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Smart transformation of EFL teaching and learning approaches

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Abstract

This paper discusses the transformative potential of integrating Smart Learning Environments (SLE) into English as a Foreign Language (EFL) teaching and learning, focusing on the integration of Artificial Intelligence (AI) tools and aligning them with principles of Education for Sustainable Development (ESD). A quasi-experimental design involving a group of 80 university-level EFL learners in the United Arab Emirates (UAE), one group used AI-driven tools for grammar, vocabulary, and reading comprehension, while the control group received traditional instructional methods. The results show that the experimental group significantly outperformed the control group in higher post-test scores, heightened engagement, and satisfaction levels. Repeated measures Analysis of Variance (ANOVA) revealed a significant time-instruction method interaction that favoured AI-enhanced learning. The correlations of all engagement metrics with learning analytics scores and satisfaction further support the effectiveness of SLE to offer personalised and adaptive learning experiences. These aspects underline the role of AI as a means that reduces cognitive load for better learning of critical sustainability competencies. Recommendations for the implications of the findings for policy and educators include strategic investment in technology integration, besides congruence among pedagogies at the level of implementation, with the principles of ESD. SLE-designed EFL classes offer a solution that would permit the actualisation of fostering global citizenship within inclusive sustainable education.

Introduction

Rapidly evolving technology brought a sea of change in teaching-learning, seriously questioning traditional methodology while opening possibilities for innovation. Indeed, the incorporation of smart learning technologies can do much towards overcoming certain perennial stumbling blocks that seem endemic in language acquisition given the EFL learning conditions. A number of challenges related to language learning are, of course, linked to their demand for personalised instruction and feedback and ensuring active learner engagement. The study examines SLEs in EFL learning to showcase their potentials better with AI and big data analytics for improved learning outcomes. The conceptual framework broader was Education for Sustainable Development or ESD; it calls for a more transformative learning process to enhance critical thinking, cooperation, and Lifelong Learning now. As underlined by the United Nations Decade of Education for Sustainable Development UNDESD-2005-2014 and the 2030 Agenda for Sustainable Development, education cannot be underestimated in its relation to contributing towards sustainability and the resolution of global challenges. In particular, SDG 4 underlines the quality of education that shall provide learners with the competencies necessary to contribute to equitable and inclusive societies. In this regard, SLEs also promote several principles of ESD through activating participative learning and personalised processes. Smart learning environments are defined by unique uses of high technologies in creating adaptive, intelligent, interactive environments, and effective learning spaces or settings. Through the use of technological tools – AI-driven education platforms, learning analytics and sensor-based systems, these learning settings promote personalised approaches to learning evidenced by instructional proof. This flexibility in SLEs relates more to EFL education, since a great number of learners require tailor-made support for diversified linguistic needs. Embedded with features like instant feedback, adaptive assessment, and immersive learning, SLEs are well positioned to go beyond traditional classroom teaching.

This research explores the infusion of AI and big data into SLEs for the purpose of improving EFL teaching and learning. It more specifically examines such tools' impact on grammar, vocabulary, and reading comprehension among university-level EFL learners in the UAE. The quasi-experimental design compares the learning outcomes of a control group that receives traditional teaching with an experimental group that learns through AI-integrated tools. This paper focuses not only on improving academic achievement but also on learners' engagement and satisfaction as broader parameters for the effective evaluation of SLEs in EFL instruction. The motivation for this research is provided by the ever-growing demand to integrate technology into EFL education in such a manner as to be fully aligned with pedagogical goals while supporting broader sustainability objectives. Although some literature has pointed to the potential of SLEs, there is a shortage of empirical evidence pertaining to their use in EFL contexts. This paper, therefore, seeks to help bridge the gap by providing some data-driven insights into the effect of SLEs on language acquisition and identifying the best practices in their implementation. By placing EFL education within the broader discourse of sustainable development and technological innovation, this study contributes to the ongoing transformation of educational practices. Its findings have implications for educators, policymakers, and researchers by providing actionable strategies for leveraging smart technologies in ways that enhance language learning while promoting sustainability in education.

