Bridging the Language Gap in STEM Education: Design, Development, and Evaluation of ME4STEM (Mobile English for STEM) Module

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ABSTRACT

Goal 4 in the Sustainable Development Goals (SDG) states that quality education could benefit Science, Technology, Engineering, and Mathematics (STEM) related fields, which are currently in high demand. However, language barrier has become an issue in the workplace, highlighting a need to enhance the English competency of STEM learners through English for Specific Purposes (ESP). Despite this, many ESP studies only focus on the communicative outcomes of ESP learning, leaving a theoretical gap in the field. Therefore, this paper aims to design a mobile module, Mobile English for STEM (ME4STEM), for STEM learners to enhance their English vocabulary competency based on various learning theories. This study employed Design and Development Research (DDR) Type 1, with content analysis used to determine words to be included in the module. The design stage involves designing the learning objectives, components, materials, flowchart and storyboard based on the needs analysis and ESP functional language, incorporating various learning theories, which are Mastery Learning, Cognitive Constructivism, Social Constructivism Theory, Problem-Based Learning and Cognitive Theory of Multimedia Learning. This study implied that theoretical foundations are vital in designing and developing a mobile app. Integrating multiple learning theories in the design and development of a mobile application gives more learning opportunities and ensures that the mobile app is holistic and feasible to be sustained. Future research can look into the evaluation of the mobile module.

Keywords: design; English; mobile; Science, Technology, Engineering, Mathematics (STEM); theoretical; vocabulary

Introduction

Quality education, as aspired in Goal 4 in the Sustainable Development Goals (SDG), shows that quality education is a national and global concern in ensuring that graduates could contribute back to society and the nation with their skills and knowledge, reducing inequalities

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in education and breaking the poverty cycle (United Nations, 2022).

In Malaysia, quality education could benefit the Science, Technology, Engineering, and Mathematics (STEM) education. As reported by the United Nations Educational, Scientific and Cultural Organisation (UNESCO), the STEM workforce is in high demand all around the world, which shows that STEM competencies for the 21st century and Fourth Industrial Revolution (IR4.0) era are highly valuable (Soo, 2019). However, in non-native countries like Malaysia, English language competency is crucial for STEM learners to ensure they could carry out their tasks efficiently and cater to the demands of the Fourth Industrial Revolution (IR 4.0) (Shrestha et al., 2018). Thus, English language competency in STEM education is important in IR 4.0.

Since STEM is exponentially recognized globally, there are more demands for STEM-related jobs (Ministry of Education, 2013; Sheldrake, 2020; UNESCO, 2020). As the number of STEM-related careers grows, the supply of STEM graduates should meet the demands of the country's economy. However, language barriers have emerged as a challenge in the workplace, with many graduates reportedly lacking sufficient English language skills for their job requirements (Agus Budiharto & Amalia, 2019; Amutan et al., 2019; Hirsch, 2017).

One reason is that English is not specifically tailored for STEM fields in the Malaysian context, highlighting the need to improve the English skills of STEM learners to enable them to compete both globally and internationally (UNESCO, 2020). Since difficulties with English often arise from a limited STEM vocabulary, this issue requires closer attention (Young et al., 2018). In Malaysia, there is a demand for graduates who possess strong English proficiency, especially because English is taught as a second language and serves as a bridge between non-native English-speaking countries (Rafiq et al., 2020). However, since English is a second language in Malaysia, there is a perception that graduates often lack sufficient language skills, which poses challenges within the Malaysian education system (Abidin & Hashim, 2021; Hirsch, 2017). The Malaysian Education Blueprint (2013-2025) emphasizes STEM education, and with the increasing demand for STEM-related jobs, addressing graduates' language deficiencies is crucial to improving education quality, as highlighted in the recent Twelfth Malaysia Plan (RMK12) (Economic Planning Unit, 2021).

STEM learners need to have adequate proficiency of English language vocabulary specified for STEM-specific contexts to efficiently carry out their work (Lacosse et al., 2020; Rafiq et al. 2025). In this regard, it is important to determine at which educational stage STEM learners should be taught this specialized vocabulary. De Meester et al. (2021) suggest that secondary schools, rather than higher education institutions, should address this issue, as language barriers during secondary education could discourage students from pursuing STEM-related courses in higher education.

In Malaysia, Form 4 and 5 learners can choose their stream of studies, either STEM or arts stream (Ministry of Education, 2013). This specific stream could introduce English for Specific Purposes (ESP) as the first step in preparing learners with adequate language competency to further their education in higher institutions (De Meester et al., 2020; Lacosse et al., 2020; Rafiq et al., 2024). Many secondary school students do not plan to pursue STEM-related studies at higher education institutions, which also poses challenges for the workforce and economy

(Ministry of Education, 2013). It is important to recognize that the English used in specialized fields differs from general English, especially with the growing role of technology in the workplace. This distinction has led to the concept of English for Specific Purposes (ESP), which refers to the English language tailored to particular communities and contexts (Hutchinson & Waters, 1987).

Creating authentic learning materials involves exposing students to topics and vocabulary relevant not only to the local context but also to the global environment (Cazzoli, 2022). De Meester et al. (2020), pointed out, language barriers in STEM education should be addressed at the secondary school level. Therefore, it is necessary to review the language level of Grade 11 in the General Certificate of Secondary Education (GCSE) curriculum from the United Kingdom, which corresponds to Malaysia's upper secondary Form 5 (Ong et al., 2021). Moreover, the GCSE content should be aligned with the Common European Framework of Reference for Languages (CEFR) B1 level, which is the standardized benchmark for all upper secondary students in Malaysia (Abidin & Hashim 2021; Ministry of Education, 2013). This alignment ensures that learners receive authentic, contextualized vocabulary instruction that connects to both local and global contexts.

Since English for STEM is yet to be introduced in Malaysia, there is a need to first introduce an alternative way of learning, via mobile application, as a means of informal learning. Informal learning through mobile apps can support and enhance students' learning experiences (Heidari et al., 2021; Rafiq et al., 2020) because these apps help connect formal education with informal learning opportunities (Khaddage et al., 2016; Sharples et al., 2006). Moreover, students tend to learn more effectively in informal settings since they engage voluntarily during their free time (Carraro & Trinder, 2021), making informal learning via mobile applications a practical approach.

