

Cultivating words: integrating immersive technologies and translation in agricultural settings

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ABSTRACT

This study explores an innovative pedagogical approach that integrates translation, educational technology, and virtual reality (VR) to enhance domain-specific language acquisition and digital engagement among undergraduate students in agricultural education. The 18 first-year students enrolled in “Agricultural Business Management” at Fan S. Noli University participated in a study combining immersive virtual experiences, translation tasks, and artificial intelligence (AI) tools. Students used platforms like Google Earth VR and 360Cities to describe agricultural environments in Albanian, and translated these texts into English using human and machine translation (Google Translate). The translated texts were then visualized through DALL·E to stimulate reflection on the semantic representation of the original scenes. Mozilla Hubs supported collaborative analysis of translation quality and peer feedback. Statistical analysis using R software (version 4.3.1) included the Welch two-sample t-test and Wilcoxon signed-rank test to compare translation outcomes. The results indicated significant improvement in technical vocabulary retention and increased students’ awareness of translation complexities. Moreover, students reported heightened motivation and positive attitudes toward technology-enhanced language learning. The study highlights the pedagogical value of immersive, interdisciplinary strategies in English for specific purposes (ESP), particularly in technical disciplines like agriculture.

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1. INTRODUCTION

Integrating immersive technologies and artificial intelligence (AI)-powered tools is transforming language learning, particularly in English for specific purposes (ESP), where the stakes of lexical precision and domain-specific communication are high. Researchers have increasingly focused on how digital innovations can enhance learner engagement, retention, and contextual understanding in recent years. Study by Cowie and Alizadeh [1] demonstrated that immersive virtual reality (VR) environments enhance learner engagement and motivation by fostering interactive and experiential learning experiences, while Divekar *et al.* [2] argue that AI tools can streamline language acquisition when combined with contextualized learning approaches. This trend is particularly evident in ESP contexts, where students must master both general language skills and field-specific terminology. In agriculture, a discipline where linguistic accuracy intersects with biology, chemistry, and environmental science knowledge, traditional approaches often struggle to ensure long-term vocabulary retention, contextual understanding, and learner engagement [3], [4].

Dou *et al.* [5] critique these conventional methods for their lack of contextual grounding. In contrast, Laadem and Mallahi [6] advocate for multimodal, learner-centered strategies incorporating visual inputs and authentic tasks to foster cognitive engagement. Further, Supuran *et al.* [7] emphasize the role of contextual cues in facilitating specialized vocabulary acquisition, particularly in technical domains.

The pedagogical model adopted in this study draws on several complementary theoretical perspectives. Situated learning theory [8] provides the foundation by emphasizing that knowledge is best acquired in authentic, context-rich environments. Multimodal learning theory [9] further reinforces this by highlighting the value of integrating visual, auditory, and textual modes to strengthen comprehension and retention. In the field of translation pedagogy, Kiraly [10] constructivist framework emphasizes collaborative, process-oriented learning, while Skopos theory [11] highlights the centrality of communicative purpose in shaping translation decisions. At the same time, Pym [12] notion of translator agency underlines the importance of learner autonomy and responsibility in decision-making. To account for discourse-level precision, Halliday and Hasan [13] register theory offers tools for analyzing context and genre. At the same time, cognitive linguistics [14] provides insights into how learners map meaning across multimodal inputs. Together, these perspectives support a model where translation functions as a linguistic exercise and a situated, purposeful, and multimodal learning process.

In response to these challenges, immersive technologies such as VR have emerged as promising instructional tools. VR fosters experiential learning by situating learners in real-world contexts, enhancing motivation and vocabulary acquisition [15]. This is supported by Khasawneh [16] who found that VR-based situational learning improves language transfer, and Kaplan-Rakowski *et al.* [17] who emphasize VR's unique potential for embodied learning. Cowie and Alizadeh [1] noted the pedagogical value of VR in higher education, emphasizing how immersive environments support experiential learning and conceptual understanding. Similarly, Long *et al.* [18] reported that immersive environments in vocational training help anchor abstract terminology through tangible, visual representation. Its value in vocational school settings, where immersive environments help anchor abstract terminology in tangible, visual environments.

