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Integrating Augmented Reality in STEM to Support English Vocabulary Acquisition: Teachers' Insights

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Abstract
In fulfillment of the requirements of Industrial Revolution 4.0, Augmented Reality is acknowledged for fostering engaging and immersive educational environments that boost student motivation and interaction. However, its real-world classroom application especially in Malaysian ESL contexts remains limited. Hence, this study explores STEM teachers' perceptions of using AR to enhance vocabulary acquisition among ESL learners in STEM subjects. In this qualitative study, four STEM teachers from a learning centre in Selangor, Malaysia, participated in the semi-structured interviews. The purpose of the study was to explore the STEM teachers' perceptions of the advantages and difficulties of integrating AR into English vocabulary learning in a STEM context, as well as their readiness to include AR into future teaching methods. The six-phase method developed by Braun and Clarke was used to analyse the data thematically. The findings revealed five main themes which are AR's usefulness, ease of use, teacher attitudes, behavioural intentions, and external barriers. Teachers recognised that AR's 3D visualisation and interactive features could enhance students' conceptual understanding and vocabulary retention. However, concerns were raised over technical complexity, lack of training, limited infrastructure, and the risk of student distraction. Despite these barriers, all participants expressed openness toward using AR in the future provided they receive proper support, accessible tools, and curriculum-aligned content. This study recommends targeted professional development, collaborative AR content development among educators, and investment in digital infrastructure. Future research should include ESL students' perspectives on vocabulary mastery in STEM contexts.
Keywords: Augmented Reality, Educational Technology, Vocabulary Acquisition, Teachers' Perception, STEM-Related Contents

Introduction

The Fourth Industrial Revolution (IR 4.0) has significantly reshaped educational settings by necessitating the integration of current latest technologies and the cultivation of future-ready skills. In the context of STEM education, Augmented Reality (AR) has emerged as a powerful tool that transforms learning environments by offering personalized, flexible, and engaging experiences (Amsal & Sagita, 2024). Through immersive learning, augmented reality and other IR 4.0 technologies like artificial intelligence (AI) and the Internet of Things (IoT) improve students' engagement with knowledge and foster deeper understanding. The shift is in accordance with the increasing need for instructional strategies that promote critical thinking, creativity, teamwork, and problem-solving abilities to impart technical knowledge. These are all necessary for navigating today's intricate industry (Behera et al., 2024). In response to these industrial demands, educators are also increasingly adopting innovative pedagogies, such as project-based learning and open-ended inquiry, which encourage divergent thinking and intellectual risk-taking (Prater & Predki, 2024). Within the Malaysian context, the adoption of Education 4.0 reflects a growing commitment among universities to align curriculum with technological advancements and 21st-century pedagogical approaches (Halili et al., 2021).

Furthermore, by establishing immersive, context-rich, and captivating learning environments that improve motivation and retention, Augmented Reality offers substantial benefits, particularly in the acquisition of STEM vocabulary. In order to maintain focus and motivation during vocabulary acquisition exercises, it has been demonstrated that AR's interactive features greatly boost student engagement (Idul & Syaiful, 2024; Khan, 2023). In contrast to traditional methods, AR has demonstrated astonishing performance in immediate recall and learning efficiency particularly when integrated with visualizations of keywords that support memory retention (Weerasinghe et al., 2022). This is due to tools such as AR flashcards further enhancing the learning experience by presenting vocabulary sequentially with gamified and visual elements that make memorization more effective (Ramadhani & Arifin, 2024). Moreover, by allowing students to interact with terminology in virtual settings, AR has been demonstrated to close the gap between theoretical understanding and practical application. As a result, it makes the learning process more meaningful and practical (Solidjonov, 2023). By incorporating labels, grammar, and contextual text onto real-world objects, AR not only reinforces vocabulary but also offers an enjoyable and practical approach to language learning. It eventually fosters deeper and more lasting linguistic competence (Solidjonov, 2023).

However, Augmented Reality indeed shows great potential for transforming STEM education, but its real-world impact remains understudied. There is still a lack of solid, localized research that measures how AR actually improves learning outcomes (Amdan et al., 2024). Without this data, educators and policymakers struggle to make informed decisions especially when it comes to evaluating AR across different schools and classrooms. Another hurdle is the curriculum integration. Currently, there are not many clear and structured frameworks to help teachers weave AR effectively into lessons or extracurricular activities (Idris & Bacotang, 2023). Although AR makes learning more engaging and immersive compared to traditional methods, depending solely on enthusiasm alone is not enough. This is because schools need better digital infrastructure, such as reliable devices, stable internet, and equitable access, which remains a major challenge, especially in rural or underfunded areas (Yunus & Tuan, 2020). Besides, as AR becomes more common in the classrooms, questions regarding student privacy still haven't been fully addressed in policy discussions (Amdan et al., 2024). All of this means that while AR is undoubtedly exciting, making it work on a large scale in Malaysia will require careful planning, investment, and support which is not just from schools, but from the entire education ecosystem.