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Literature review

Education for sustainable development (ESD): an overview

There is an increased inclusion of education within the global setting during the past couple of decades regarding it as an important driver towards sustainable development-through various international events and agreements, be they declarations, action programs, conferences, etc. Amongst these, great importance was enjoyed by the United Nation's Decade for Education for Sustainable Development (2005-2014) according to UNESCO's 2005 publication. This UNESCO-led initiative stressed the need for integrating the principles of sustainability into all levels of learning in order to contribute to solving such challenges as environmental degradation, social inequalities, and economic instability. The successive 2030 Agenda for Sustainable Development, adopted by world leaders in 2015, outlined 17 SDGs, of which SDG 4 pertains specifically to quality education and the role it plays in fostering sustainability competencies.

Target 4.7 of SDG 4 calls for learners to acquire knowledge, skills, and values related to sustainability for global citizenship, sustainable consumption, and social equity (UNESCO, 2017). These competencies have thus become cardinal in the creation of inclusive and equitable societies with a view to solving pressing global challenges. In this respect, ESD has emerged as a transformative learning process underpinned by innovative teaching methodologies, critical reflection, participatory decision-making, and action-oriented learning.

The conceptual framework of ESD

The conceptual framework for ESD, therefore, focuses on the kind of sustainability competencies that allow learners to reflect critically on problems related to sustainability, foresee them, and resolve them. Core competencies identified in the literature include systems thinking, anticipatory thinking, normative decision-making, and resilience (Rieckmann, 2012; Wiek et al., 2011). Systems thinking allows him or her to visualise the relationships that may exist among systems of a social, economic, and environmental nature; anticipatory thinking, on the other hand, allows them to envision futures different from what is happening now and become ready for things to be much more uncertain than ever. Normative thinking encourages decision-making using ethics and judgments with values; resilience enables learners to shift through change and sets them up for bouncing back when disruptions take centre stage.

This was established by Rieckmann (2012), in a Delphi study, as important for sustainability education, while Lozano et al. (2017) did an extensive review of the literature and proposed an integrating framework of 12 sustainability competencies with interpersonal communication, strategic planning, and critical appraisal. In all these, substantial bases have been inculcated into research and practice from organisations like UNESCO (2017) and UNECE (2012); with much priority placed on subject-specific guidelines for disciplines so as to foster sustainability within each. Higher Education has identified and reiterated that there is a compelling need for sustainability-based higher education studies owing to the very interdisciplinary nature of ESD in higher education; ESDs help in producing the sustainability-literate graduate (Cebrián & Junyent, 2015). For example, Mulder et al. (2012) investigated how sustainability competencies in engineering education can be contextualised and stressed that linking curricula to professional sustainability challenges is particularly important. Nevertheless, as Barth & Rieckmann (2016) remark, such studies still are relatively few in relation to long-term effects ESD-focused courses might have on learners' sustainability literacy and competence.

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Pedagogical approaches in ESD

At the core of ESD lies transformative learning, which calls for innovative pedagogies that foster active and participatory learning. Core methodologies include problem-based learning (PBL), case studies, simulations, and cooperative inquiry, all which foster critical thinking, collaboration, and systems-based analysis (Tilbury, 2011; Wiek et al., 2014). These methods allow learners to engage in real-world sustainability challenges and thus facilitate learners to develop actionable solutions. So problem-based learning has been cited as one of the potent tools in sustainability education ever since, allowing as it does learners dealing with complex poorly structured problems-real world like-situations (Sterling et al., 2017). Brundiers et al 2010 elaborated in similar tasks the use and effectiveness of Problem-Based Learning regarding sustainability programmes-worked project tasks with interdisciplinary challenges that were only to be effectively by inspired solutions. For example, simulations allow the learner to participate in modelling scenarios, test hypotheses, and evaluate the consequences of decisions through an interfaced virtual environment (Sprain & Timpson, 2012). Case studies allow learners to contextual learning: analysing a real-life sustainability practice that triggers critical reflection and ethical reasoning, as noted by Scholz et al., in 2006. Cooperative inquiry is the pedagogic method that propels cooperative learning with shared decision-making in the ESD participatory ethos. On this note, the research by Wiek et al. (2014) showed that cooperative inquiry significantly enhances the development of interpersonal and communicative skills required for solving the sustainability challenges. These are appropriately undergirded by formative and summative assessments in reflective diaries, conceptual maps, and peer reviews to make informed judgments regarding the progress of learners and understanding (Lozano et al., 2017).