At the same time, AI-powered translation tools are reshaping translation pedagogy. While Rapa *et al.* [19] raise concerns about over-reliance on tools like Google Translate, others argue that post-editing and critical engagement with machine-generated outputs can strengthen metalinguistic awareness [20], [21]. Karasaliu [22] emphasizes that the pedagogical value of AI lies not in automating language production but in encouraging learners to evaluate translation accuracy, lexical choices, and contextual appropriateness. Bory *et al.* [23] observe that AI translation tools struggle with domain-specific terminology due to semantic and cultural inconsistencies.

Recent research further supports this integrated pedagogical direction. Papadakis *et al.* [24], [25] illustrate how cloud simulations and augmented reality synergistically support experiential learning in higher education. Lampropoulos and Papadakis [26] report increased engagement when AI-driven social robots are introduced into educational environments. In addition, Lobanova *et al.* [27] identify perceived usefulness and self-efficacy as predictors of student AI tool adoption.

Empirical findings from ESP contexts reinforce these findings. Rizkina *et al.* [28] report that AR-enhanced vocabulary applications significantly improve retention of technical terms. AI chatbots foster learner autonomy and content retention in CLIL-based ESP instruction [29]. Mumtaz *et al.* [30] highlight ethical concerns in AI tool implementation, while Robillos and Bustos [31] demonstrate how technology-enhanced, task-based instruction can positively affect language production among EFL learners.

Despite this growing body of literature, the combined application of immersive VR and AI-assisted translation in ESP education remains underexplored. While Gu [32] and Escobar-Álvarez [33] acknowledge digital tools' motivational and lexical gains, few studies examine how immersive environments and machine-supported translation can work synergistically in real-world, disciplinary contexts. Previous studies [28], [29] often focus on isolated tools rather than comprehensive, integrated instructional models.

This study addresses this gap by conceptualizing translation as an epistemic (knowledge-generating) and communicative (meaning-conveying) process. It combines VR immersion, AI-supported translation, post-editing, and peer reflection into a unified instructional model for ESP in agriculture. Specifically, it explores the pedagogical efficacy of using Google Earth VR, 360Cities, Mozilla Hubs, Google Translate, DALL·E, and multilingual agricultural dictionaries in enhancing vocabulary retention, translation accuracy, and learner engagement over a semester-long course.

While exploratory in scope (due to its small, context-specific sample and lack of a control group), this study proposes an interdisciplinary model integrating digital innovation with specialized language instruction. Its findings offer preliminary insights to inform ESP curriculum design in agriculture and related fields, and may serve as a foundation for future empirical research. Figure 1 offers a visual overview of the integrated pedagogical framework. This model highlights how immersive environments and AI-assisted translation tools interact to support vocabulary acquisition and learner engagement in ESP instruction.

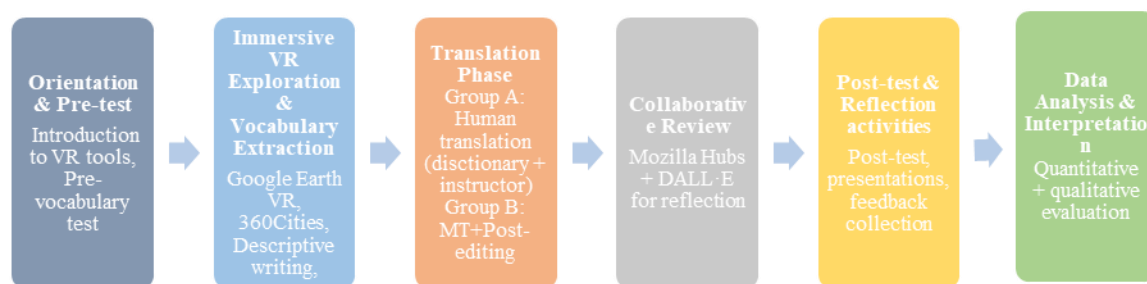


Figure 1. Pedagogical implementation framework

2. RESEARCH METHOD

2.1. Research design

This study adopted a semester-long mixed-methods research design to examine how immersive technologies and AI-assisted translation tools influence ESP learning outcomes. It was conducted over 15 weeks and was structured into two primary phases: i) assessing vocabulary development through pre- and post-tests, and ii) analyzing translation quality across five thematically organized tasks. The following hypotheses guided the study:

2.1.1. Vocabulary improvement

For the first phase, the hypotheses focus on the potential impact of immersive technologies and tasks on students' vocabulary retention and translation quality.