To fully utilise Augmented Reality in the classroom, a collaborative and multifaceted approach is essential. Policymakers have an important part to play and it is not just by creating policies that promote digital inclusion, but also by supporting infrastructure improvements and establishing ethical standards for how immersive technologies are used in schools (Amdan et al., 2024). At the same time, developers and edtech innovators need to work hand-in-hand with teachers to create AR content that fits into existing curricula and works well even on basic devices. As a result, all students can benefit regardless of their background (Charunin et al., 2024). This is particularly crucial in a multicultural setting like Malaysia, where access to technology can differ greatly between regions and English is a second language (Yunus & Tuan, 2020). Efforts to promote AR in education should also align with national goals tied to IR 4.0 as a call for a future generation of students who are not only tech-savvy but also adaptable and innovative (Schwab, 2022). Regardless, in the end, it relies heavily on the teachers' creativity, preparedness, and support will shape how successfully AR transforms learning in the classroom.

Hence, this study seeks to examine STEM teachers' perceptions regarding the usefulness of AR in enhancing vocabulary acquisition for ESL learners in STEM subjects. This research wishes to contribute findings to help achieve a balance between language support and content learning in ESL-STEM contexts. Since vocabulary proficiency underpins content mastery, understanding teachers' perspectives can reveal key enablers and barriers to AR adoption. The findings will inform the development of AR-supported pedagogical strategies that are aligned with teachers' needs and the realities of their teaching environments. Subsequently, this can support more effective and inclusive STEM education across diverse learning settings.

Research Question
What are the perceptions of STEM teachers regarding the usefulness of using Augmented Reality (AR) to enhance vocabulary acquisition in STEM-related content among ESL learners?

Literature Review
The integration of Augmented Reality (AR) in STEM education has emerged as a transformative approach to address traditional learning challenges. This literature review examines the current state of research on AR applications in STEM vocabulary education by analyzing the advantages, challenges, teacher attitudes, and systemic barriers that influence AR adoption in STEM-related contents. The review is grounded in the Technology Acceptance Model (TAM) by Davis (1989) which focuses on perceived usefulness (PU) and perceived ease of use (PEOU) as predictors of technology adoption.

Enhancing Student Understanding through Visualisation
There are revolutionary advantages to incorporating Augmented Reality into STEM education that tackle persistent pedagogical issues. In domains where complicated terminologies and procedures frequently present learning obstacles, AR's immersive capabilities enable students to engage with abstract concepts and make them tangible while enhancing comprehension (Bernsteiner et al., 2023; Erlangga et al., 2024). This is due to the

fact that AR bridges the gap between abstract STEM concepts and student comprehension by providing interactive 3D models of molecular structures, anatomical systems, and engineering designs. This visualization capability transforms traditional learning approaches by enabling students to manipulate and explore complex scientific phenomena in real-time. In chemistry, AR visualizations of molecular interactions have been shown to deepen cognitive engagement and long-term retention (Ripsam & Nerdel, 2024; Erlangga et al., 2024). Students can observe chemical bonding processes and molecular behavior patterns that would otherwise remain theoretical concepts. Similarly, in physics education, AR simulations of invisible forces such as electromagnetic fields help students grasp theoretical principles more effectively (Giang et al., 2024; Tarigan, 2024). The ability to visualize abstract phenomena like wave propagation or field interactions provides students with concrete mental models that support deeper understanding. This alignment of AR with curricular goals ensures that visualization directly supports learning outcomes rather than serving merely as entertainment (Muñoz et al., 2024; Psycharis et al., 2023).

Improving STEM Vocabulary and Terminology

AR enhances STEM vocabulary acquisition by contextualizing terminology within immersive experiences that connect abstract terms to visual and interactive elements. Labels, annotations, and interactive glossaries embedded in AR applications reinforce subject-specific language while benefiting both native and non-native speakers (Idul & Syaiful, 2024; Gestiardi et al., 2022). This contextual approach to vocabulary learning moves beyond traditional memorization techniques by creating meaningful associations between terms and their practical applications. For example, AR-based anatomy applications overlay multilingual terms on virtual dissections while promoting dual mastery of content and language (Belda-Medina & Marrahí-Gómez, 2023; Kumar et al., 2024). Students can explore anatomical structures while simultaneously learning medical terminology in the English language. These AR tools also cater to diverse learning styles and foster inclusivity by accommodating visual, auditory, and kinesthetic learners (Πέικος & Sofianidis, 2024; Mokmin et al., 2022).