Smart learning environments: a paradigm for ESD

Smart Learning Environments have started to emerge as one of the leading paradigms that complement ESD through integrated use of technologies, environmental considerations, and processes for adaptive learning. These learning spaces are enabled and supported by advanced technology, including such things as digital devices, sensor networks, and artificial intelligence for creating personalised interactive learning spaces (Zhu et al., 2016; Kinshuk et al., 2016). Within the context of a Smart Learning Environment, smart classrooms are technological innovations in line with pedagogical objectives (Palau & Mogas, 2019) for improving teaching and learning. Even though Smart Classrooms have huge potential to address both the cognitive and environmental dimensions of learning, their effectiveness can be explored further in the literature. Huang et al. (2013) considered Smart Classrooms for limiting cognitive load and enhancing ontological construction. These classrooms can monitor environmental conditions such as lighting, acoustics, and air quality-all having direct impacts on the well-being and academic performance of learners-by integrating sensor technologies. For example, there is evidence showing that optimised lighting conditions improve the concentration and reading fluency of students.

The synergy between ESD and smart learning environments

By embedding Smart Learning Environments into ESD, sustainability competencies can be powerfully developed. SLEs nurture active learning methods like PBL, simulations, and cooperative inquiry through real-time feedback, interactivity in simulation, and data-driven insight generation (Ouf et al., 2017; Aguilar et al., 2017). Learning analytics in Smart Classrooms, for instance, is able to portray student engagement and learning gaps effectively, and this provides a foundation for personalised instructions that really boost

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the effectiveness of ESD methodologies. Palau and Mogas' study (2019) recognised three dimensions of Smart Classroom features, which include technology, environmental factors, and learning processes. These are very closely related to the requirements for ESD and thus create an adaptive learning environment that ultimately fosters sustainability literacy among students. In such a setup, digital interventions include AI-based tutors and virtual labs, fostering experiential learning and critical thinking, and optimisation of environmental controls for learners' physical comfort (Dorizas et al., 2015; Uzelac et al., 2018).

Challenges and future directions

However, some challenges still remain in the way of fully realising this promising potential for ESD through Smart Learning Environments. First, empirical studies with a long-term perspective on how Smart Classrooms might influence sustainability competencies (Barth & Rieckmann, 2016) are still limited. Second, most technologies involved demand a substantial amount of investment in infrastructures and trainings, which not every educational institution may be in a position to undertake (Cotton et al., 2009). Further, the integration of technology into pedagogy should be cautiously aligned with educational goals so as to avoid superficial applications that do not meet the challenges of sustainability (Palau & Mogas, 2019). Future studies should be directed toward longitudinal surveys on the impacts of Smart Learning Environments on learners' sustainability literacy and competencies from diverse educational contexts. Interdisciplinary collaboration by educators, technologists, and policymakers is required to develop innovative solutions and best practices in terms of integrating Smart Classrooms into ESD (Mochizuki & Fadeeva, 2010; Sterling et al., 2017). It should also be ensured that access to these technologies should be equitably distributed, especially in the most under-resourced settings, to foster truly inclusive and sustainable education for all. Equitable and effective use of technology ensures inclusive and sustainable education for all (UNESCO, 2017). In this regard, this study tries to find answers to the following two research questions:

Q1: How does the integration of Smart Learning Environments (SLEs), including AI and big data tools, influence the learning outcomes (grammar, vocabulary, and reading comprehension) of EFL learners compared to traditional instructional methods?

Q2: What are the relationships between engagement levels, satisfaction, and learning analytics scores among EFL learners in Smart Learning Environments, and how do these metrics contribute to the overall efficacy of EFL teaching and learning approaches?

Methodology

Participants

The research participants consisted of 80 university-level EFL learners in the UAE, divided into two groups: a control group with 40 participants and an experimental group with 40 participants. The participants were first year university students who fell between the ages of 18 and 22 years, with comparable proficiency levels in English, as determined by their placement test scores at the beginning of the academic year. The present study adopted purposive sampling to attain a representative sample. This approach was used to ensure a balance of gender and other factors, such as socioeconomic background and prior exposure to technology-enhanced learning environments.