- H_0 (null hypothesis): students have no significant difference in vocabulary or translation quality before and after the intervention.
- H_A : (alternative hypothesis): the integration of immersive technologies and translation tasks results in a significant improvement in vocabulary and translation quality.

2.1.2. Translation group comparison

In the second phase, the hypotheses examine whether machine-assisted translation with post-editing leads to higher translation scores compared to human translation.

- H_0 : human and machine-assisted translation groups have no significant difference in translation scores.
- H_A : machine-assisted translation (with post-editing) results in significantly higher scores than human translation.

2.2. Participant selection

The study involved 18 first- and second-year undergraduate students from the Department of Agricultural Sciences at Fan S. Noli University, Albania. All participants were native Albanian speakers with intermediate to advanced English proficiency, prior exposure to ESP instruction, and moderate digital literacy. The project was carried out under the ethical oversight of the Department of Education and Philology at Fan S. Noli University. Although the institution does not operate a formal Institutional Review Board, approval was secured through departmental academic committee review and compliance with national research ethics protocols. Participation was voluntary and students were fully informed of their right to withdraw at any stage. Written consent was obtained from all participants. Anonymity was preserved by assigning coded identifiers and ensuring no personal data was linked to responses.

The research adhered to internationally recognized guidelines for ethical practice, including the British Educational Research Association (BERA), the European Code of Conduct for Research Integrity, and the 2013 revision of the Declaration of Helsinki. Given the small, non-probabilistic sample ($N=18$) and the absence of a control group, the findings should be considered exploratory and not generalizable. Institutional and logistical constraints made it impractical to include a parallel comparison group. Instead, a within-subject pre/post-test design was implemented to capture vocabulary development and translation competence changes. While this design limits causal inference, it provides proper exploratory evidence of progression within the studied cohort.

2.3. Technological infrastructure and research tools

During the intervention, students engaged with several immersive and AI-powered platforms. Google Earth VR and 360Cities were employed to simulate authentic agricultural landscapes, enabling students to observe, describe, and extract contextually relevant vocabulary. Following the production of

descriptive texts in Albanian, students were divided into two groups: i) group A utilized human translation methods, including a multilingual dictionary [34] and consultation with the course instructor; and ii) group B relied on Google Translate as the primary translation tool, supplemented by post-editing, group discussion, and critical evaluation.

Mozilla Hubs served as a virtual collaboration platform where students engaged in peer feedback, annotated translated texts, and participated in vocabulary discussions. This environment facilitated both asynchronous and real-time interaction and provided a less intimidating space for quieter students to contribute more actively than in traditional classroom settings. Additionally, DALL·E was introduced as a visual feedback tool to prompt reflection on semantic accuracy and contextual fidelity. The generated images were used solely for pedagogical exploration and not as part of a formal assessment.

2.4. Research workflow

The 15-week study followed a structured implementation schedule: i) administration of pre-intervention ESP vocabulary test and orientation sessions introducing students to the VR tools (weeks 1-2); ii) completing 5 translation tasks, each aligned with a thematic focus: organic farming, genetically modified organisms (GMOs), climate change, smart farming, and pest control (weeks 3-12); iii) administration of the post-intervention ESP vocabulary test (week 13); and iv) collection of reflective feedback, delivery of collaborative presentations, and final data collection (week 14-15). Figure 2 illustrates the cyclical learning model implemented throughout the intervention. It integrates immersive vocabulary input, translation tasks, peer collaboration, multimodal revision, and outcome evaluation.

