authentic by focusing on the topics that are taken from daily life and the surrounding environments (LaCosse et al., 2020) instead of irrelevant and intangible issues. In this way, the students have ample chances to communicate about authentic topics of interest while they learn the content and the academic language required for that content (Engelbret, 2015).

Notably, the integration of STEAM pedagogy and language curriculum should be delineated based on pedagogical standards and models of both disciplines (Schoettler, 2015). CBLI is a popular and widely accepted model of integrating STEAM into language education (Hatami-Nasab, 2023). CBLI draws heavily on the communicative approachthat views language as a means of meaningful communication. In this scheme, the purposeful use of language is fulfilled when language is at the service of acquiring content knowledge that triggers cognition and interaction processes(Richards & Rodgers, 2014).

Empirical research shows that teaching content and language in an integrated manner has a reciprocal effect on students' development of knowledge base and competencies. CBLI arms students with the linguistic information and communication skills they need to understand the content by expanding their vocabulary size (Wang, 2013) and written language skills(Douglas, 2017).Based onthe relatively high association between reading comprehension and science literacy (Neri et al., 2021), a line of research has focused on the benefit of CBLI for developing reading skills.

In a pioneering study, Kasper (1997) carried out a study on intermediate EFL learners and concluded that content-based instruction not only enhanced students' reading performance but also facilitated their follow-up academic achievement and raised the possibility of finishing their studies.Similarly, Glenn (2005) reported that students' English reading and content reading improved as a result of integrating content-based instructional strategies into teaching reading. In the same vein, Tsai and Shang (2010) investigated the effect of CBLI on EFL students' reading comprehension in a literature curriculum. Results showed that CBLI impacted students' reading and critical thinking skills in a positive way. Marashi and Sanatipour (2015) examined the effectiveness of competitive and cooperative Content-Based Instruction (CBI) in EFL reading and writing classes and reported a significant effect of the cooperative CBI on literacy development. Duo-Terron (2022) examined the effects of the STEAM program on primary students' development of linguistic and mathematical skills

and whether the understanding of writing and problem-solving skills wererelated. The results of the study showed that the coordinated use of STEAM improved the learning outcomes of linguistic and mathematical competence of students and that the improvement of reading comprehension within the STEAM program contributed to improving the competence to solve problems. In another study, Amirinejad and Rahimi (2023) examined the impact of incorporating digital storytelling into CBLI on young language learners' development of self-regulation and English literacy. Their results showed that teaching STEAM topics in an integrated language course had a significant impact on learners' development of English reading and writing as well as introjected and external self-regulations.

In contrast to these works, Namaziandost et al. (2019) compared the effectiveness of CBI with Task-based Language Teaching (TBLT) on the development of reading skills. While the progress of both groups of students in reading was evident, TBLT was reported to be more effective on language learners' reading comprehension. Hatami-Nasab and Rahimi (2023) also reported a non-significant result for the effect of a STEAM-integrated online language course on university students' willingness to communicate in oral and written interactions.

The controversy over the effectiveness of CBLI in teaching reading is attributed to teachers' lack of knowledge and skills in implementing CBLI (Creese, 2005; Pawan, 2008). CBLI as a form of communicative language teaching integrates language instruction with school or academic content instruction (Wesche, 2010), while STEAM focuses on developing 21st-century education skills, i.e., mainly problem-solving and critical thinking skills. Therefore, integrating CBLI with pedagogical models of reading that teachers are familiar with and use frequently is highly recommended. One of the reading approaches that EFL teachers use prevalently is the pre-during-post reading cycle through which the teacher first activates the background knowledge of the students on the topic and then asks them to read and comprehend the text. After reading the passage, their understanding is checked by post-reading activities such as asking reading comprehension questions. Despite the vast literature on CBLI, integrating STEAM-based activities into the pre-reading phase of the pre-during-post reading cycle within a CBLI is open to further inquiry, particularly when students' comprehension and cognitive demand of the task are focused on.