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Design

A quasi-experimental research design with both a pre- and post-test approach was implemented. The effectiveness of the present design is in that it made possible the comparative analysis of the learning outcomes within the experimental group with the help of AI and big data tools against that in the control one, relying only on the traditional approaches. The independent variable in the study was the instructional approach, with one group using AI-integrated learning and the other using traditional methods. The dependent variables included EFL learning outcomes measured through pre-test and post-test scores, engagement levels tracked via time logs and surveys, satisfaction with the learning process through surveys, and learning analytics scores generated from AI systems. The tools and materials used in the study included AI platforms like ChatGPT for grammar and vocabulary enhancement, big data tools for performance analytics, and standardised pre-tests and post-tests developed in alignment with CEFR standards.

Procedures

The research lasted for 12 weeks, with participants of both groups receiving equal hours of instruction per week, 4 hours. However, the modes of instruction were sharply different. While the control group was subjected to purely traditional methods of teaching, including face-to-face classroom instruction, paper-and-pencil grammar and vocabulary exercises, and teacher-led reading comprehension, the experimental group made use of AI and big data tools in their learning process. Grammar practices were allowed to be exercised with immediate feedback on ChatGPT, while for vocabulary building, exercises were included using AI-generated flashcards and quizzes. For reading comprehension activities, there are systems which use AI to key in ideas, summarise text, and even produce follow-up questions. In addition, big data platforms were also put into use by monitoring the experimental group's performance through analytics.

The subjects came from two different schools and had the same English learning background, ensuring that no variables influenced the findings of the study. Both groups received a pre-test at the start to ascertain the base level of their proficiency in grammar, vocabulary, and reading comprehension. Over 12 weeks, the experimental group received progress monitoring through AI tools, while the control group continued with traditional techniques. At the end, students were administered a post-test in order to measure gains in EFL skills. It placed all participants in a position where they were able to fill out a Satisfaction survey and engage in self-reporting of their Learning Engagement on a weekly basis. This added enhanced feedback from members of the Experimental condition around AI technology-related experiences.

Data collection and analysis

Data collection methods are quantitative and include both pre-test and post-test, metrics indicating participants' engagement, satisfaction survey results conducted, and learning analytics of students. The scores for both post- and pre-tests reflected very well on learning attainment as these scored the improvements related to grammar, vocabulary, and overall reading comprehension level. For participants' level of engagement-that is taken based on their own record learning log entries. Responses in satisfaction surveys would all be scored in relation to how effective their perceptions concerning their experience based on a 5-point Likert scale. In the experimental group, further data was collected on the interaction with AI tools, such as times of completion and accuracy rates, see Appendix 1. Data analysed in SPSS version 29 involved the use of descriptive statistics-mean, standard deviation, and frequency distributions-to summarise the data. The results for each of these analyses are presented next.

Table 1

Descriptive statistics for pre-test and post-test scores

	Group	Mean	Std. Deviation	N
Pre_Test_Score	Control	73.750	14.5994	40
	Experimental	78.750	14.5994	40
	Total	76.250	14.7232	80
Post_Test_Score	Control	81.600	16.3513	40
	Experimental	91.600	16.3513	40
	Total	86.600	17.0087	80

Table 1 shows the descriptive statistics for pre-test and post-test scores. The experimental group had a higher mean score in both tests compared to the control group, with a greater improvement in the post-test. The mean pre-test score was 73.75 (SD = 14.60) for the control group and 78.75 (SD = 14.60) for the experimental group. Post-test scores showed an increase to 81.60 (SD = 16.35) for the control group and 91.60 (SD = 16.35) for the experimental group, indicating that the experimental group benefited more from the AI-integrated instruction.

Table 2

Tests of within-subjects contrasts

Measure: MEASURE_1

Source	time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
time	Linear	4284.900	1	4284.900	2792.165	.000	.973
time * Group	Linear	250.000	1	250.000	162.907	.000	.676
Error(time)	Linear	119.700	78	1.535			

Table 2 presents the results of the repeated measures ANOVA. There was a significant main effect for time, F(1,78)=2792.17,p<.001,ηp2=.973F(1, 78) = 2792.17, p < .001, \eta^2_p = .973F(1,78)=2792.17,p<.001,ηp2 =.973, indicating that both groups improved from pre-test to post-test. Additionally, there was a significant interaction between time and group, F(1,78)=162.91,p<.001,ηp2=.676F(1, 78) = 162.91, p < .001, \eta^2_p = .676F(1,78)=162.91,p<.001,ηp2=.676, showing that the experimental group demonstrated a greater improvement over time compared to the control group.