This model visually represents the progression of the instructional phases. The process began with immersive vocabulary grounding via VR platforms, followed by the translation phase. Group A relied on human translation with dictionary support, and group B utilized Google Translate with guided post-editing. The collaborative phase enabled peer review and instructor feedback through Mozilla Hubs, while reflective revision activities (supported by DALL·E image prompts) helped students visualize and interrogate semantic discrepancies. The cycle concluded with an outcome evaluation based on post-tests and rubric-based translation assessments. This cyclical approach supported iterative engagement, encouraging deeper lexical understanding and contextual awareness.

The five thematic translation tasks were chosen from existing ESP course modules and validated by two subject-matter experts for appropriateness of content and difficulty, ensuring alignment with intermediate-to-advanced English proficiency levels. Each translation task was assessed using a 20-point rubric, assessing five criteria: terminology accuracy, grammar correctness, fluency, contextual appropriateness, and stylistic consistency.

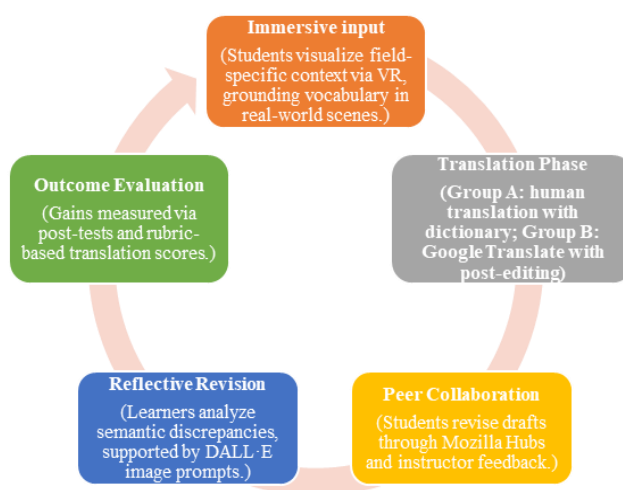


Figure 2. Learning implementation sequence

2.5. Quantitative vocabulary assessment

Students completed identical pre- and post-tests of matching, fill-in-the-blank, and multiple-choice items targeting 50 domain-specific agricultural terms. The vocabulary test underwent expert review by 2 ESP instructors and was piloted for clarity and content validity. Table 1 presents the descriptive statistics for both assessments.

The mean post-test score increased from 44.1 to 67.9, indicating notable vocabulary gains over the semester. Additionally, the median score rose from 43 to 67.5, and the interquartile range narrowed, reflecting improved performance and greater consistency across students. These results suggest a general upward shift in ESP vocabulary proficiency following the intervention.

Table 1. Descriptive statistics for pre-test and post-test ESP vocabulary scores

Test	Variable	N	Min	Max	Median	Iqr	Mean	SD	SE	CI
Post-test score	Scores	18	58	78	67.5	6.75	67.9	5.12	1.21	2.54
Pre-test score	Scores	18	38	54	43	6.25	44.1	5.04	1.19	2.51

Note: SD=standard deviation; SE=standard error; CI=95% confidence interval

2.6. Translation task analysis

The five translation tasks were thematically grouped and administered on a bi-weekly basis. Students collaborated in teams based on the assigned translation method. Final translations were evaluated using a standardized rubric, and scores were analyzed to assess differences in translation quality between the two groups. The rubric was adapted from established ESP translation assessment frameworks and validated through expert review by 2 ESP instructors familiar with agricultural discourse. It included five dimensions: terminology accuracy, grammar and syntax, fluency, contextual appropriateness, and stylistic consistency. A pilot scoring session was conducted to calibrate the rubric, ensuring shared understanding of scoring criteria among evaluators.

The 2 independent coders examined student journals and peer-review logs through thematic coding, with an inter-rater agreement of 85%. These qualitative findings were cross-checked to strengthen reliability against quantitative measures such as vocabulary test scores and rubric-based translation assessments. Analyst triangulation was also employed, with both coders independently confirming the emergent categories. Discrepancies in scoring were resolved through discussion until consensus was reached, and a third reviewer was available in case of persistent disagreement, though this was not required in practice.