Pre-reading activities,comprehension, and cognitive load

The pre-reading stage of reading a passage is generally about how a person gets prepared for a reading task and comprehension. Developing pre-reading skills such as pre-viewing and collecting information about the topic makes readers more strategic and helps them process the written input more efficiently (Mokhtari et al., 2018). Integrating pre-reading activities into the cycle of teaching reading is done with the goal of establishing reading purpose, tapping prior knowledge, providingthe information needed for comprehension (e.g., vocabulary, background), setting up expectations, stimulating interest, building confidence and motivation, and explaining or supporting text organization (Grabe & Stoller, 2011).Pre-reading activities encompass a wide range of activities such as brainstorming, vocabulary teaching, questioning, using audio-visual aids and technology, mini-reading, and previewing.

The main goal of the pre-reading phase is to activate readers' background knowledge, i.e., schemata, and involve them in active reading. Schemata arethe mental structures for the storage of information in the brain based on personal experiences. This knowledge, as a part of human cognition, helps make a bridge between what is known and what is going to be faced

or take place. Schemata play a crucial role in comprehension as “understanding a text is an interactive process between the text itself and the reader's acquired background knowledge” (Espinosa, 1996, p. 239).

Empirical studies show that activating readers’ background knowledge can be successfully done by utilizing pre-reading activities. Pre-reading activities have been reported to affect language learners’ comprehension (Alemi & Ebadi, 2010), attitudes toward reading a text (Al Akremi, 2016), and attention to vocabulary while reading (Pellicer-Sánchez et al., 2021) across different contexts of language learning. Notably, the critical role of pre-reading activities within cognitive load theory has been overshadowed by such studies.

Cognitive load is thenumber of resources or storage capacity the WM can allocate to a task (Sweller,2016). When the resources are not enough or beyond the cognitive capability of a person, cognitive overload occurs (Sweller, 2022). Cognitive load is associated with the mental effort a learning task inherently requires (i.e., the intrinsic load); the way the instructor organizes and teaches the content (i.e., the extrinsic load); and the schemata the mental activity demands(i.e., the germane load) (Swelleret al., 2011).

Warm-up activities are assumed to minimize extrinsic load (EL), manage the intrinsic load (IL), and foster the germane load (GL), as they help learners free the capacity of the WMand thus experience a less tedious reading task (Sayyadi et al., 2022).Putting this more precisely, warm-up activities essentially tap prior knowledge that as one characteristic of the subjects-along with task characteristics and the interaction of task and subject- constitute the causal factor of the cognitive load (Paas et al., 1994). More background knowledge is associated with a lower cognitive load as more WM resources are at the disposal of the student for information processing (Mihalca et al., 2011). Students with higher background knowledge and lower cognitive load are more engaged in learning tasks (Dong et al., 2020) and can form new schemata more easily (Myhill & Brackley, 2004).

Based on cognitive load theory, the reason for this association is that IL is caused by element interactivity, or the number of new elements that should be processed by WM in doing a task or learning something (Sweller et al., 2011). Element interactivity has a positive association with IL and a negative association with prior knowledge, as prior knowledge helps learners manage the number of elements that should be processed in the WM. As for EL, which is generated as a result of instructional design, a negative association between incorporating warmup activities and EL is expected to be observed. Activating prior knowledge through warmup activities adds to the efficiency of the instruction because in this way two principles of pre-training and segmenting are applied in instruction which lowers the extraneous processing load. Conversely, GL, as a function of learners’ cognitive resources that can be brought to the task, is not directly related to the complexity or simplicity of the tasks but is associated with other cognitive resources that can impact learning gains (Schnotz& Kürschner, 2007). In this sense, high GL as a result of expertise in a topic/subject “helps to redistribute resources from extraneous processes to deal with the intrinsic load” (Endres et al., 2023, p. 306).

Despite the existence of this strong theoretical support, the effectiveness of pre-reading activities on reading comprehension and its associated cognitive load particularly in CBLIis open to further research.

Problem Situation

In the last decade, high school students' interest in STEAM fields of study, particularly science, and engineering, has significantly declined in Iran. As statistics show,seats of these majors are not filled in many universities and the country may face a crisis in jobs related to STEAM in the near future (Karbalaee, 2022). Urgent and immediate action from the policymakers and statesmen is required to integrate the STEAM curriculum into primary and secondary education to make students interested in these subjects.