While there are numerous mobile apps related to STEM, most focus on specific skills such as experiments or lab report writing, which are key aspects of STEM education (Heil et al., 2016). A systematic review by Persson and Nouri (2018) highlighted a shortage of mobile apps tailored for secondary school students, particularly in language learning and STEM subjects. Their study identified only six existing apps targeting formal education in secondary schools. To improve the English skills of STEM learners in Malaysia, informal learning—especially vocabulary development related to STEM—is essential. However, no mobile apps currently exist for informal learning in the secondary school setting, particularly for English in STEM, indicating a gap in available ESP apps for this context (Persson & Nouri, 2018).

Literature review

Research on English for Specific Purposes (ESP) has gained momentum since the 1960s. ESP addresses a wide range of fields such as arts, business, and sciences, and some courses even blend disciplines from both the arts and sciences. Pollard and Olizko (2019) explored how arts can be incorporated into ESP for tertiary-level chemical engineering, merging creativity and authentic materials within a STEM-related area. Another recent study by Dolidze and Doghondze (2020) focused on the use of technology in ESP instruction at the tertiary level.

Likewise, Fedorenko et al. (2020) examined ESP for technical skills among Ukrainian chemical engineering students. This growing emphasis on integrating technology in ESP research is bringing fresh perspectives to the field. Most ESP studies tend to focus on adult learners, particularly those in higher education (Lavrysh & Saienko, 2020; Lou et al., 2020; Mostafavi et al., 2021; Nikolaeva & Synekop, 2020; Otto, 2021; Saienko et al., 2019). This highlights a noticeable gap in ESP research concerning secondary school students.

Previous studies on ESP functional language have been carried out by various researchers and proven that ESP functional language provides more benefits than structural language. A study by Marcu (2020) identified the functionality of ESP in English in a manufacturing context. It was reported that scaffolding English language words concerning the function of each word in the manufacturing context encourage learners to gain more resourceful materials, and it is less restrictive. Supporting this is a study by Tosuncuoğlu et al. (2022), who looked into the different orientations of teaching ESP from GE and reported that ESP specifies learners' needs, which allows learners to gain autonomy in learning. It was also mentioned that the functional element in ESP, specifying the functions of language used in specific contexts, could allow learners to relate language learning to their situation, which is more beneficial. These two studies imply that introducing English words to learners in specific contexts encourages more learning autonomy and is less restrictive for learners since they can apply the words in real-life contexts.

Studies in STEM and ESL are still scarce regarding the adamant role of the English language in the STEM field. A study by LaCosse et al. (2020) mentioned that English as a second language (ESL) learners who are enrolled in the STEM field lack the linguistic abilities to represent their tasks and performance efficiently. This is because ESL vocabulary and STEM are different. Supporting the study were studies from a few other researchers who also pointed out the differences in ESL and STEM vocabularies (Chubko et al., 2019; Lee & Stephens, 2020; Pollard & Olizko, 2019; Saienko et al., 2019). Relating this issue to the Malaysian context, it could be seen that one of the problems in STEM education is the language barrier. A study by Baharin and Kamarudin (2018) mentioned that the language barrier has caused STEM learners to be afraid and uninterested in pursuing STEM in higher education. A more recent study by Sabirin et al. (2020) supported the issue of the language barrier among STEM learners in Malaysia. This shows that the English language for STEM needs to be investigated.

Aside from the language barrier, past studies also have shown that language content for STEM should be authentic (Mallia, 2017; Puteri Zarina et al., 2019; Zhai, 2019). As mentioned by these researchers, STEM materials differ from learning the language's content. This is because STEM vocabulary differs; hence authentic materials and content should be used instead. Looking into STEM and English in Malaysia, as Junaini et al. (2019) mentioned, a lack of STEM vocabulary is one of the STEM learners' difficulties. The vocabulary, mainly the technical terms in English, is not similar to the general English taught in Malaysian schools. In addition, schools in Malaysia generalize English language teaching; thus, the content is not contextualised to a specific field of study (Fang & Liu, 2020). To bridge this gap between the English language and STEM education, there is a need for a supplementary English course for STEM education.

Cognitive constructivism is highly relatable to the process of vocabulary learning. A previous case study by Suhendi et al. (2021) on Indonesian students' achievement and ability through implementing cognitive constructivism showed positive results. They mentioned that students' abilities improved, allowing them to be creative as their knowledge was developed based on previous lessons. In addition, they also mentioned that cognitive constructivism is more effective in encouraging individual learning, as learners' cognitive abilities differ from one another. Similarly, Mohamad Siri (2018) also mentioned that cognitive constructivism allows learners to construct their knowledge cognitively. This would render learners more effective learning opportunities if they could learn independently (Mohamad Siri, 2018; Suhendi et al., 2021) to construct their knowledge suited to the current 21st-century demands (Orak & Al-Khresheh, 2021; Yadav, 2021). Orak and Al-Khresheh (2021) emphasised technological advancements to encourage English language learners to construct knowledge by implementing a cognitive constructivism strategy. It was also mentioned that learners who practise their knowledge in real-life contexts would allow optimum learning. As Suhendi et al. (2021) supported, cognitive constructivism could enhance individual learning by introducing a positive environment.

Social constructivism is a theory looking at how learners learn with the aid of their surroundings, actively constructing learning. Based on previous studies, social constructivism provides opportunities for learners to analyse their learning and make progress by themselves (Amna Saleem et al., 2021). A review by Du and Liang (2021) explored how social constructivism directed multimedia implementation in teaching English and said that combining social constructivism with multimedia promotes the effectiveness of English language teaching, improving learners' learning abilities. A constructivist platform could encourage learners to cooperate and construct their learning. This is supported by Jacobs and Renandya (2021), who mentioned that learners prefer to learn via cooperation, thinking, and using the Internet. These learners' choices reflect the social constructivist approach. One notion is that social constructivism does not focus on traditional teaching and learning, whereby learners sit, listen and absorb knowledge. Instead, they are encouraged to seek information actively (Vygotsky, 1997). Tomak (2022) supported this statement by stating that learners who scaffold the learning of their peers tend to perform better and have higher critical and collaboration skills. In addition, these learners also learn better from peers whose language proficiency is more elevated than theirs because they are more comfortable and could understand each other (Mohamad Siri, 2018). This shows that scaffolding is not only limited to teacher-student interaction but also student-student interaction, which promotes a more desirable outcome. Hence, social constructivism in language learning is vital, not only for language improvement but also for developing 21st-century skills.