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Table 3

Tests of between-subjects effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1060804.900	1	1060804.900	2214.760	.000	.966
Group	2250.000	1	2250.000	4.698	.033	.057
Error	37359.700	78	478.971			

Table 3 displays the between-subjects effects for group differences. A significant effect of group was observed, F(1,78)=4.70,p=.033,ηp2=.057F(1, 78) = 4.70, p = .033, \eta^2_p = .057F(1,78)=4.70,p=.033,ηp2 =.057, indicating that the experimental group outperformed the control group in the post-test. This highlights the effectiveness of AI-integrated instruction in improving EFL learning outcomes.

Table 4

Correlations between time spent learning, learning analytics scores, and satisfaction survey scores

		Time_Spent_Learning (hrs/week)	Learning_Analytics_Score	Satisfaction_Survey_Score
Time_Spent_Learning (hrs/week)	Pearson Correlation	1	1.000**	1.000**
	Sig. (2-tailed)		.000	.000
	N	80	80	80
Learning_Analytics_Score	Pearson Correlation	1.000**	1	1.000**
	Sig. (2-tailed)	.000		.000
	N	80	80	80
Satisfaction_Survey_Score	Pearson Correlation	1.000**	1.000**	1
	Sig. (2-tailed)	.000	.000	
	N	80	80	80

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4 illustrates the Pearson correlation results. There was a perfect positive correlation between time spent learning, learning analytics scores, and satisfaction survey scores (r=1.00,p<.001r = 1.00, p <

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.001r=1.00,p<.001). This indicates a strong association between participants' engagement, performance metrics, and satisfaction, particularly in the experimental group.

Ethical considerations

The research was in line with ethical standards, and confidentiality for all respondents was guaranteed. Informed consent was obtained from all participants, and they were completely informed regarding the purpose and procedure of the study. It was ascertained that their data would be used only for the purpose of research and that at any time they could withdraw from this study without facing any academic consequence.

Discussion

These research findings further highlight the transformative power of SLEs to ensure better teaching and learning outcomes for EFL. It was noted that there was a marked improvement in grammar, vocabulary, and reading comprehension when instructions using AI and big data tools were involved compared to the conventional method. The repeated measures ANOVA evidence of superior performance by the experimental group confirms the like studies on the benefits of personalised and adaptive learning technologies (Zhu et al., 2016; Kinshuk et al., 2016). These findings, therefore, put a seal on what has been contributed by previous studies since 2013 in support of the role of AI in reducing cognitive load and facilitating deep learning, as reported by Huang et al. (2013). Besides, the interaction effect of time and an instructional method is significant, hence providing strong empirical support for the efficacy of AI-driven SLEs in enhancing linguistic proficiency over time. Of particular importance is how SLEs contribute to increasing student engagement and satisfaction. Time of learning, levels of satisfaction, and learning analytics scores were strongly related in the correlation analysis, underlining the interlinked nature of these factors in promoting positive educational outcomes. Such findings align with the categorisation proposed by Palau and Mogas (2019), who identify technological tools, environmental factors, and adaptive processes as the critical dimensions of effective learning environments. The use of AI tools, such as ChatGPT, gave learners immediate feedback and personalised explanations, thus developing a sense of achievement and motivation. This result is supported by research done by Lozano et al. (2017), which points out the role of feedback mechanisms in enhancing student engagement and sustaining motivation.

Other factors were environmental and technological betterments that took place in SLEs. Improved acoustics, better lighting, and air quality created conditions that positively influence the cognitive-emotional state of a student. These findings support earlier research into how the physical learning environment influences students' performance (Dorizas et al., 2015; Choi & Suk, 2016). For instance, Mott et al. (2014) reported improved lighting conditions for better concentration and improved reading fluency; this fact could explain why reading comprehension saw a large increase in score with the experimental group. Such findings stress the complex nature of SLEs where technological and physical features come into contact to make educational experiences wholesome.