The only school subject that has integrated STEAM topics into the curriculum in the country is the EFL program, as thenew series of textbooks for high schoolshave been authored based on CBLI. Vision Series (Alavi Moghaddam et al., 2018) exploits STEAM topics, and many texts and passages of the books are linked to STEAM domains. As the books utilize STEAM topics and passages for teaching reading, the cognitive load of their content, especially reading passagesis high for students who lack prior content knowledge (Sayyadi et al., 2022). As a result, using suitable techniques to activate the readers' background knowledge on topics can reduce the difficulty of reading passages that mainly revolve around STEAM topics. This would guarantee the success of the CBLI curriculum in reaching its goals and boosting students' interest in STEAM domains in the short term and encouraging the students to pursue STEAM careers in the future.

Purpose and Significance of the Study

The main purpose of the current study was to integrate STEAM activities into the pre-reading phase of teaching reading in a content-based instruction to examine their effects on reading comprehension and its associated cognitive load. As the passages of the textbook lack enough pre-reading activities,EFLstudents often cannot read them fluently and do not understand themwell. This makes reading comprehension in Englisha difficult task for high school students.

The study would give guidance to EFL teachers on the benefit of STEAM-based activities for students' success in language learning in general and reading comprehension in particular. This is especially enlightening for education policymakersand materials developers to plan for the integration of the STEAM approach in other curriculumsby selecting appropriate instructional content and pedagogical practices. The pedagogical value of the STEAM approach is unknown to many educators and teachers, especially in countries like Iran where the education of sciences and engineering fields is a major issue. In addition to the lack of Iranian high school students' interest in STEAM fields (Aligholi, 2022), their performance in international tests such as TIMSS is not satisfactory and their scores are below the scale centerpoint (500) both in mathematics and science (https://timss2019.org/reports). This shows that investment in STEAM education is a prime concern to boost students' motivation to select STEAM fields in secondary and tertiary education and later as their future jobs.

Empirical studies on integrated STEAM teaching would give useful insights to educators on how to implement STEAM pedagogy to not only promote learning outcomesin any school subject matter but also give awareness to students on the educational values of STEAM domains and their related professions. To help in resolving the issues of STEAM education in Iran, the current study aims to answer the following research questions:

1. Do STEAM-based pre-reading activities impact the development of reading comprehension?
2. Do STEAM-based pre-reading activities impact the management of the cognitive load of reading comprehension?

Method

Research Design

"Experimental design is the process of carrying out research in an objective and controlled fashion so that precision is maximized and specific conclusions can be drawn regarding a hypothesis statement" (Bell, 2009, p. 672). As the study aimed at establishing the effect of the independent variable (STEAM-based pre-reading activities) on the dependent variable (reading comprehension and cognitive load), the pre-test-post-test control group design was used. The participants were divided into two groups randomly,and their reading comprehension and its associated cognitive load were examined before and after the instruction. The schematic representation of the design is shown below:

G1 Q1 T1 X T2 Q2

G2 Q1 T1 O T2 Q2

Where:

G1 stands for the experimental group

G2 stands for the control group

T1 stands for reading pre-test

Q1 stands for cognitive load scale pre-test

X stands for the treatment

O stands for no treatment

T2 stands for reading post-test

Q2 stands for cognitive load scale post-test

Participants

Sixty female students who were studying in grade 10 of secondary public high school took part in the study. Their major was sciences. The age range of the sample was 16-17 years old. The participantswere dividedrandomly intotwo groups; the experimental group and the controlgroup. Both groups had 30 students each.

The students' first language was Persian and none attended any other English courseswhen the research was in progress. English is a foreign language in Iran and it is not the medium of instruction or an administrative language of the country.

Data Collection Tools

In this research, two research instruments (one test and one scale) along with pre-reading activities were used to gather the required data. The details of the instrumentation are explained below.