Mastery learning has produced positive feedback, particularly in enhancing learners' skills. One feature of mastery learning is the systematic way of delivering lessons, a step-by-step approach that allows learners to understand the lesson clearly. Besides the skills, English as a Foreign Language (EFL) learners who learnt via a mastery learning approach were also reported to have higher self-efficacy and better communication skills (Abd Ellateef, 2021). This is because learners could explain their learning clearly, as the mastery learning approach provides them with step-by-step instruction, contributing to their confidence in acquiring knowledge. Supporting this statement, Komalawardhana et al. (2021) also said that the students achieved the lesson's concepts better via mastery learning. They studied Chinese, Japanese, Arabic, and Indonesian students, promoting game-based learning via a mastery learning approach. As these studies reported, mastery learning offers an opportunity for learners to develop themselves for the future, which aligns with the National Education Philosophy, which is to create a holistic individual (Ministry of Education, 2013).

Problem-based learning is an approach widely used in this 21st-century era because it is also one of the skills required in the current world. In a study by Nurul Iskandar et al. (2021), teaching and learning English as a foreign language (EFL) for vocational students via problem-based instruction is effective. This is because vocational school students require critical thinking, problem-solving, and adequate language abilities. Due to that, the integration of problem-based learning in EFL classrooms provides more exposure to learners to relate learning to their contexts. This is supported by Alemi et al. (2021), who reported similar findings from 379 Iranian students in soft and hard science fields. These students were positive towards problem-based learning as it could assist language learning. In enhancement, the learners also mentioned that problem-based learning grants them the autonomy to collaborate with others to solve real-life problems . side from that, studies have also shown that problem-based learning is fun (Jasti & Pavani, 2021) and develops students' understanding (Putra et al., 2021) because they are allowed to construct their learning. This enhances their critical thinking and communication skills as they should work with their peers to solve problems. This is crucial as one of the features of problem-based learning is providing space for learners to apply their knowledge and solve real-world issues.

Cognitive Theory of Multimedia Learning (CTML) promotes the dual coding element, which means that visuals should always accompany audio to encourage the retention of vocabulary learning. The CTML is the most suitable theory underpinning vocabulary learning because it promotes multimedia design to enhance the retention of words in a learner's memory (Mayer, 2014). A previous study by Aravind and Rajasekaran (2021) showed that multimedia tools designed with CTML provide a better learner retention outcome. One feature of CTML that contributes to these is the usage of video subtitles. As mentioned by Asllani and Paçarizi (2021), to introduce vocabulary to learners, they need to see the image, listen to the audio and read the words (know the spelling). This contributes to a pedagogical feature in video creation, whereby subtitles should be included rather than only audio and images.

Likewise, Teng and Zhang (2021) conducted a similar study on 95 students. They reported similar findings, which show that learners need to be introduced to the word, definition, information of the word, and audio, all combined in a video. This could enhance the vocabulary learning environment of learners and increase their retention. However, Kanellopoulou et al. (2019) mentioned that multimedia integration in second language learning is viable, but excessive usage of videos is still unclear in improving vocabulary retention. Mayer (2014) also emphasised that learners need to be able to listen and see to make sense of their learning. Thus, integrating subtitles into video is an aspect to consider when designing a video-based lesson.

The cognitive constructivist approach plays a crucial role in vocabulary learning by ensuring that content is presented within meaningful contexts. Piaget (1974) introduced this approach to encourage learners to engage with real-world situations and review lessons to strengthen their memory. However, when applied to the authentic learning environments of ESP, many studies tend to emphasize communicative outcomes rather than vocabulary acquisition itself (Bosco et al., 2020; Masita, 2020; Ran, 2020). This represents a theoretical gap since constructivism emphasizes social interaction. Nonetheless, as Bloom (1968) pointed out, language acquisition first requires cognitive development before social engagement, highlighting the need to focus on building learners' cognitive skills when learning authentic ESP vocabulary, especially in STEM fields.

Hence, mastery learning, combined with cognitive constructivism, social constructivism, problem-based learning, and cognitive theory of multimedia learning in mobile learning, would benefit learners. For this study, the novelty of integrating these theories into mobile learning is proven to be an advantage for teachers, learners, and stakeholders in achieving a positive outcome for the education of STEM and English. Therefore, this paper aims to design a mobile module, Mobile English for STEM (ME4STEM), for STEM learners to enhance their English vocabulary competency based on various learning theories.

Methods

This study employed Design and Development Research (DDR) Type 1. The DDR Type 1 in this study provides a substantial approach to addressing the gap in the lack of research associating STEM education with English language learning. Design and Development Research has been chosen for this study because it is the most suitable approach for solving an issue in a particular context. The problem found in this study is related to the English language competency of STEM learners. Since this study does not generalize the findings, a more practical approach is needed; hence DDR is chosen. Plus, the issue of STEM learners is related to real-life contexts, which requires an authentic solution that DDR can provide.

The design and development phase is the second phase in this research, which includes two stages: 1) design and 2) development. The design stage refers to designing the learning objectives based on the results of the needs analysis. Also, the learning components were designed in this stage based on the learning theories and approaches chosen. The interface and layout design were also determined in this stage.

The design stage began with designing the learning objectives, whereby learning objectives for the mobile app were designed based on the needs analysis in the first phase and ESP functional language. After the objectives were created, the learning components were designed based on the learning theories used for this study: the ESP functional language, mastery learning, cognitive constructivism, social constructivism and problem-based learning.

The rationale for choosing mastery learning is to ensure learners can master the learning with the mobile app by reviewing and gaining corrective feedback. The elements of mastery learning (learning video, practice, and assessment) are components of the mobile app. The learning theories are chosen to provide a solid foundation for this study.

Cognitive constructivism is applied to design learning modules that connect with learners' existing knowledge and experiences, helping them integrate new information with what they already know. This theory supports the review aspect of the study. Successful learning depends on learners' ability to effectively process information. Social constructivism is also incorporated because it promotes peer interaction and discussion, which helps learners fully grasp the material; this is reflected in the use of discussion forums. Since learners engage in discussions, problem-based scenarios are included to encourage the use of STEM-related vocabulary. This approach aligns with constructivist principles, as problem-based learning is rooted in constructivism (Barrows 1996).