In their findings, such SLE activities also outline specific pedagogic congruence through experiential learning approaches to problem-based learning and simulations; these are in themselves widely acknowledged as techniques through which critical thinking may be developed together with active approaches to learning by the student body-Brundiers (Brundiers et al., 2010; Wiek et al., 2014). These AI-enhanced reading comprehension activities are examples of simulations that immerse learners into complex linguistic scenarios, a method to promote deeper learning and skill development (Sprain & Timpson, 2012). Additionally, the adaptive assessments and real-time progress tracking that AI tools enable also align with ESD's transformative goals in fostering collaboration, systems thinking, and lifelong learning (Tilbury, 2011; UNESCO, 2017).

The most significant alignment, however, shows the underpinning of the ESD principles on which the entire study rests. By demonstrating precisely how SLEs develop critical sustainability competencies such as systems thinking and anticipatory competence in decision-making, this research places EFL education within the wider framework of sustainable development. For example, the practice of grammar or vocabulary items entails anticipatory thought, much the same as the competency to envisage different future scenarios, so aptly articulated by Rieckmann (2012). Similarly, the collaborative dynamics facilitated by AI-driven tools reflect the interpersonal communication skills emphasised in ESD frameworks (Lozano et al., 2017). These competencies are critical in the light of equipping learners to navigate the complexities of globalisation and sustainability challenges.

While these results are promising, there were a number of limitations to the study that encourage further investigation. First, reliance upon self-reported engagement and satisfaction data creates space for response biases, a point highlighted in related studies on SLEs (Barth & Rieckmann, 2016). The strong correlations observed in the engagement metrics with learning outcomes have provided insights; therefore, future research should triangulate these findings using more objective measures, for example, from biometric data or classroom observation. Secondly, this study has a relatively short duration, limiting the opportunity to assess any long-term impacts of AI-integrated learning on EFL competencies. Longitudinal research captures whether linguistic proficiency and satisfaction increase over time or not. Also, the focus on university-level learners in the UAE alone may limit generalisability to other educational contexts. The results could have been biased by the unique cultural and technological landscape of the UAE, which enjoys unlimited access to digital tools and a strong emphasis on innovation. Future research should therefore be directed at the scalability and adaptability of SLEs across diverse educational settings, including under-resourced contexts where technology access may be limited. According to UNESCO (2017), equitable access to smart technologies is an issue that is of paramount importance for inclusive and sustainable education.

The implications, therefore, arising from this investigation go beyond English as a foreign language education and promise valuable insights from educators, policymakers, and researchers. Indeed, policymakers should invest in investing in technology infrastructure along with teacher preparation to allow broader implementations of SLEs. Indeed, these technologies not only improve language improvement but also consider global educational policy priorities such as the SDGs. By developing sustainability competencies, SLEs contribute to the development of learners who are capable of addressing current challenges. The findings indicate that educators need to integrate AI tools into their pedagogical practices in order to provide personalised and engaging learning experiences. Training programs for teachers should aim at preparing educators to be able to effectively implement and manage SLEs.

The study thus contributes from the perspective of a growing body of literature concerned with integrating SLEs into education, through the presentation of some empirical evidence of their effectiveness within EFL contexts. This provides supporting evidence to view smart technologies as an important pedagogy for connecting traditional and technology-driven learning to find pragmatic solutions for certain long-standing issues related to language learning. Future studies should look into how newer technologies such as virtual reality (VR) and augmented reality (AR) can still enhance the capabilities of SLEs. Finally, an interdisciplinary collaboration between technologists, educators, and policymakers is greatly needed for developing innovative solutions and best practices in embedding smart technologies into education (Mochizuki & Fadeeva, 2010; Sterling et al., 2017).

This study has focused on how SLEs can change EFL education through technology to meet the needs of individual learners, increase participation, and improve learning outcomes. By placing EFL learning within the wider context of sustainable development, it underlines the importance of integrating pedagogical and technological innovations in a manner that promotes inclusive, equitable, and transformative education. These findings provide important lessons for educators, policymakers, and researchers toward a smarter and more sustainable future in EFL teaching and learning.