2.7. Statistical analysis tools

All statistical analyses were conducted using RStudio (version 4.3.1). Given the unequal variances and small sample size, descriptive statistics and Welch's two-sample t-tests were employed to compare pre- and post-test means to assess vocabulary development. In addition, the Wilcoxon signed-rank test [35] was conducted to confirm the robustness of the results under non-normality conditions.

The normality of the difference scores was assessed using the Shapiro-Wilk test [36], which indicated a violation of normality assumptions. Consequently, for comparisons between the two translation groups (groups A and B), the Mann-Whitney U test [37] was employed to analyze non-parametric data. Significance was set at $p < 0.05$ for all tests. These statistical procedures ensured rigorous validation of the findings across both parametric and non-parametric frameworks.

3. RESULTS AND DISCUSSION

Combining quantitative test scores with qualitative student reflections, the findings comprehensively show how translation tasks and immersive technologies shaped learner outcomes in this semester-long ESP intervention.

3.1. English for specific purposes vocabulary gains from immersive instruction

Integrating immersive technologies such as Google Earth VR and 360Cities, alongside digital collaboration tools, significantly enhanced students' acquisition of domain-specific vocabulary. As illustrated in Table 1, the mean vocabulary score increased from 44.1 (pre-test) to 67.9 (post-test), while the median score rose from 43 to 67.5. The narrowing interquartile range indicates improved performance and greater consistency among students. Figure 3 visually represents these score distributions, following the graphical conventions outlined by Chambers *et al.* [38].

To determine whether these improvements were statistically significant, we tested the following hypotheses: $H_0: \mu_{post.test} = \mu_{pre.test}$ versus $H_a: \mu_{post.test} \neq \mu_{pre.test}$, where $\mu_{post.test}$ and $\mu_{pre.test}$ represents the mean vocabulary scores before and after the intervention. Given the small sample size and unequal variances, a Welch two sample t-test was conducted as recommended by Marden [39]. The test yielded a statistically significant result ($t=14.08$, $df=33.992$, $p<0.001$), with a 95% confidence interval of [20.39; 27.27], indicating a robust difference between pre- and post-test means, as in Table 2.

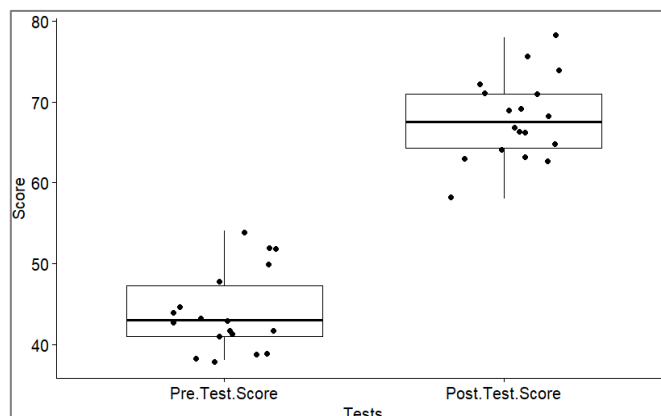


Figure 3. ESP vocabulary scores before and after intervention (note: the median score increased in the post-test, and the overall distribution shifted toward higher values)

Table 2. Welch two-sample *t*-test comparing pre-test and post-test vocabulary scores

Mean post-test	Mean pre-test	t-statistic	Df	p-value	95% confidence interval
67.94444	44.11111	14.08	3.992	9.568e-16	[20.39340; 27.27327]

The Wilcoxon signed-rank test, a non-parametric alternative suitable for small samples and non-normal distributions [35], confirmed these findings ($Z=3.87$, $p<0.001$). Triangulation with qualitative data, particularly students' reflective journals and post-task self-assessments, further reinforced the trustworthiness of these conclusions. Students frequently cited the ability to visualize agricultural terms in real-world settings as a key factor in enhancing their retention and usage. Together, these findings provide strong evidence for the pedagogical value of the intervention. They also align with prior research indicating that VR-supported ESP instruction enhances semantic retention, particularly when learners associate new terminology with visual-spatial representations [40], [41].