Promoting Active Learning and Engagement

Moreover, AR applications transform passive learning environments into interactive ones where students actively participate in knowledge construction. The gamification elements that are often integrated into AR educational tools increase student motivation and create positive learning experiences that encourage continued engagement especially in STEM subjects. Research indicates that students using AR-enhanced instruction demonstrate higher levels of participation and sustained attention compared to traditional teaching methods (Shamsudin & Talib, 2023; Bernsteiner et al., 2023). Furthermore, students can collaborate to solve challenges using shared virtual objects and settings in AR-enabled collaborative learning experiences. This collaborative aspect develops important 21st-century skills while reinforcing STEM vocabulary through peer interaction and discussion (Psycharis et al., 2023; Muñoz et al., 2024). So, AR indeed promotes good active learning and strengthens engagement compared to traditional methods.

Technical Difficulties in using AR

Despite its significant potential, AR adoption in educational settings faces numerous technical, pedagogical, and infrastructural challenges that can hinder the successful implementation of it. Technical limitations such as device compatibility, software glitches, and internet dependency disrupt seamless implementation particularly in under-resourced institutions (Le & Dinh, 2021; Godoy, 2022; Muniandy, 2024). The main issue is educators often lack adequate training to leverage AR effectively which leads to suboptimal usage or complete abandonment of these technologies (Ali et al., 2022 and Idul & Syaiful, 2024). AR's technical complexity poses significant challenges for both teachers and students who may not possess the digital literacy skills required for effective implementation. Issues like frequent system faults, high hardware requirements such as smartphones or tablets with AR capabilities, and unreliable internet connectivity hinder consistent classroom application (Marín-Rodriguez et al., 2023; Nincarean, 2024). Teachers have a high possibility to report frustration when troubleshooting technical issues which diverts valuable instructional time and undermines lesson objectives (Ali et al., 2022; Idul & Syaiful, 2024; Mkwizu & Bordoloi, 2024). The learning curve associated with AR technology can be particularly steep for educators who are not familiar with digital tools. Many teachers require extensive training to understand not only how to operate AR applications but also how to integrate them effectively into their existing curriculum and pedagogical practices (Wyss & Bäuerlein, 2024; Muniandy, 2024).

The Need for Simplicity and Accessibility in Using AR

For AR to be widely adopted in education, it's important that the applications are easy to use and affordable, without overwhelming users with unnecessary complexity. When designs are too complicated, they can discourage teachers and students especially in areas where digital literacy is still developing and users may not have the technical skills to navigate advanced interfaces (Nincarean, 2024; Muniandy, 2024). Thus, by creating simpler, and more streamlined AR experiences such as offline modules or lightweight apps can undoubtedly help close accessibility gaps and ensure that the benefits of AR aren't limited by technology constraints (Tarigan, 2024; Kumar et al., 2024). Moreover, schools and institutions also need to play their part by offering proper teacher training. When teachers feel confident and understand how to use AR in line with their lessons, they're more likely to use it effectively in the classroom (Mystakidis & Christopoulos, 2022; Ilona-Elefteryja et al., 2020).

Content Quality and Pedagogical Alignment

One of the biggest challenges in using AR in education is making sure technology actually supports learning instead of distracting from it. If AR content isn't thoughtfully designed, it can easily overwhelm students, especially with too many visual effects or complicated interactions which can interfere with their ability to absorb vocabulary and other key concepts (Yépez, 2024; Ali et al., 2022). While the novelty of AR can grab students' attention at first, that excitement can quickly turn into a distraction if the technology isn't used within a well-structured learning environment. This is why it is important for educational AR tools to be built on solid teaching principles that clearly connect with curriculum goals and learning outcomes. Achieving this means that developers need to work closely with educators, so the content they create truly complements what teachers are already doing, rather than working against it (Jumriani et al., 2025; Godoy, 2022).

Positive Outlook and Interest

Educators' acceptance of AR technology is pivotal for successful integration into STEM vocabulary instruction. Teacher attitudes significantly influence adoption rates and implementation quality since they serve as the primary gatekeepers for classroom technology use. Teachers' adoption decisions are largely influenced by perceived of usefulness, ease of use, and the degree of institutional support available, even though many of them are aware of AR's potential to improve engagement and conceptual clarity (Mokmin et al., 2022; Ripsam & Nerdel, 2024; Tiede et al., 2022). Survey research reveals strong teacher interest in AR technology with 87% of educators expressing willingness to adopt AR for STEM instruction when given appropriate support and training (Mokmin et al., 2022). Teachers consistently praise AR's ability to simplify abstract topics such as quantum physics concepts and molecular structures while also raising levels of student engagement and motivation (Muñoz et al., 2024; Rahmat et al., 2023). Positive attitudes toward AR correlate strongly with prior exposure to digital tools and educational technology which highlights the crucial role of professional development in shaping teacher perceptions (Tiede et al., 2022; Marín-Marín et al., 2023). Teachers who have taken part in technology training courses are more assured of their capacity to successfully incorporate Augmented Reality into their lesson plans.