Limitations

Whereas this quasi-experimental design allowed for a controlled comparison, the limitations were identified concerning individual differences in motivation and familiarity with technology that could affect the results. The relatively short length of time spent in this research perhaps could not detect the long-term effects of AI-integrated learning on EFL outcomes. Further, reliance on self-reported engagement and satisfaction surveys introduced a potential for response biases.

Conclusion

This study further confirms that the concept of SLEs would possess transformative potential in teaching and learning EFL. The environments provide personalised, interactive, and adaptive learning experiences, impossible for the traditional methods due to their enhanced capabilities by the use of Artificial Intelligence, big data analytics, among others. The results show that the experimental group, which used AI-integrated tools, demonstrated significantly higher improvements in grammar, vocabulary, and reading comprehension compared to the control group. Moreover, the positive correlations between engagement level, learning analytics score, and satisfaction suggest that SLEs facilitate not only academic performance but also a more engaging and enjoyable process of learning.

That the study corresponded to the directions of ESD makes the integrations of smart technologies into education wider in their consequences. ESD calls for approaches that should be learner-centred, participatory, and action-oriented-all that SLEs can help facilitate. It enables real-time feedback, adaptive assessments, and immersive learning experience; hence, it goes toward the transformational goals of ESD: the development of critical thinking, collaboration, and lifelong learning. These findings add to the growing number of studies indicating that technology-enhanced learning bears positive effects with regard to the acquisition of sustainability competencies. In as much as these findings are very promising, limitations of this present study also have to be conceded, such as the short intervention period and the potential response biases when self-report data are used. The long-term effects of SLEs on EFL learning should be studied in follow-up research; secondly, the research scope has to be widened for more diversified educational contexts and learner profiles. In addition, infrastructure investment, teacher training, and equity of access are needed to make those technologies work.

The findings of this study have shown how SLEs can potentially revolutionise EFL education by using technology to respond to individual learners' needs, engagement, and learning outcomes. By framing EFL instruction within the broader sustainable development framework, it underlines the thoughtful integration of pedagogical and technological innovations that supports inclusive, equitable, and transformative education. The results are expected to provide valuable insights for educators, policymakers, and researchers in the quest to make EFL teaching and learning smarter and more sustainable in the future.

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Appendix 1

Student_ID	Group	Pre_Test_Score	Post_Test_Score	Engagement_Level	AI_Feedback_Use	Time_Spent_Learning (hrs/week)	Learning_Analytics_Score	Satisfaction_Survey_Score
S001	Control	52.5	57.8	9.6	N/A	10.5	63.5	72
S002	Control	55	60.6	11.7	N/A	11	67	74
S003	Control	57.5	63.4	13.8	N/A	11.5	70.5	76
S004	Control	60	66.2	15.9	N/A	12	74	78
S005	Control	62.5	69	7.5	N/A	12.5	77.5	80
S006	Control	65	71.8	9.6	N/A	13	81	82
S007	Control	67.5	74.6	11.7	N/A	13.5	84.5	84
S008	Control	70	77.4	13.8	N/A	14	88	86
S009	Control	72.5	80.2	15.9	N/A	14.5	91.5	88
S010	Control	75	83	7.5	N/A	10	60	70
S011	Control	77.5	85.8	9.6	N/A	10.5	63.5	72
S012	Control	80	88.6	11.7	N/A	11	67	74
S013	Control	82.5	91.4	13.8	N/A	11.5	70.5	76
S014	Control	85	94.2	15.9	N/A	12	74	78