After that, the materials for the mobile learning module were designed based on the Cognitive Theory of Multimedia Learning. The Cognitive Theory of Multimedia Learning is chosen to ensure relevant multimedia is selected to cater to learners' visual and auditory memory. Not too much information is presented in the mobile app as it may cause an overload of information (Mayer, 2009). In this study, the materials include videos with subtitles and images with words to adhere to the theory.

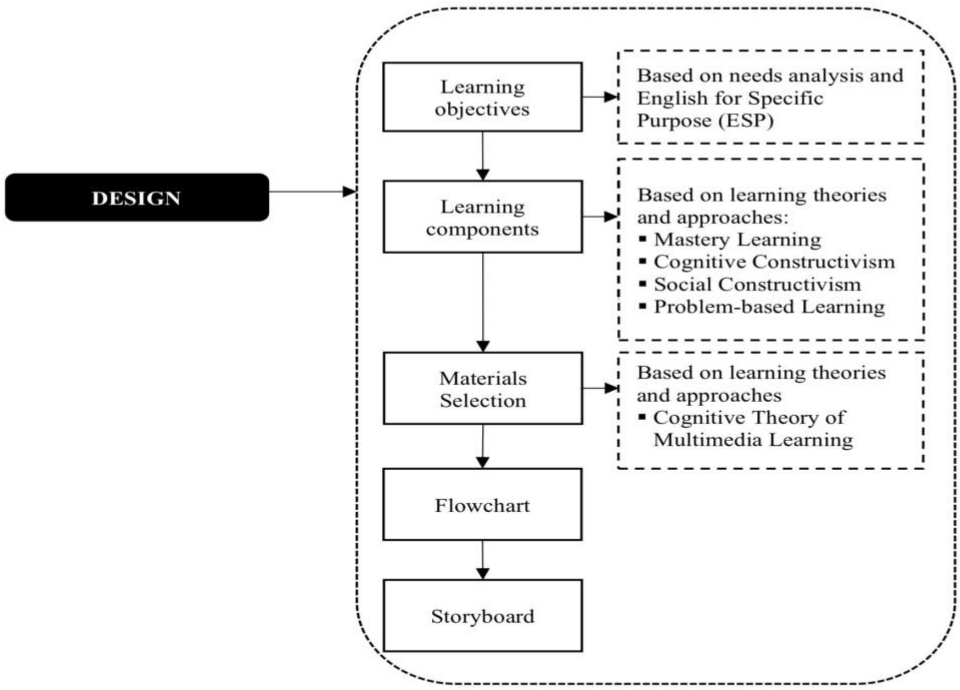
This shows that teachers and educators should create authentic problem-based tasks to encourage learners to construct cognitive solutions by socially interacting with their peers through mastery of learning. Hence, all these theories work hand-by-hand in ensuring a novel learning mobile module can be developed for STEM learners. Then, the flowchart of the mobile learning module was designed, followed by the storyboard.

Results/Findings and discussion

The design of the mobile app adhered to the needs analysis findings in Phase 1. Figure 1 shows the Design stage's process.

Figure 1.

The design stage



Based on Figure 1, the learning objectives for the mobile module were designed based on the findings of the needs analysis. Referring to the needs analysis, the problem of STEM learners was a lack of vocabulary. Hence, the mobile module's objectives were designed to enhance the vocabulary of STEM learners. Also, to identify the objectives needed, content analysis was carried out.

a. Learning objectives

Content analysis was carried out in this phase to ensure that the vocabulary chosen was suitable and adequate for STEM learners. Two steps were involved in the analysis: 1) reviewing content from seven sources and 2) matching the vocabulary to the Malaysian CEFR B1 syllabus.

First, the researcher reviewed seven sources: 1) GSCE (General Certificate of Secondary Education) Science, 2) GSCE Information Communications Technology (ICT), 3) GSCE Digital Technology, 4) GSCE Mathematics, 5) KSSM Form 4 Science, 6) KSSM Form 4 Maths and 7) Pitch like a Pro (Open learning resource which had been evaluated). The choice of sources for content analysis depends on the researchers' aim (Berelson, 1952), and since there is a lack of authentic resources for STEM education (refer to 1.3.4), using these seven sources is necessary (Abidin & Hashim, 2021; Md Nawawi et al., 2021; Ministry of Education, 2020; Ong et al., 2021). Table 1 shows the vocabulary words gathered for each source.

Table 1.

Number of vocabulary for each source

Source	Science vocabulary (n)	Technology vocabulary (n)	Engineering vocabulary (n)	Mathematic vocabulary (n)
GSCE Science	27			
GCSE ICT		49		
GCSE Digital Technology			33	
GCSE Mathematics				106
KSSM Science	68			
KSSM Mathematic				49
Pitch like a Pro	8	16	30	16
TOTAL	**103**	**65**	**63**	**171**
TOTAL (WORDS) FOR ALL				**402**

As displayed in Table 1, a total of 402 words were extracted from the seven sources. The rationale for reviewing other sources is that STEM is an integrated subject. Only focusing on one STEM strand would not be effective for the learners. Hence, reviewing sources related to STEM gives a broader input to the vocabulary used by STEM learners across the globe. After compiling the vocabulary from seven sources, the researcher matched the vocabulary to the Malaysian CEFR B1 syllabus, as displayed in Table 2.

Table 2.