A2 Key Test: The A2 Key test was used to assess the participants' reading comprehension before and after the study. The A2 Key test is targeted at Level A2 on the Common European Framework of Reference (CEFR) and is the second test of English proficiency(above A1 and below B1) developed by Cambridge Assessment English (Cambridge English Qualifications, A2 Key, 2020). A2 Key test evaluates the participants' English proficiency and competence in reading, writing, listening, and speaking skills.The test assesses the candidates on each skill and gives both independent scores for each skill and an overall English proficiency score.A2 Key was used in this study because based on the EFL curriculum of Iran, the students who leave grade 10 should reach A2 level proficiency based on CEFR.

In this study, the reading module was used to assess students' reading comprehension ability.The administration time for A2 Key reading was 40 minutes. The A2 Key reading module has 30 questions organized into five parts:

- Reading six short real-world texts (6 questions)
- Reading seven questions and three short texts (7 questions)
- Reading one long text (5 questions)
- Reading a factual text (6 questions)
- Reading and completing an open cloze (6 questions)

NASA Task Load Index: The NASA Task Load Index (TLX) was used to measure workload in activation (Hart, 2006) of reading comprehension. The NASA-TLX is a popular self-reported instrument for measuring workload. It is a multi-dimensional scale and has six subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. The main assumption behind the scale is that the combination of these 6 subscales presents the overall workload experienced by the participants (Hart, 2006).

Pre-reading activities: The main textbook of the course was Vision 1 (Alavi Moghaddam et al., 2018). All pre-reading activities were designed and performed based on the lessons of this book and the topics of the reading passages considering the integrative model of STEAM, where at least two or more domains were worked on. The details of Vision 1 lessons and the designed activities for the experimental group are summarized in Table 1. The STEAM-based materials were prepared by the researchers before the study. Two experienced teachers reviewed the materials for their suitability for the linguistic and cognitive difficulty. Based on their suggestions, some changes and revisions were made to the materials.

For the control group, the pre-reading activities of the textbook were used. The pre-reading section of the book is labeled 'Get Ready' which makes students familiar with the

theme of the lesson and some linguistic features of the passage such as grammatical points and vocabulary items.

Table 1

Reading Topics and Content for the Experimental Group Based on Vision 1

Lesson	Theme of the lesson	Title of the passage	Content of the passage	STEAM domains in focus	Types of pre-reading activities
1	Saving Nature	Endangered animals	Scientific issues regarding endangered animals and the plans to protect them	Science Technology	Video clips: Scientific facts (numbers, graphs, images, …) Worksheets: Introducing technological devices and strategies
2	Wonders of Creation	A Wonderful Liquid	Scientific issues about blood and details about its features	Science Technology Mathematics	Video clips: Science of imitating models and systems of nature Worksheet: Technological devices
3	Value of Knowledge	No Pain No Gain	Description of the scientists' difficult lives and hard work	Science Mathematics Engineering	Video Clips: Introducing devices and equipment Worksheets: explaining mathematics in life
4	Traveling the World	Iran: A True Paradise	Details of Iran and its tourist attraction	Arts Engineering	Video clips: Architecture tourist attractions Worksheets: Describing artists and their styles

Data Collection Process

Research procedure

First, the researcher selected 60 participantsbased on convenience sampling and put them randomly in two groupswith 30 students in each. Both groups participated in the A2 Key test and completed NASA TLX regarding its cognitive load before the study.