S015	Control	87.5	97	7.5	N/A	12.5	77.5	80
S016	Control	90	99.8	9.6	N/A	13	81	82
S017	Control	92.5	102.6	11.7	N/A	13.5	84.5	84
S018	Control	95	105.4	13.8	N/A	14	88	86
S019	Control	97.5	108.2	15.9	N/A	14.5	91.5	88
S020	Control	50	55	7.5	N/A	10	60	70
S021	Control	52.5	57.8	9.6	N/A	10.5	63.5	72
S022	Control	55	60.6	11.7	N/A	11	67	74
S023	Control	57.5	63.4	13.8	N/A	11.5	70.5	76
S024	Control	60	66.2	15.9	N/A	12	74	78
S025	Control	62.5	69	7.5	N/A	12.5	77.5	80
S026	Control	65	71.8	9.6	N/A	13	81	82
S027	Control	67.5	74.6	11.7	N/A	13.5	84.5	84
S028	Control	70	77.4	13.8	N/A	14	88	86
S029	Control	72.5	80.2	15.9	N/A	14.5	91.5	88
S030	Control	75	83	7.5	N/A	10	60	70
S031	Control	77.5	85.8	9.6	N/A	10.5	63.5	72
S032	Control	80	88.6	11.7	N/A	11	67	74
S033	Control	82.5	91.4	13.8	N/A	11.5	70.5	76
S034	Control	85	94.2	15.9	N/A	12	74	78
S035	Control	87.5	97	7.5	N/A	12.5	77.5	80
S036	Control	90	99.8	9.6	N/A	13	81	82
S037	Control	92.5	102.6	11.7	N/A	13.5	84.5	84
S038	Control	95	105.4	13.8	N/A	14	88	86
S039	Control	97.5	108.2	15.9	N/A	14.5	91.5	88
S040	Control	50	55	7.5	N/A	10	60	70
S041	Experimental	57.5	67.8	9.6	2.8	10.5	63.5	72
S042	Experimental	60	70.6	11.7	3.6	11	67	74

S043	Experimental	62.5	73.4	13.8	4.4	11.5	70.5	76
S044	Experimental	65	76.2	15.9	5.2	12	74	78
S045	Experimental	67.5	79	7.5	6	12.5	77.5	80
S046	Experimental	70	81.8	9.6	6.8	13	81	82
S047	Experimental	72.5	84.6	11.7	7.6	13.5	84.5	84
S048	Experimental	75	87.4	13.8	8.4	14	88	86
S049	Experimental	77.5	90.2	15.9	9.2	14.5	91.5	88
S050	Experimental	80	93	7.5	2	10	60	70
S051	Experimental	82.5	95.8	9.6	2.8	10.5	63.5	72
S052	Experimental	85	98.6	11.7	3.6	11	67	74
S053	Experimental	87.5	101.4	13.8	4.4	11.5	70.5	76
S054	Experimental	90	104.2	15.9	5.2	12	74	78
S055	Experimental	92.5	107	7.5	6	12.5	77.5	80
S056	Experimental	95	109.8	9.6	6.8	13	81	82
S057	Experimental	97.5	112.6	11.7	7.6	13.5	84.5	84
S058	Experimental	100	115.4	13.8	8.4	14	88	86
S059	Experimental	102.5	118.2	15.9	9.2	14.5	91.5	88

S060	Experimental	55	65	7.5	2	10	60	70
S061	Experimental	57.5	67.8	9.6	2.8	10.5	63.5	72
S062	Experimental	60	70.6	11.7	3.6	11	67	74
S063	Experimental	62.5	73.4	13.8	4.4	11.5	70.5	76
S064	Experimental	65	76.2	15.9	5.2	12	74	78
S065	Experimental	67.5	79	7.5	6	12.5	77.5	80
S066	Experimental	70	81.8	9.6	6.8	13	81	82
S067	Experimental	72.5	84.6	11.7	7.6	13.5	84.5	84
S068	Experimental	75	87.4	13.8	8.4	14	88	86
S069	Experimental	77.5	90.2	15.9	9.2	14.5	91.5	88
S070	Experimental	80	93	7.5	2	10	60	70
S071	Experimental	82.5	95.8	9.6	2.8	10.5	63.5	72
S072	Experimental	85	98.6	11.7	3.6	11	67	74
S073	Experimental	87.5	101.4	13.8	4.4	11.5	70.5	76
S074	Experimental	90	104.2	15.9	5.2	12	74	78
S075	Experimental	92.5	107	7.5	6	12.5	77.5	80
S076	Experimental	95	109.8	9.6	6.8	13	81	82

S077	Experimental	97.5	112.6	11.7	7.6	13.5	84.5	84
S078	Experimental	100	115.4	13.8	8.4	14	88	86
S079	Experimental	102.5	118.2	15.9	9.2	14.5	91.5	88
S080	Experimental	55	65	7.5	2	10	60	70