Number of vocabulary for each source

Domains	Vocabulary (n)	Vocabulary matched with CEFR B1 (n)
Science vocabulary	103	13
Technology Vocabulary	65	54
Engineering vocabulary	63	13
Mathematic vocabulary	171	17
TOTAL	**402**	**97**

Table 2 shows the total number of vocabulary matched with CEFR B1. The total number of vocabulary chosen for the app is 97. The vocabulary was then grouped into eight modules. The vocabulary was categorised based on its uses, and vocabulary from all domains was combined into one field, STEM. After that, the learning components were determined. The 97 words were divided into eight modules as follows:

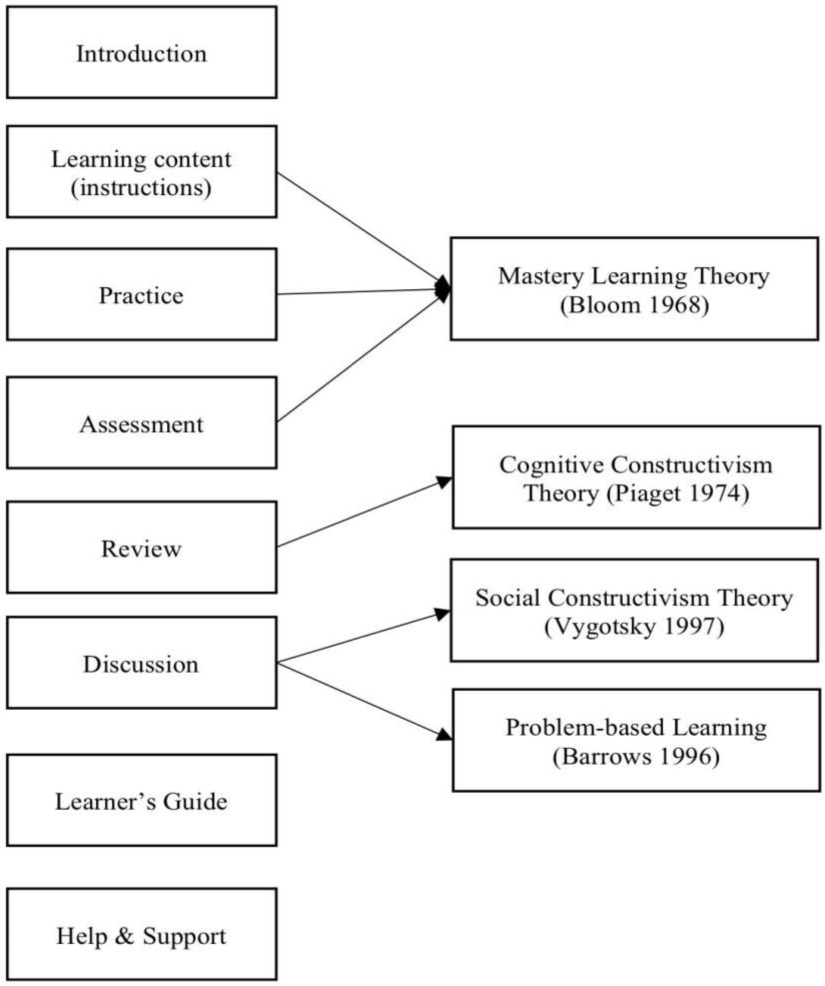
- **Module 1:** The Rise of Machines (Words included: CD-Rom, disk, hardware, programme, radio, remote control, software, user,virus, volume, webcam)
- **Module 2:** Help! It is a Blackout Emergency (Words included: back-up, boot, connect, electric, electricity, electronic, plug, power, switch, window)
- **Module 3:** Crash-Test (Words included: accurate, argument, break down, control, design (verb), display, out of order, pump, reason, speed, stop, test)
- **Module 4:** Our Companion Robot (Words included: button, communicate, digital, download, hand-held, install, internet, message, network, password, search, server, technology)
- **Module 5:** The Cloud System (Words included: access, attach, blog, document, drive, e-mail, file, link, solution, system)
- **Module 6:** Dear Math (Words included: arithmetic, circle, distance, division, edges, equals, face, interval, less than, multiplication, order of operations, plus, product, subtract)
- **Module 7:** Save Mother Nature (Words included: energy efficiency, environment, recycle, region, traditional medicine, tree)
- **Module 8:** Let's Experiment (Words included: calibrate, cause, effect, experiment, hypothesis, observation, pattern, perform, predict, problem, range, reliable, repeatable, socio-scientific, theory, uncertainty, valid, variable)

To further elaborate, the words chosen were categorised into their respective modules. The number of words for each module adheres to Beck et al. (2013) and Graves, (2016) vocabulary size, which is between eight and twenty words per day

b. Learning components

The learning components were determined once the learning objectives and vocabulary were identified. Using the theories and approaches, the components required in the mobile app were designed, as displayed in Figure 2.

Figure 2.
Design of the learning components (first draft)