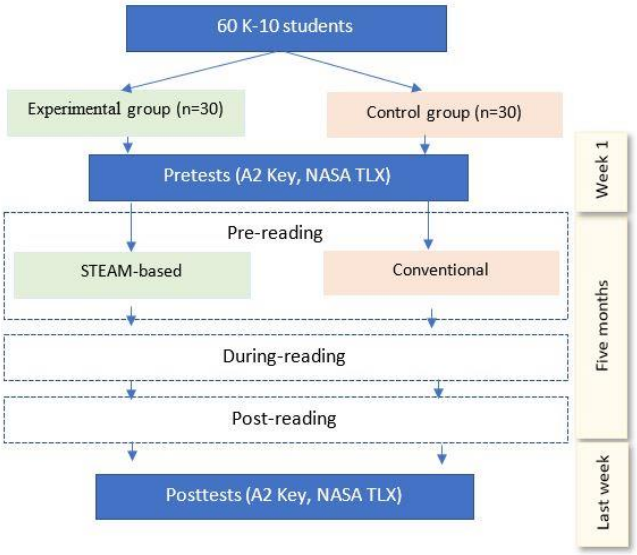
Then the instruction began. For the experimental group, STEAM-based pre-reading activities were used. STEAM-based pre-reading activities included video clips, animations,and worksheets designed in accordance with the theme of the lessons and readings of Vison1 by the researchers (Table 1). The control group was instructed conventionally using the pre-reading activities of the textbook. The length of the instruction, the textbook, and the teacher

of both groups were the same (Fig. 1). The class consisted of two 60-minute sessions per week. The whole experiment lasted for five months.

At the end of the course, and after the instruction, the A2 Key test and NASA TLX were administered again. The data were entered into SPSS 23 and were analyzed by suitabletechniques. Results were then interpreted and discussed.

Figure 1

Research Procedure



Instructional procedure

The Experimental Group: The experimental group received instruction based on a three-cycle of pre-during-post reading approach. In the pre-reading part, the students were exposed to STEAM-based activities. There are six steps to run a class based on STEAMpedagogy as follows (Riley, 2016)

1. Focus: First the teacher selects a question or problem that is linked to the STEAM domains to work on.

2. Detail: The teacher thinks of components of the problem/question. The studentsnotice the links and associations within or between the fields and initiate to use their knowledge and skills to solve the problem.

3. Discovery: The students begin discovering what solutions are available or not working.

4. Application: The students suggest their solutions and explanations based on what was worked on in stage 3, ‘Discovery’.

5. Presentation: After creating the solutions, they are shared with others to gain feedback.

6. Link: The students reflect on what was presented and have the opportunity to rework their solution and suggest another one.

After taking these steps, the teacher taught the reading passage, and post-reading activities were done.

The Control Group: The control group was taught based on a three-cycle of pre-during-post readingstrategy as well. The instruction differed from the experimental group in terms of the types of pre-reding activities that were mainly the tasks of the textbook. This included introducing the theme of the lesson and the topic of the passage and doing warm-up activities (Get Ready). Following that, the students read the text and did post-reading activities.

Data Analysis

Descriptive statistics, Multivariate Analysis of Variance (MANOVA), Multivariate Analysis of Covariance (MANCOVA), andindependent samples *t*-tests were utilized to analyze the collected data.

The descriptive statistics included the mean, standard deviation, and range of the scores.The missing data and normality of the distribution of scores were also checked (Pallant, 2020).To check the participants' entry level of reading comprehension and cognitive load, an independent samples *t*-test and MANOVA were used.

To answer research question 1, anindependent samples *t*-test was used. *T*-test is used for comparing the mean values of two independent groups to detect a significant difference between them. To answer research question 2, MANCOVA was used. MANCOVA was run to examine both groups' cognitive load of reading comprehension after the experiment by neutralizing the effect of pre-test scores of NASA TLX. The mentioned analyses were done using SPSS 23.

Validity and Reliability

NASA TLX has been used with Iranian participants and has shown suitable reliability (Sayyadi et al., 2022). The A2 Key test has also been used with Persian speakers of English in Iranian high schoolsand has shown good validity and internal consistency (Rahimi et al., 2022).

Table 2

Reliability of A2 Key and NASA TLX

Administration	Instruments	Cronbach's alpha
Pre-test	A2 Key	0.86
	NASA TLX	0.81
Post-test	A2 Key	0.91
	NASA TLX	0.92

The reliability indices of the instruments were estimated in this study by Cronbach's alpha and KR-21 for both pre-tests and post-tests (Table 2).

Ethical Issues

The students and their parents were informed of the aims and process of the research.The permit to carryout this research was first obtained from the Review Board of the Faculty of Humanities at Shahid Rajaee Teacher Training University dated24.6.2020and numbered 25332. The permit was also obtained from the Graduate Office Review Board at Shahid Rajaee Teacher Training University dated 20.09.2020 and numbered 25332. This study had no funding and conflict of interest.