Conditions for Acceptance and Adoption AR in STEM Education

Teacher acceptance of AR technology depends on several factors that influence their willingness to incorporate these tools into their instructional practices. Perceived of usefulness emerges as a primary factor where teachers must see clear connections between AR applications and improved student learning outcomes (Tiede et al., 2022; Marín-Marín et al., 2023). Educators are more likely to adopt AR when they can identify specific ways the technology addresses existing pedagogical challenges or enhances their teaching effectiveness. Ease of use represents another critical factor in teacher acceptance as complex or time-consuming applications may discourage adoption even among enthusiastic educators (Wyss & Bäuerlein, 2024; Muniandy, 2024). Teachers prefer AR tools that integrate seamlessly into existing lesson plans without requiring extensive preparation time or technical expertise.

Desire to Explore and Experiment AR in STEM Education

Despite challenges and concerns, educators demonstrate a strong desire to explore AR as a teaching tool particularly when provided with opportunities to experiment in low-stakes environments. Professional development programs that include hands-on exploration and pilot projects are instrumental in building teacher confidence and demonstrating AR's practical classroom applications (Ilona-Elefteryja et al., 2020; Mystakidis & Christopoulos, 2022). Teachers value opportunities to test AR applications with small groups of students before implementing them more broadly. This experimental approach allows educators to identify potential challenges and develop strategies for effective integration while building their technical skills and pedagogical understanding (Ripsam & Nerdel, 2024; Mokmin et al., 2022). It shows that many teachers possess the urge to try AR as a teaching tool in their classrooms.

Barriers to Adopt AR in STEM Education

Despite enthusiasm for AR technology, teachers exclaims several significant barriers that prevent or limit their adoption of these tools. Time constraints represent a primary concern as teachers struggle to find adequate time for learning new technologies while managing existing instructional responsibilities (Wyss & Bäuerlein, 2024; Muniandy, 2024). The pressure to cover curriculum requirements and prepare students for standardized assessments often takes priority over technology integration efforts. Moreover, inadequate training emerges as another significant barrier where teachers feel unprepared to use AR effectively or troubleshoot technical problems that may arise during instruction (Ali et al., 2022; Idul & Syaiful, 2024). Many educators express concerns about their technical competence and worry about appearing incompetent in front of students when technology fails to function properly. Next, lack of technical support within schools further compounds these challenges as teachers may feel isolated when attempting to implement AR applications without adequate institutional backing (Mkwizu & Bordoloi, 2024; Muniandy, 2024). Schools must address these gaps through targeted training programs, ongoing technical support, and pilot projects that provide scaffolded introduction to AR technology.

Technology Acceptance Model (TAM) as Framework

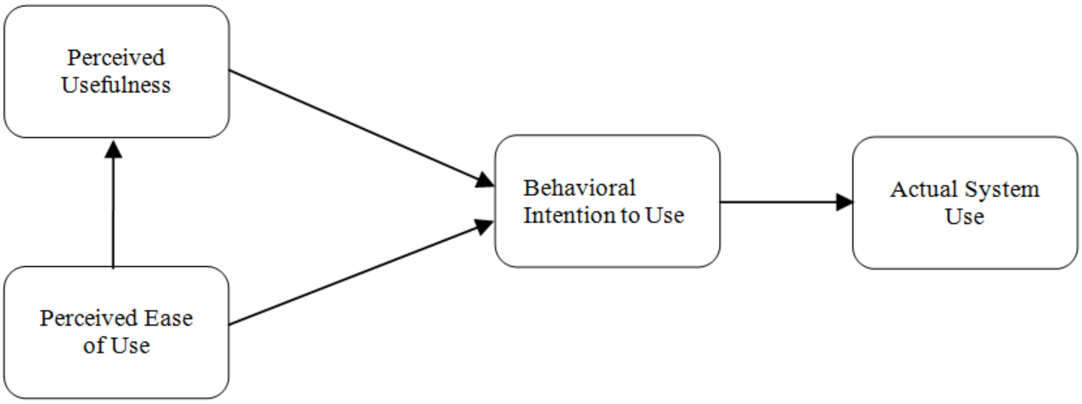

Figure 1:Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) provides a robust framework for evaluating user adoption of Augmented Reality in interview platforms, particularly for autistic individuals, by focusing on two core constructs: perceived of usefulness (PU) and perceived ease of use (PEOU) (Musa et al., 2024). In the context of AR, PU reflects the degree to which users believe the technology enhances their interview performance such as through interactive simulations or contextualized social cues while PEOU captures the intuitiveness and minimal effort required to navigate the platform (Adiani et al., 2022; Kumar et al., 2023). Studies applying TAM to AR interview tools highlight how features like real-time feedback and customizable scenarios directly influence PU by addressing neurodiverse users' unique needs, whereas streamlined interfaces and minimal technical complexity bolster PEOU (Riar et al., 2022). All in all, these perceptions shape users' attitudes and behavioral intentions, ultimately determining the platform's adoption and effectiveness in reducing employment barriers for autistic individuals (Musa et al., 2024; Adiani et al., 2022).