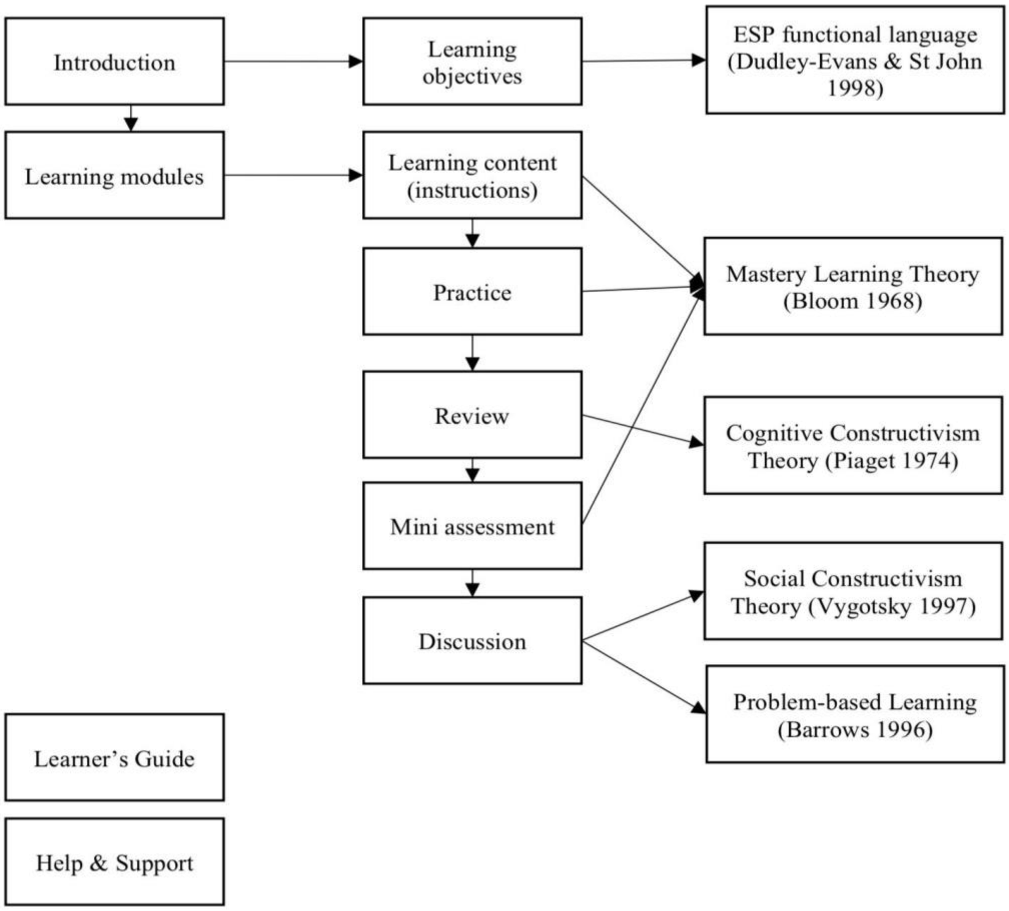


Based on Figure 2, the learning components include the introduction to help and support. Referring to the Mastery Learning Theory by Bloom (1968), the three theories' three constructs were learning content (instructions), practice and assessment. The review constructs from Cognitive Constructivism by Piaget (1974) ensured that the vocabulary was remembered. Since a mobile app should not only be monotonous, the discussion element was underpinned by Vygotsky's social constructivism theory (1968) and Barrows's problem-based learning (1996). The learner's guide and help and support components were also included.

However, the components were not specific enough. The first draft did not include English for Specific Purposes (ESP) in the components, which is the foundation of this app. Hence, the learning components were redesigned to integrate the learning theories and approaches better. Figure 3 below shows the learning components' finalised draft design.

Figure 3.

Design of the learning components (finalised)



As shown in Figure 3, the ESP functional language (Dudley-Evans & St John, 1998) was the foundation for the app because the learning objectives were designed. After the introduction, the learning modules, consisting of five components, were included. The arrangement of components was rearranged accordingly. The review component was integrated within the mastery learning theory, as the review helps enhance students' understanding of the vocabulary. The assessment was also changed to a mini-assessment because it caters to the assessment for each unit.

c. Materials selection

After the outline of the learning components was finalised, the materials were selected based on the Cognitive Theory of Multimedia Learning by Mayers (2009). The materials cater to the dual-coding theory, both audio and visual integration. Each audio should be represented visually, as learners need mental representation to understand the information. Due to that, videos, images, and texts were included in the app. Table 3 shows the materials selected for each component.

Table 3.
Materials selected for each component

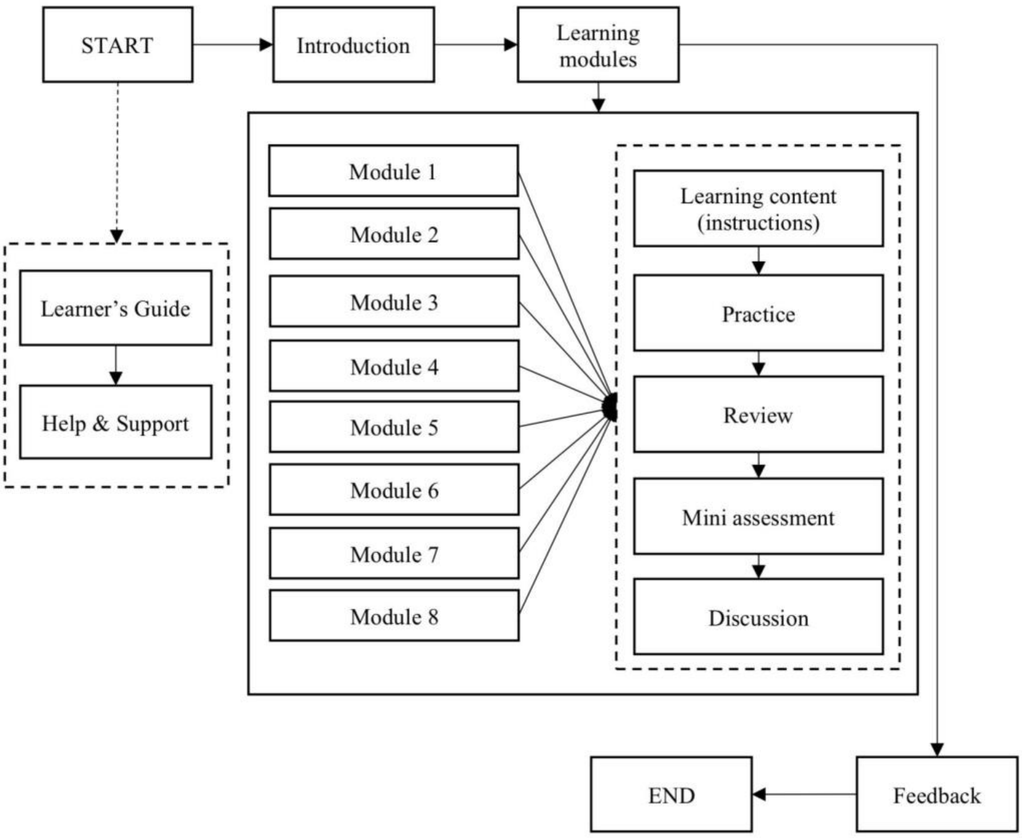
Unit	Learning content	Practice	Review	Mini assessment	Discussion
Module 1: The Rise of Machines	Video	Word Wall Quiz Multiple choice questions (MCQ)	Image carousel with text	Video of real-life context and gap filling in Word Wall	Forum for discussing problems in a real-life context
Module 2: Help! It is a Blackout Emergency	Video	Word Wall (MCQ) Quiz	Image carousel with text	Video of real-life context and gap filling in Word Wall	Forum for discussing problems in a real-life context
Module 3: Crash-Test	Video	Genially MCQ Quiz	Image carousel with text	Video of real-life context and gap filling in Word Wall	Forum for discussing problems in a real-life context
Module 4: Our Companion Robot	Video	Word Wall (MCQ) Quiz	Image carousel with text	Video of real-life context and gap filling in Word Wall	Forum for discussing problems in a real-life context
Module 5: The Cloud System	Video	Genially MCQ Quiz	Image carousel with text	Video of real-life context and gap filling in Word Wall	Forum for discussing problems in a real-life context
Module 6: Dear Math	Video	Genially MCQ Quiz	Image carousel with text	Video of real-life context and gap filling in Word Wall	Forum for discussing problems in a real-life context
Module 7: Save Mother Nature	Video	Word Wall (MCQ) Quiz	Image carousel with text	Video of real-life context and gap filling in Word Wall	Forum for discussing problems in a real-life context
Module 8: Let’s Experiment	Video	Genially MCQ Quiz	Image carousel with text	Video of real-life context and gap filling in Word Wall	Forum for discussing problems in a real-life context