Findings

The goal of the study was to explore the effects of STEAM-based pre-reading activities on the development of reading comprehension and managing its associated cognitive load. Before answering the two research questions, the results of the pre-test data analysis will be presented.

An independent samples *t*-test was run to examine both groups' reading comprehension before the experiment (Table 3).

Table 3

The Result of t-Test on A2 Key Pre-test Scores across Groups

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.		df	Sig.	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	6.339	0.015	-0.402	58	0.689	-0.600	1.493	-3.588	2.388
Equal variances not assumed			-0.402	51.890	0.689	-0.600	1.493	-3.596	2.396

As Table 3 shows, before the study, both groups' reading comprehension was at the same level [t (58) =-0.402, p=0.689>0.01).

A one-way analysis of variance (MANOVA) was run to examine both groups' cognitive load of reading comprehension before the experiment. The result of MANOVA (Table 4) illustrated thatthe participants' cognitive load of reading comprehension was not the same (Wilks' Lambda=0.624, F=5.321, p=0.000<0.01)before the study. Therefore, this difference would be neutralized in the post-test data analysis by considering the pre-test scores as the covariate.

Table 4

The Results of Multivariate Tests on NASA TLX Pre-test Scores Across Groups

	Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Group	Pillai's Trace	0.376	5.321	6.000	53.000	0.000	0.376
	Wilks' Lambda	0.624	5.321	6.000	53.000	0.000	0.376
	Hotelling's Trace	0.602	5.321	6.000	53.000	0.000	0.376
	Roy's Largest Root	0.602	5.321	6.000	53.000	0.000	0.376

Research question 1: Do STEAM-based pre-reading activities impact the development of reading comprehension?

To compare the two groups' performance on the A2 Key test, another independent samples *t*-test was used.

Table 5

The Results of an Independent Samples Test on A2 Key Post-test ScoresAcross Groups

	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	13.517	0.001	-3.728	58	0.000	-4.033	1.082	-6.199	-1.868
Equal variances not assumed			-3.728	44.521	0.001	-4.033	1.082	-6.213	-1.854

As Table 5 shows, the two groups' reading comprehension was significantly different after the study [t (58) = -3.728, p=0.001>0.01). Based on Table 6, the experimental group outperformed (M= 24.63, SD= 2.810) the control group (M= 20.60, SD= 5.217) in A2 Key post-test.

Table 6

Descriptive Statistics of A2 KeyReading Post-test Scores

Group	N	Mean	SD
Control	30	20.60	5.217
Experimental	30	24.63	2.810

Research question 2: Do STEAM-based pre-reading activities impact the management of the cognitive load of reading comprehension?

To compare the cognitive load of reading comprehension after the experiment, MANCOVA method was used. The NASA TLX pre-test scores wereregarded as the covariate to neutralize the differences between the groups observed in the pre-test. First, the assumptions of MANCOVA, i.e., normality, test of multicollinearity, homogeneity of regression slope, and homogeneity of variance-covariance matrices (Pallant, 2020) were tested. As the assumptions were not violated, the main MANCOVA was performed (Table7).

Table 7

Multivariate Tests on NASA TLX Post-test Scores across Groups

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Group	Pillai's Trace	0.406	5.236	6.000	46.000	0.000	0.406
	Wilks' Lambda	0.594	5.236	6.000	46.000	0.000	0.406
	Hotelling's Trace	0.683	5.236	6.000	46.000	0.000	0.406
	Roy's Largest Root	0.683	5.236	6.000	46.000	0.000	0.406

As Table 7 displays, the two groups' general cognitive load is statistically different after the study [Wilks' Lambda=0.594; F(2, 55)= 5.236, p=0.000; η_p^2=0.406]. Now, by taking the Tests of between-subjects effects into account, the dependent variables, i.e., post-test scores of six sections of NASA TLX, would be compared across groups independently (Table 8). It should be noted that to reduce the chance of a Type 1 error (i.e., finding a significant result when there is not really one), a higher alpha level by applying Bonferroni adjustment was set. As six separate analyses were considered here, the original alpha level of 0.05 was divided by 6, and thus a new alpha level of 0.008 was gained.