Methodology

This study aimed to explore the STEM teachers' perceptions regarding the usefulness of using Augmented Reality to enhance vocabulary acquisition in STEM-related content among ESL learners. A qualitative approach was selected to allow for deeper insights of participants' experiences, attitudes, and contextual challenges associated with the integration of AR in STEM teaching. This approach aligns with the interpretivist paradigm, which prioritises understanding how individuals interpret their personal and professional realities (Creswell, 2018).

Research Design

This research adopted a qualitative approach to gain an in-depth understanding of STEM teachers' insights into the integration of Augmented Reality for English vocabulary acquisition in STEM subjects. The study focused on the perceptions, experiences, and instructional challenges faced by four secondary school teachers. As Creswell (2018) notes, qualitative research is valuable for uncovering rich, contextual insights through open-ended exploration of complex educational issues. This design was selected to capture detailed narratives regarding how AR is perceived and potentially utilised in facilitating STEM-related vocabulary learning among ESL learners.

Participants

The participants in this study consisted of four STEM teachers employed at a reputable learning centre located in Selangor, Malaysia. The learning centre caters to a wide range of students from various school backgrounds, including those enrolled in the Dual Language Programme (DLP). A purposive sampling method was used to ensure the selection of teachers with relevant experience in integrating digital tools within STEM instruction, particularly in classrooms with ESL learners. This method ensured that participants could provide informed perspectives aligned with the study’s objectives.

Instrument

Semi-structured interviews served as the primary data collection instrument for this study. This instrument was chosen to allow flexibility in responses while ensuring consistency across participants. The instrument was designed to examine STEM teachers’ perceptions regarding the application of AR for improving English vocabulary acquisition in STEM topics. As highlighted by Ruslin et al. (2022), semi-structured interviews enable researchers to delve into participants’ views comprehensively while remaining focused on the central research questions. The interview questions were adapted from Wenfei et al. (2023), with modifications to better suit the context of STEM education and AR integration. Key themes included perceptions of AR’s usefulness, ease of use, and its role in teaching technical vocabulary.

Data Collection Procedure

The interviews incorporated a mix of open-ended and guided questions, allowing teachers to express their thoughts freely while addressing the core topics of the study. All interviews were conducted face-to-face and audio-recorded with the participants’ consent. Each session lasted approximately 10 to 15 minutes. Ethical considerations were strictly observed in which participants received detailed information about the study and provided verbal consent to agree to join this research willingly. Anonymity and confidentiality were ensured throughout the research process.

Data Analysis

Data from the interviews were analysed using Braun and Clarke’s (2024) six-phase thematic analysis method. The process involved familiarising with the data, generating initial codes, identifying themes, reviewing and defining themes, and compiling the findings into a final report. The flexibility of thematic analysis makes it suitable for a variety of qualitative research settings which also include studies exploring technology integration in education. During analysis, recurring patterns in participants’ responses were coded and grouped using qualitative analysis tools. These were then organised into overarching themes that reflect the participants' collective insights on the integration of AR for vocabulary teaching in STEM subjects.

Findings and Discussion

"What are the perceptions of STEM teachers regarding the usefulness of using Augmented Reality to enhance vocabulary acquisition in STEM-related content among ESL learners?"

To answer the research question on the perceptions of STEM teachers regarding the usefulness of using Augmented Reality to enhance vocabulary acquisition among ESL learners, several key themes emerged from the interview data. These include Perceived Usefulness, where teachers acknowledged AR's potential to support vocabulary learning through engaging visuals and real-time interaction. Perceived Ease of Use also surfaced, highlighting teachers' views on how user-friendly and accessible AR tools must be for effective classroom integration. In addition, their Attitudes toward AR reflected a mix of excitement and caution, depending on their prior exposure and confidence with technology. Lastly, their Behavioural Intentions revealed a general willingness to adopt AR, provided there is adequate support, training, and infrastructure. These themes collectively provide insight into the multifaceted perceptions that influence AR adoption in STEM-based ESL instruction.

Themes	Codes	Excerpts
Perceived Usefulness	Enhanced visualization	"AR could be very beneficial in STEM lessons as students can see for themselves how the phenomenon happens." – *Teacher 1* "I think it's very, very much helpful for students, especially in science subjects, because they can visualize it. They can have the 3D model especially related to… I can't I can't remember the chapter, but it's related to orientation of the body, The orientation, like the ventral part. Okay, the orientation of our body, so the students can visualize, yes, they can see clearly and they can move sound 360, So they can understand better what's ventral, they can understand the dorsal part is, the words, yes. " – *Teacher 2* "I think it has potential, particularly for helping students ask students, visualized abstracts or spatial context like shapes and graphs, and equations, in terms of 3D. Like volume in English. Okay, so this could make the terms more understandable." – *Teacher 3* "I believe AR could help a lot, especially to improve their vocabulary in terms of mathematics. And so it can show like 3D models and interactive visuals, because it's AR." – *Teacher 4*
	Vocabulary retention	"Yes, yes. I feel like uh it helps the students understand even more, especially in terms of vocabulary." – *Teacher 1*