As displayed in Table 3, each component had specific materials. In the learning content (instruction), videos were chosen to introduce the content for the unit. In practice, adhering to the needs analysis, multiple-choice questions (MCQ) were embedded in online platforms, such as Word Wall and Genially, to vary the learning materials chosen. For review, the image carousel displaying the vocabulary was the material chosen. The image carousel includes the text or vocabulary for the images displayed. For the mini-assessment, videos of real-life contexts were used to enhance learners' understanding of the content vocabulary. After that, gap-filling in Word Wall was included because it was one of the most preferred learning activities in needs analysis. Finally, in the discussion, a forum was chosen to encourage learners' participation in discussing and solving problems related to real-life contexts. All activities were designed based on ESP by Dudley-Evans & St John (1998).

d. Flowchart

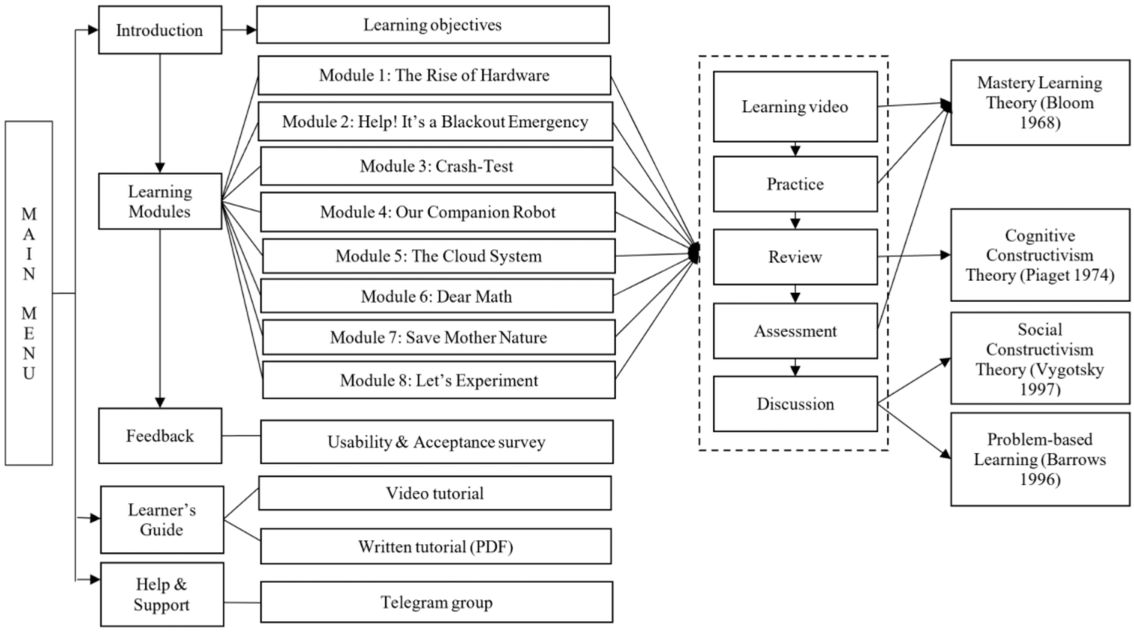
Once the materials were selected, the flowchart was designed to ensure the mobile app had a smooth flow. The flowchart is displayed in Figure 4 below.

Figure 4.
Flowchart



Based on the flowchart in Figure 4, the mobile app started with an introduction followed by learning modules. There were eight modules in the mobile app. Each module had five components known as 1) learning content (instructions), 2) practice, 3) review, 4) mini-assessment, and 5) discussion. After completing each unit, learners went to feedback, where they could provide feedback for the overall app. Learners who needed guidance navigating the app could go to the learner's guide. If they require more help, they could contact the developers via help and support. A more detailed flowchart was designed with the units of the module. The detailed flowchart is represented in Figure 5 below.

Figure 5.
Detailed flowchart



The app started with the main menu based on the detailed flowchart in Figure 5. Then, learners could go to the introduction page, where the learning objectives were displayed. After that, they could go to Learning Modules, where eight modules exist. Each module had five components: 1) Learning video, 2) Practice, 3) Review, 4) Mini-assessment, and 5) Discussion.

Mastery Learning underpinned the learning video, practice, and mini-assessment (Bloom, 1968). The construct learning content (instructions) in Bloom's Mastery Learning was changed to a learning video for the app because the content in that section consists of only vocabulary videos. The review component was underpinned by Cognitive Constructivism by Piaget (1974), whereby reviewing the lesson enhances learners' cognitive abilities. Finally, the discussion was underpinned by Social Constructivism (Vygotsky, 1997) and Problem-based Learning (Barrows, 1996). Due to the nature of the discussion, these two theories underpinned the discussion section. The discussion allowed learners to interact with each other to solve real-life problems.

After completing the learning modules, learners could go to feedback to comment on the app. For the learner's guide and help and support, learners who need guidance could first go to the learner's guide. There was a video tutorial in the learner's guide. If they could not follow the guide, they could go to help and support, whereby a Telegram group with the developers was created to assist learners in real-time.

e. Storyboard

After designing the flowchart, the storyboard for the mobile app was designed. The storyboard was done using an online storyboard design for a mobile app (milanote.com). The storyboard for the mobile app is displayed in the following figures (Figure 6 to Figure 11).

Figure 6.