3.2. Comparative translation task performance

Students completed five thematic translation tasks, each evaluated on five key dimensions: terminology accuracy, grammar and syntax, fluency, contextual appropriateness, and stylistic consistency. Table 3 summarizes the average group scores for each task. Group B, which used machine translation with post-editing, consistently outperformed group A (human translation) in most dimensions, particularly on tasks 3, 4, and 5, which involved complex and abstract content such as climate change and innovative farming technologies. Group A, however, performed slightly better in task 1, which was lexically more straightforward and more contextually transparent. Semantic equivalence (rubric dimension 4) showed the most significant variability, particularly in task 3 (climate change) and task 5 (pest control), indicating challenges in handling specialized environmental terminology and contextual lexical nuances. This pattern aligns with established ESP translation research, which identifies semantic fidelity in technical and domain-specific texts as a persistent challenge for both human and machine translators [7], [23], [30].

Table 3. Human translation and machine translation + post-editing data

Task number	Method	Terminology accuracy (4 pts)	Grammar and syntax (4 pts)	Fluency and readability	Contextual appropriateness (4 pts)	Consistency and style (4 pts)	Total score (20 pts)
1	Man. tr.	1	2	2	1	2	8
2	Man. tr.	2	2	2	2	2	10
3	Man. tr.	2	1	2	2	2	9
4	Man. tr.	3	2	3	3	2	13
5	Man. tr.	3	3	4	4	3	17
1	Mach. tr.	3	2	3	2	2	12
2	Mach. tr.	3	3	3	3	2	14
3	Mach. tr.	3	3	4	2	3	15
4	Mach. tr.	4	4	4	3	4	19
5	Mach. tr.	4	4	4	3	4	19

Note: differences were tested using Mann–Whitney U tests.

Figure 4 illustrates these group differences using boxplots. As shown on the visual comparison provided in Figure 4, group B (machine-assisted) demonstrated a higher median performance and reduced score variability (especially toward the latter part of the intervention). This pattern indicates greater consistency and improved output over time. When complemented by guided post-editing, these effect sizes suggest that a meaningful pedagogical impact of AI-assisted translation can improve technical precision and fluency. They support findings from prior studies showing that AI tools improve syntactic coherence and lexical accuracy in translation tasks [42], [43]. Nevertheless, persistent challenges in conveying pragmatic and cultural meaning highlight the need for human oversight and collaborative revision.

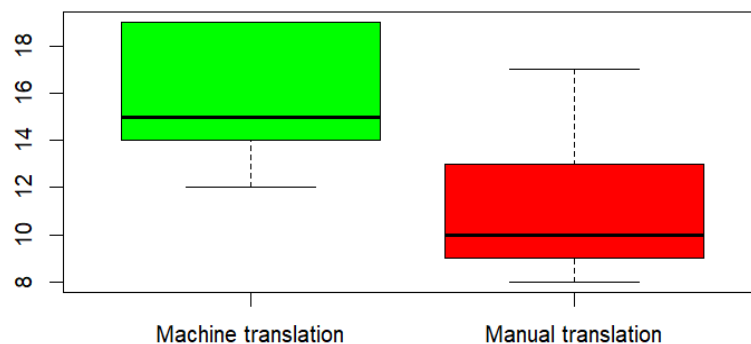


Figure 4. Translation quality by group

3.3. Analysis by translation skill

Table 4 compares average rubric scores across five dimensions for group A (human translation) and group B (machine translation). Statistically significant differences were found in terminology accuracy ($p=0.01592$), grammar and syntax ($p=0.02039$), and fluency and readability ($p=0.03632$), with group B consistently outperforming group A. These results indicate that AI-assisted translation combined with collaborative post-editing contributes to greater structural precision and textual clarity, consistent with Yuxiu [44] findings on improved learner outcomes through AI-supported reflective translation tasks.