Based on Table 8, there are statistically significant differences between the two groups' post-test scores in Mental Demand (F= 18.485, p=0.000<0.008), Physical Demand (F= 11.612, p=0.001<0.008), and Frustration (F= 11.267, p=0.001<0.008).The descriptive statistics (Table 9) show that the experimental group's mean values in Mental Demand, Physical Demand, and Frustration are lower than those of the control group.

Table 8

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Group	Mental Demand	144.446	1	144.446	18.485	0.000*	0.266
	Physical Demand	94.895	1	94.895	11.612	0.001*	0.185
	Temporal Demand	76.644	1	76.644	3.845	0.055	0.070
	Performance	70.520	1	70.520	5.185	0.027	0.092
	Effort	19.710	1	19.710	1.199	0.279	0.023
	Frustration	133.075	1	133.075	11.267	0.001*	0.181

* p<.008

This indicates that the experiment had a considerable effect on reducing the mental effort that was required to read and understand the STEAM content. In other words, activating the prior knowledge of STEAM themes made comprehension of the passages easier for the students. Moreover, the reading task became less strenuous when students became familiar with the topics of the passages and thus they felt that reading was not as laborious and hard as it was before the study. Also, activating their schemata made them experience less annoyance, irritation, and stress when they were reading the passages on STEAM topics.

Table 9

Descriptive Statistics of NASA TLX Post-test Scores for Both Groups

Parts	Group	Mean	Std. Deviation
Mental Demand	Control	14.28	2.711
	Experimental	8.30	4.721
Physical Demand	Control	11.41	3.077
	Experimental	5.77	3.626
Frustration	Control	12.03	3.794
	Experimental	6.17	3.779

Conclusion, Discussion, and Implications

The benefit of integrating the STEAM approach into secondary education for the national and international labour market is undeniable. In countries like Iran where STEAM fields are not gaining enough attention in secondary and tertiary education, combining STEAM pedagogy with other attractive school subjects such as foreign languagesbecomes extremely important. Disappointingly, research on this issue is scarce and just a few studies have probed into the benefits of CBLI in arousing students' enthusiasm for STEAM fields. As a result, this study was planned and performedwith the goal of yielding more insight intothe advantages of incorporating STEAM warm-up activities into reading instruction to make reading comprehension less tedious and more fruitful.

The findings of the study display that STEAM pre-reading tasks can contribute to the development of reading comprehension in an EFL reading class. It is known that pre-reading activities decrease the uncertainty the students bring to the task of reading texts (Vacca & Vacca, 1989) and help students bridge their previous knowledge and the new information they find in the text (Ajideh, 2006). In this way, the reading task becomes purposeful and engaging and readers feel more motivated to sustain the reading and comprehend the passage. Warm-up activities are designed on the grounds that they can familiarize students with the topic of the text and the language elements they will discover, thereby facilitating future understanding.

Pre-reading on its own hasevidently an impact on reading comprehension(Madaoui, 2013), but as the findings of this study show, comprehension is enhanced when warm-up activities are made based on STEAM education. STEAM approach strengthens curiosity and enthusiasm in STEAM domains by letting students spot their competencies and skills as well as their artistry. However, this desire to acquire STEAM content is dependent on students' understanding of the themes and relating them to their own preferences and needs. When

students are well introduced to each topic, they can understand technical concepts and terms and this science literacy assists them in processing and synthesizing the passage more successfully (Neri et al., 2021). When readers lack the required linguistic knowledge such as lexical items or grammatical structures to read a text,they process the text in a bottom-up manner rather than in a top-down manner, and thus they cannot fully comprehend the text (Alptekin & Erçetin, 2009).