		"To be honest, I think technology alone doesn't guarantee better vocabulary retention. Sometimes students just watch videos or click through the quiz without actually engaging. So in my experience, I think that the vocabulary takes better to repeat the use in discussion and guided practice." – *Teacher 3* "Especially to improve their vocabulary in terms of mathematics... It can show like 3D models and interactive visuals." – *Teacher 4*
Perceived Ease of Use	Technical Complexity	"The technology itself could be quite complicated especially for someone who has never used it." – *Teacher 1* "I think more to the technical part. We have to learn and we have to get used with the tools, with the terms, with the technologies and stuff. So if we don't get used to it, we cannot use it or perform it in the class." – *Teacher 2* "So basically, most teachers would say technical issues like hardware or internet access…" – *Teacher 3*
	Simple and User friendly	"module can be improved by adding by making it more user friendly for both the teachers and the students themselves. So it can be easily used by everyone. - *Teacher 1* "this module is maybe you can make it more uh teacher and student friendly.." - *Teacher 2* "The module should be simple to use, require minimum setup and work on common devices." – *Teacher 3* "I would suggest maybe make it like user friendly for both teachers and students." – *Teacher 4*
Attitude Towards Use	Positive attitude towards AR	"I think I would be open to using AR... it can help me greatly." – *Teacher 1* "I am open to use that (AR) because I think it has more benefits than it does not help. Yes. students will gain a lot of knowledge from using AR in the class. It's like an experiment, a hands-on experiment. Understanding theory, but using hands-on experiments." -*Teacher 2*
	Willingness to try with condition	"I'm open to exploring it, but I would need to see clear evidence that it improves the learning outcomes." – *Teacher 3* "I would be open to it if it's easy to use and also really adds value to the lesson." – *Teacher 4*

Behavioural Intention	Intent to use in future	"I think I would be open to using AR as I mentioned it can help me greatly, as in physics or in science or as a general" – *Teacher 1* I hope in future I can use this AR module... so I can first-hand experience how it works." – *Teacher 2*
	Intent based on usability	"If it has the comprehension without overcomplicating the lesson... it could be worth trying." – *Teacher 3* "It would be great if it can make learning more engaging without taking too much time to set up." – *Teacher 4*
External Barriers	AR not familiar in teaching setting	"I've never seen or heard AR being used in an education setting." – *Teacher 1* “No, I've never used or I've never seen (the AR).” – *Teacher 2* “Okay, um in terms of AR, not directly in a live class, but I have seen examples online.” – *Teacher 3* “in terms of AR, I think I haven't used it myself.” – *Teacher 4*
	Students distracted by technology	“I think AR has a great potential, especially in STEM subjects, but it shouldn't be distracting for the students, so um so I feel like uh it has to strike a balance between interesting and educational.” – *Teacher 1* “One more thing, students can get distracted.” - *Teacher 2* "Some get distracted easily or take lessons less seriously." – *Teacher 3* Also most of them get distracted easily when they use gadgets, right? – *Teacher 4*
	Lack of resources/devices	I think the main challenge would be the access to the device and also reliable Internet. – *Teacher 4* "Sometimes we face issues like poor Internet connection or not enough devices for every student." – *Teacher 4*

Table 1: Thematic Analysis of Interviews based on TAM Framework

The thematic analysis revealed five core themes aligned with the TAM framework, Perceived of Usefulness, Perceived Ease of Use, Attitude Towards Use, Behavioural Intention, and External Barriers. Each theme is supported by multiple codes and direct excerpts from participants, which are critically analyzed below to understand their significance and implications.

Perceived of Usefulness

One of the strongest themes to emerge was the perceived of usefulness of AR in enhancing learning, especially in STEM subjects. Teachers consistently emphasized its value of AR in enhanced visualization. Teacher 1, 2 and 3 reaffirm that the tool has potential in transforming static content into engaging, visual experiences. This demonstrates a belief in the power of AR to bridge abstract scientific concepts with concrete understanding. It also highlights how spatial interaction helps in internalizing anatomy-related content and reflects how AR can address different cognitive learning challenges, particularly in subjects like mathematics and science reaffirming the tool's potential in transforming static content into engaging, visual experiences. All participating teachers expressed a belief in the potential of AR to enhance students' understanding, particularly in visualizing abstract STEM concepts. Teachers shared that AR's 3D features enable students to grasp complex ideas by "seeing for themselves how the phenomenon happens." This aligns with existing literature, where AR is praised for its ability to improve conceptual comprehension by transforming abstract scientific content into concrete, interactive experiences (Ripsam & Nerdel, 2024; Erlangga et al., 2024).