In contrast, no statistically significant differences emerged in contextual appropriateness ($p=0.3681$) or stylistic consistency ($p=0.07885$), suggesting persistent challenges in capturing pragmatic nuances and stylistic cohesion. These results highlight the complexity of cultural and contextual meaning, a challenge neither human translators nor machine translation systems appear fully equipped to resolve independently. A Mann–Whitney U test on total translation scores yielded a p-value of 0.0376, allowing rejection of the null hypothesis and confirming significant group differences in overall translation quality [45].

These findings imply that while AI-assisted translation offers tangible benefits, it remains insufficient without active human intervention, particularly in refining pragmatic meaning and ensuring terminological precision within specific contextual frameworks. This supports calls for hybrid models in translation education that integrate AI-assisted tools with reflective, collaborative, and instructor-guided revision strategies [46]. Such approaches align with previous research into multimodal pedagogies in specialized language instruction, including Laadem and Mallahi [6], who emphasize the value of integrated digital environments in enhancing vocabulary acquisition and translation competence within ESP settings.

Table 4. Rubric-based comparison of translation quality between both groups

Aspects	Mean of group B (machine translation)	Mean of group A (human translation)	p-value
Terminology accuracy	3.4	2.2	0.01592
Grammar and syntax	3.2	2	0.02039
Fluency and readability	3.6	2.6	0.03632
Contextual appropriateness	2.6	2.4	0.3681
Consistency and style	3	2.2	0.07885
Total score	15.8	11.4	0.0376

3.4. Student reflections on engagement and learning

Qualitative analysis of student journals and peer discussion logs revealed several recurrent themes related to learner engagement and reflective practice. Students reported increased confidence in using specialized agricultural vocabulary, attributed to the authentic, visually immersive contexts provided by

platforms such as Google Earth VR and 360Cities. These virtual environments allowed learners to anchor new terminology to tangible, real-world settings, enhancing comprehension and retention.

Many participants preferred initiating their translation tasks with AI-assisted translation tools, especially under time constraints. Nonetheless, they consistently acknowledged the necessity of human oversight for refining idiomatic expressions and culturally nuanced terms. This highlights an emerging learner awareness of the complementary roles played by machine translation and human post-editing in achieving accurate and contextually appropriate translations.

Integrating DALL·E as a visual output generator proved instrumental in deepening students' metacognitive engagement. By observing their translated content materialize as images, students could identify subtle linguistic inaccuracies and reflect on semantic mismatches. This form of multimodal feedback aligns with contemporary translation pedagogy findings, which emphasize visual feedback loops' efficacy in promoting critical reflection and deeper learning [47], [48].

Additionally, the collaborative virtual environment Mozilla Hubs facilitated dynamic peer interactions, enabling real-time negotiation of meaning and collective resolution of ambiguous terminology. Instructor observations and student reflections underscored that participants actively engaged in these peer-review sessions demonstrated more consistent use of domain-specific vocabulary and stronger post-editing practices. This suggests a positive correlation between collaborative engagement and the development of critical translation skills. Several students voiced challenges in translating complex terms such as "soil salinity" and "carbon sequestration", often expressing doubts about the machine-generated suggestions for such specialized vocabulary reliability. These reflections underscore the pedagogical importance of fostering critical appraisal skills alongside technological fluency, encouraging students to scrutinize and refine AI outputs rather than accepting them uncritically.

3.5. Implications and pedagogical interpretation of results

The results of this study should be interpreted within the scope of its exploratory design. It is important to differentiate between empirical findings (such as measurable gains in vocabulary acquisition and rubric-based translation quality) and the interpretive conclusions that suggest the underlying pedagogical mechanisms responsible for these outcomes. This distinction is essential to clarify how the observed effects can inform broader theoretical and instructional practices.

The findings advocate for integrating immersive environments and translation tools in ESP settings, not as isolated interventions, but as interconnected, mutually reinforcing learning mechanisms. The evidence indicates that machine translation and guided post-editing and collaborative interpretation activities can effectively enhance learner performance. Translation should be positioned as a central, interdisciplinary process within ESP curricula, rather than a marginal skill. This is particularly critical in specialized fields such as agriculture, where mastery of domain-specific terminology, cultural nuances, and genre conventions is fundamental. Accurately comprehending and translating context-specific lexicon underpins both linguistic competence and professional expertise.