Moreover, the STEAM pre-reading activities help students apply more reading strategies and make them active and responsive readers. In this way, global reading strategies such as setting a purpose for reading, previewing text content, and predicting what the text is about (Mokhtari & Sheorey, 2002) through pre-reading activities are modelled, practiced, and deployed. The deployment of reading strategies has a direct link with reading comprehension and can lead to a more concerted effort from the side of the reader to read the text no matter how difficult it seems to be (Mokhtari et al., 2018).

The findings of the study also showed that STEAM pre-reading activities could lower the cognitive load of reading and let students experience less mental and physical pressureas well as frustration while reading the text. This is in agreement with previous research, particularly in the EFL context, that suitable warm-up activities can lower the cognitive load of comprehension tasks (Sayyadi et al., 2022). When the cognitive load reduces, the WM can allot more resources to process the input. As for reading, a positive association between reading and WM in both L1 (Peng et al., 2018) and L2 (Chow et al., 2021) has been reported, meaning that the higher the WM capacity, the better the comprehension ability of the readers (Daneman & Hannon, 2007).It is known that learning outcomes of the implementation of STEAM activities and their effect on learning performance depend on the cognitive load of the task (Wu et al., 2022). In this regard, reading activities assist students in gathering the information they need to accurately comprehend the problems in STEAM courses (Sun & Zhong, 2023).

In the case of this study, STEAM-based pre-reading activitiescould increase students' innovation and make the pre-reading activity more operational by connecting the previous knowledge and the new information presented in the text (Taylor, 2016). Since pre-reading activities promote problem-solving and logical thinking, learners can predict the concepts of the coming text and this actually makes them ready for the challenges in reading comprehension. In this way, the anxiety about reading declines, and thus students become more engaged in reading tasks. Reading anxiety is a predictor of reading comprehension (Chow et al., 2021) and can affect readers' WM resources and consequently comprehension because the volume of information that can be retained would become limited if the readers have reading anxiety (Eysenck et al., 2007).

In agreement with a few previous studies, the outcomes of the study generally support the association between reading comprehension and students' problem-solving skills and performance in STEAM programs. Fang and Wei (2010), for instance, reported that school students who spend more time reading books perform better in both reading and scientific subjects than those who do not in STEAM learning. Similarly, Duo-Terron et al. (2022) showed that STEAM teaching can increase problem-solving skills which itself has a positive association with reading comprehension. The reason lies in the fact that reading is a basic task for enhancing students' cognitive capacity, learning outcomes, and educational attainments (Ritchie et al., 2015). Reading culture can improve technological problem-solving (Evans et

al., 2015) and the creation of innovative ideas and inquiry-based required in STEM programs (Pearsonet al., 2010).

The findings of the study should be interpreted considering the limitations the researchers encountered while performing the research. First and foremost, the number of participants was limited to 60 female students, and due to practicality issues larger sample and boys could not be included in the design of the study. Recruiting participants of different backgrounds is recommended for future studies. Due to time limitations, the study utilized an experimental design and analyzed quantitative data, while observations were not carried out and qualitative data were not gathered. Follow-up studies are urged to perform mixed methods research and triangulate the quantitative data with the qualitative ones to shed light on the findings of the current study. Last but not least, this study was done in public schools and students of private schools did not take part in the study. Future studies are recommended to widen the context of research and include participants from both private schools and language institutes.

The study contributes to the literature in three ways. First, it illustrates that the STEAM approach can play a great role in language education if it is suitably merged with the pedagogical trends of language teaching and learning. Second, it displays that warm-up activities are valuable for increasing language learners' comprehension and lowering their associated cognitive load. Third, it affirms that the integrated STEAM approach can affect readers' both cognition and emotion and by increasing the capacity of their WM pave the way for more joyous and less threatening reading experiences.

The study offers two practical implications for the Ministry of Education. First, policymakers should pay special attention to integrated STEAM by revising the current curriculum of secondary education in Iran. Second, in-service teacher training courses should be held for teachers to increase their awareness of the STEAM approach and how it is combined with other school subjects.

Contribution Rate of the Researchers

Author 1 collected the data and helped in writing the manuscript. Author 2 conceptualized, supervised, and guided the study; she wrote, edited,and revised the manuscript.

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Statement of Conflict of Interest

There is no conflict of interest to disclose.

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