The sub-code vocabulary retention also emerged, though with mixed responses. Teacher 1 stated, *"Yes, yes. I feel like uh it helps the students understand even more, especially in terms of vocabulary."* However, Teacher 3 cautioned, *"Technology alone doesn't guarantee better vocabulary retention...vocabulary takes better to repeat the use in discussion…"*

The use of immersive visuals, as noted by Belda-Medina & Marrahí-Gómez (2023), strengthens the link between vocabulary and its context, especially in anatomy or technical vocabulary. However, the contrast points to the dual-edged nature of technology shows that while it can support vocabulary learning through visual aids, it still requires structured pedagogical support to be effective. While most teachers believed AR enhances vocabulary understanding through meaningful visuals, some emphasized the importance of structured pedagogy for vocabulary retention which align with findings from Idul & Syaiful (2024), who note that AR should complement, not replace, effective teaching strategies.

Perceived Ease of Use

The perception of how easy or difficult it is to use AR was categorized into technical complexity and simple and user-friendly. Teacher 1 expressed concern that underscores the importance of training and professional development. Teacher 3 exclaimed infrastructural issues, highlighting external usability barriers. On the other hand, a desire for simplification came through clearly. Teacher 1 suggested, *"Module can be improved by making it more user-friendly for both teachers and the students…"*, while Teacher 4 also mentioned that, *"I would suggest maybe make it like user friendly for both teachers and students."*

This dichotomy shows that while teachers are open to AR, they are cautious about its practical integration and stress the importance of intuitive design. Teachers expressed mixed perceptions regarding AR's usability. While optimistic about its instructional value, concerns emerged over technical complexity and access. Several participants highlighted that without sufficient training, AR tools could be difficult to operate, especially for educators unfamiliar with advanced technologies. This is consistent with Ali et al. (2022) and Wyss & Bäuerlein (2024), who argue that digital literacy and ease of navigation are crucial for successful AR adoption. At the same time, teachers called for simpler, more user-friendly interfaces that accommodate both teachers and students. Literature suggests that simplified AR applications such as offline modules and lightweight mobile apps can significantly lower the entry barrier (Kumar et al., 2024; Tarigan, 2024). Therefore, for AR to be successfully adopted, the design must prioritize intuitive usability and provide adequate technical support.

Attitude towards Use of AR

Overall, teachers demonstrated a positive attitude towards AR, recognizing its educational potential. Teachers 1 and 2 demonstrate willingness to adopt AR in perceived student benefits and a belief in experiential learning. However, this positivity was conditional for some, leading to the sub-theme willingness to try with condition. Teacher 3 stated, *"I'm open to exploring it, but I would need to see clear evidence that it improves the learning outcomes."* Similarly, Teacher 4 added, *"I would be open to it if it's easy to use and also really adds value to the lesson."* These cautious endorsements suggest that while attitudes are generally favorable, actual adoption depends on demonstrable benefits and usability.

Generally, the teachers demonstrated a positive attitude toward AR, grounded in their belief that it can enhance student engagement and understanding. This is in line with findings by Tiede et al. (2022), which indicate that teachers with prior exposure to educational technologies tend to exhibit stronger enthusiasm for AR tools. However, this positive attitude was sometimes tempered by conditional openness. Teachers expressed willingness to adopt AR if it was easy to use and demonstrably effective. This finding reflects the core tenets of TAM, where perceived usefulness and ease of use significantly influence user acceptance (Davis, 1989). Similar sentiments were found in Marín-Marín et al. (2023), who noted that educators' readiness to integrate AR depends on the clarity of its benefits and its alignment with existing teaching strategies.

Behavioural Intention

The teachers' intention to use AR in future classrooms was largely influenced by their earlier themes. Teachers 1 and 2 intentions are clear and reflect forward-looking mindsets provided the conditions are favorable. However, intent based on usability was also evident. Teacher 3 explained, *"If it has the comprehension without overcomplicating the lesson... it could be worth trying."* Similarly, Teacher 4 said, *"It would be great if it can make learning more engaging without taking too much time to set up."* These statements reiterate that usability and time efficiency are pivotal in converting positive intention into practice.

Most participants indicated an intention to use AR in the future, particularly if provided with appropriate support and resources. Teachers stated their interest in firsthand experiences with AR modules, expressing hope to explore its practical implementation. However, their intent was contingent upon factors like simplicity, time efficiency, and accessibility. This reflects the TAM construct of behavioural intention, which is shaped by prior perceptions of usefulness and ease of use. As noted by Mokmin et al. (2022), behavioural intention is stronger when teachers feel confident in their ability to implement AR effectively. Thus, while willingness is evident, institutional support and ongoing training are essential to convert intent into action.