Immersive VR tools emerged as powerful contextual scaffolds by situating language tasks within authentic, real-world environments. Platforms such as Google Earth VR and 360Cities allowed learners to directly associate specialized terminology with relevant visual and situational cues, thereby facilitating improved semantic precision and retention. These findings substantiate principles of situated learning theory and align with contemporary ESP pedagogical models that emphasize authentic, context-rich learning environments [10], [46], [47]. Moreover, the instructional model helped address persistent challenges in handling culturally embedded expressions and pragmatic meaning (particularly when using machine translation tools) by emphasizing collaborative post-editing and human-guided revision.

3.6. Limitations and directions for future research

Despite offering valuable insights into the pedagogical potential of immersive technologies and AI-assisted tools in ESP instruction, this study is subject to several limitations. The relatively small sample size (N=18), drawn from a single institution and academic discipline, constrains the generalizability of the findings. Furthermore, the absence of a control group and the use of non-probabilistic sampling methods reduce the strength of causal inferences that can be drawn.

While methodological triangulation (incorporating both qualitative and quantitative data) enhanced trustworthiness, the statistical analyses were limited to basic inferential techniques. Future research could benefit from more advanced analytical approaches to elucidate the influences of learner variables such as prior translation experience, digital literacy, and domain-specific background knowledge. Subsequent studies should employ more rigorous experimental designs, including randomized controlled trials and cross-institutional comparisons, to validate and extend the current findings. Long-term studies could further explore the sustainability of vocabulary gains and the long-term impact of AI-assisted translation tools on

learner autonomy across diverse ESP disciplines. Additionally, further inquiry is necessary to disentangle the relative contributions of immersive technologies, structured feedback mechanisms, and their synergistic interaction. Clarifying these components will be instrumental in identifying the specific factors that drive measurable learning gains and inform evidence-based pedagogical interventions.

4. CONCLUSION

This study examined how immersive technologies and AI-assisted translation tools can support domain-specific vocabulary acquisition and translation competence in agricultural ESP contexts. The instructional design combined experiential learning with task-based translation activities and structured collaborative review processes by integrating Google Earth VR, 360Cities, Google Translate, and Mozilla Hubs. Quantitative analyses revealed statistically significant improvements in vocabulary proficiency and translation quality, particularly among students using AI-assisted translation followed by post-editing. Complementary qualitative data underscored increased learner engagement, metacognitive development, and collaborative learning, especially when technological tools were embedded within authentic, discipline-specific learning environments. Situating translation as a linguistic and cognitive process, this research contributes a theoretically grounded, practice-oriented model that reflects current pedagogical shifts in ESP and translation education.

Although exploratory, the findings suggest hybrid approaches (blending immersive platforms with guided AI tool use) can enrich ESP instruction in technical domains. Future studies should replicate this model across diverse ESP contexts using comparative or randomized controlled designs to validate and extend the findings. This integrated framework may be a foundation for future curriculum design and empirical inquiry in technology-enhanced ESP education, particularly in contexts where field-specific translation and lexical mastery are critical.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nvestigation

R : **R**esources

D : **D**ata Curation

O : Writing - **O**riginal Draft

E : Writing - Review & **E**editing

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

Informed consent was obtained from all participants, and data were anonymized, securely stored, and used exclusively for academic research purposes, per the ethical principles outlined in the British Educational Research Association (BERA) guidelines and European Code of Conduct for Research Integrity.

ETHICAL APPROVAL

The study adhered to institutional and international ethical standards for research involving human participants. While Fan S. Noli University does not have a formal Ethics Review Board, the Faculty of Education and Philology reviewed and approved the research under its internal ethics oversight procedures.

DATA AVAILABILITY

The data supporting this study's findings are available on request from the corresponding author [AK]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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