External Barriers

Despite positive perceptions, several external barriers were cited, most notably a lack of familiarity, potential distraction, and limited resources. Teachers admitted AR is not familiar in teaching settings. Teacher 1 said, *"I've never seen or heard AR being used in an education setting."*, and Teacher 4 echoed, *"I think I haven't used it myself."* This lack of exposure hinders confidence and readiness to integrate AR in classrooms. Another concern was students being distracted by technology. Teacher 1 warned, *"...it has to strike a balance between interesting and educational."*, and Teacher 3 noted, *"Some get distracted easily or take lessons less seriously."* These worries underline the importance of controlled and purposeful use of AR. Lastly, the lack of resources/devices was seen as a major obstacle. Teacher 4 pointed out, *"Sometimes we face issues like poor Internet connection or not enough devices for every student."* This reinforces the need for infrastructural support if AR is to be implemented effectively.

Despite positive perceptions, teachers identified several external barriers to AR adoption. A major concern was the lack of familiarity and training. Most participants had never seen AR applied in real classroom settings. This echoes findings by Muniandy (2024) and Ilona-Elefteryja et al. (2020), who argue that limited exposure to AR technology hampers teacher confidence and readiness. Another concern was the potential for distraction, where students might be more focused on the technology itself than the learning content. This supports the observations by Yépez (2024), who warned that AR, if not well-integrated, can become an entertaining distraction rather than an instructional tool. Additionally, infrastructure issues such as insufficient devices and unstable internet connections were highlighted, consistent with findings by Nincarean (2024) and Godoy (2022), who note that under-resourced environments are less conducive to AR-based instruction.

Conclusion

In conclusion, this study offers meaningful insights into STEM teachers' perceptions of integrating Augmented Reality for vocabulary acquisition, particularly within English-medium STEM instruction. However, several limitations must be acknowledged. Although all participants taught Science and Mathematics in English, one was not directly involved in the Dual Language Programme (DLP), which may have influenced the depth of language-related responses. Time constraints also limited the duration of interviews, as teachers were managing busy schedules. Moreover, the study focused only on Science and Mathematics educators, excluding other key STEM disciplines such as Technology and Engineering. This study only covers a portion of STEM context as it focuses only on Science and Math. Besides, most teachers were unfamiliar with AR prior to the study, requiring introductory explanations to envision its classroom application. Despite these limitations, the study highlights critical implications for educational practice. Consistent with the Technology Acceptance Model (Davis, 1989), teachers were more inclined to consider AR integration when they perceived it as useful and easy to use. However, successful implementation depends on system-level support. As recommended by previous research (Mokmin et al., 2022; Tiede et al., 2022), the development of curriculum-aligned AR content must involve teacher input to ensure usability and pedagogical alignment. Furthermore, ongoing professional development, not just one-time workshops, is essential for building confidence and competence among educators. Addressing infrastructure limitations, such as access to devices and internet connectivity, is equally crucial to ensuring equitable use of AR in classrooms.

From a theoretical standpoint, this study extends the Technology Acceptance Model (Davis, 1989) by situating it within the underexplored domain of AR-supported vocabulary learning in STEM-based ESL classrooms. It shows how perceived usefulness and ease of use influence teacher adoption when technology must serve both language and content learning goals, consistent with prior findings that educators adopt AR when they see clear links to improved learning outcomes and when tools integrate seamlessly into lessons (Tiede et al., 2022; Marín-Marín et al., 2023). This contributes new knowledge by linking TAM's constructs to the dual challenge of teaching STEM concepts and English vocabulary in multilingual settings. Contextually, the study addresses a gap in Malaysian research by documenting how linguistic diversity and uneven digital access shape teachers' readiness to integrate AR. While previous TAM applications to AR have centred on contexts such as interview preparation for neurodiverse users (Musa et al., 2024; Adiani et al., 2022; Kumar et al., 2023; Riar et al., 2022), this study extends its theoretical boundaries to a Malaysian ESL–STEM environment, revealing how the same constructs are mediated by linguistic diversity and infrastructural disparities. Critically, these findings underscore that policy and practice cannot rely solely on the novelty of AR to drive adoption, rather, successful integration demands targeted teacher training, curriculum-aligned content, and equitable access to technology. Contextually, this work fills a notable gap in Malaysian educational research by providing empirically grounded insights that can guide the strategic implementation of AR in ways that strengthen both STEM mastery and English language proficiency. Future research should expand to include a wider range of STEM subjects and school types to enhance generalisability. Investigating AR's effectiveness in vocabulary instruction across other subjects such as Technology, Engineering, or cross-disciplinary STEM modules would provide a broader understanding of its potential. In addition, incorporating student perspectives and conducting empirical studies would offer deeper insight into AR's impact on language retention, engagement, and learning outcomes over time. Thus, by addressing these areas will undoubtedly help strengthen AR's role in creating more inclusive, engaging, and effective vocabulary instruction within STEM education.

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