The main menu and introduction pages

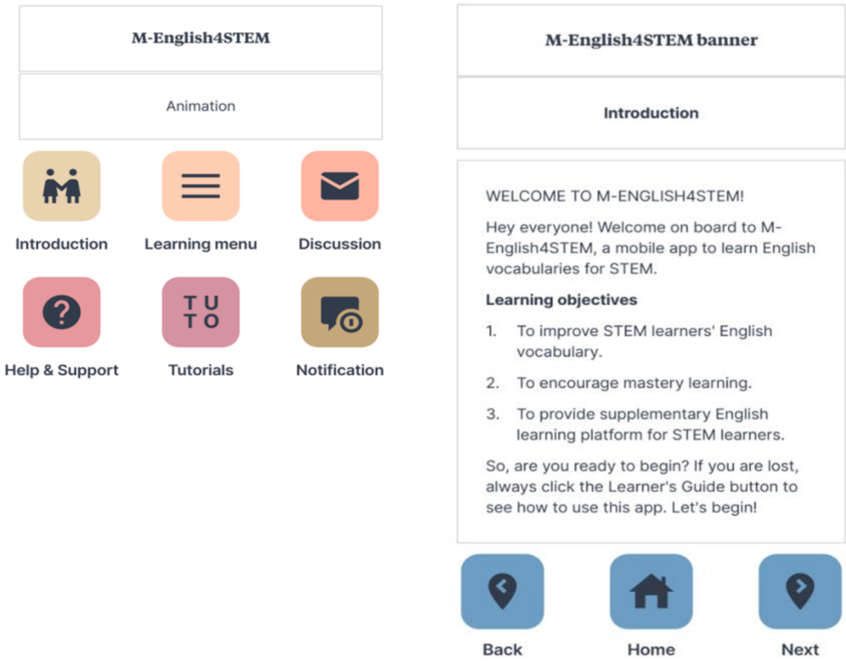


Figure 7.

The learning menu and Module 1 front page

Figure 8.

Learning video and practice pages

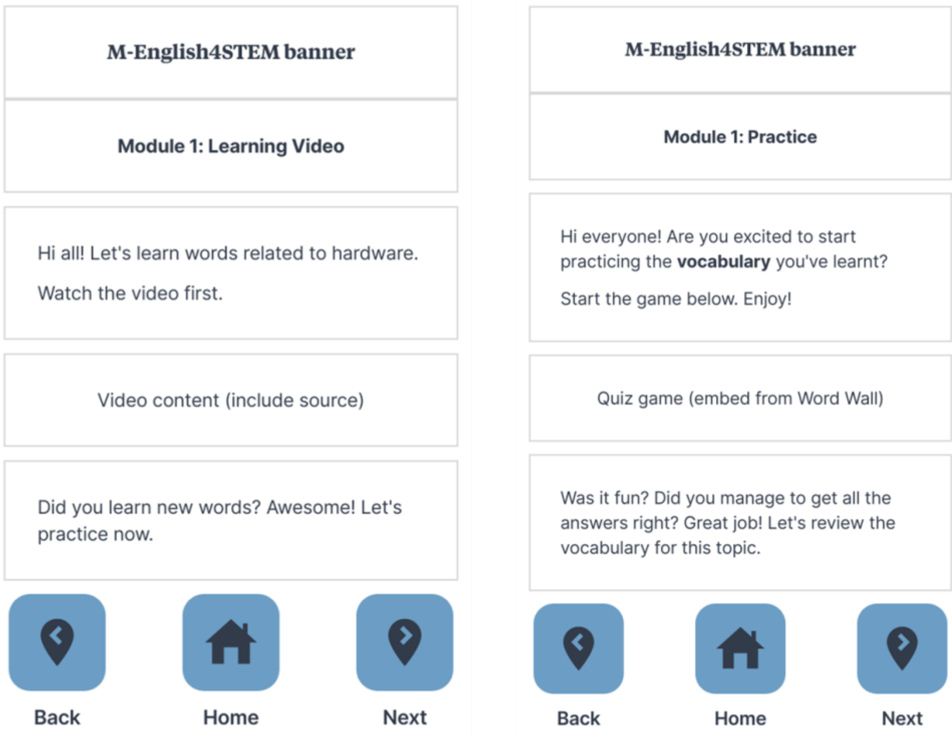


Figure 9.

The review and mini-assessment pages

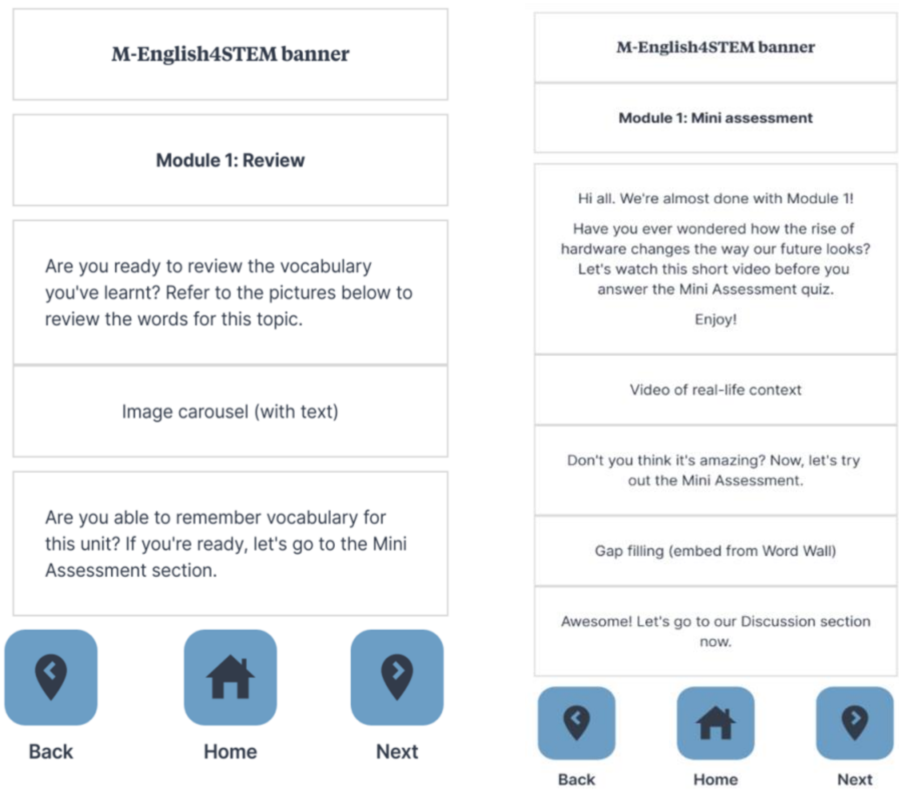


Figure 10.

The discussion and feedback pages

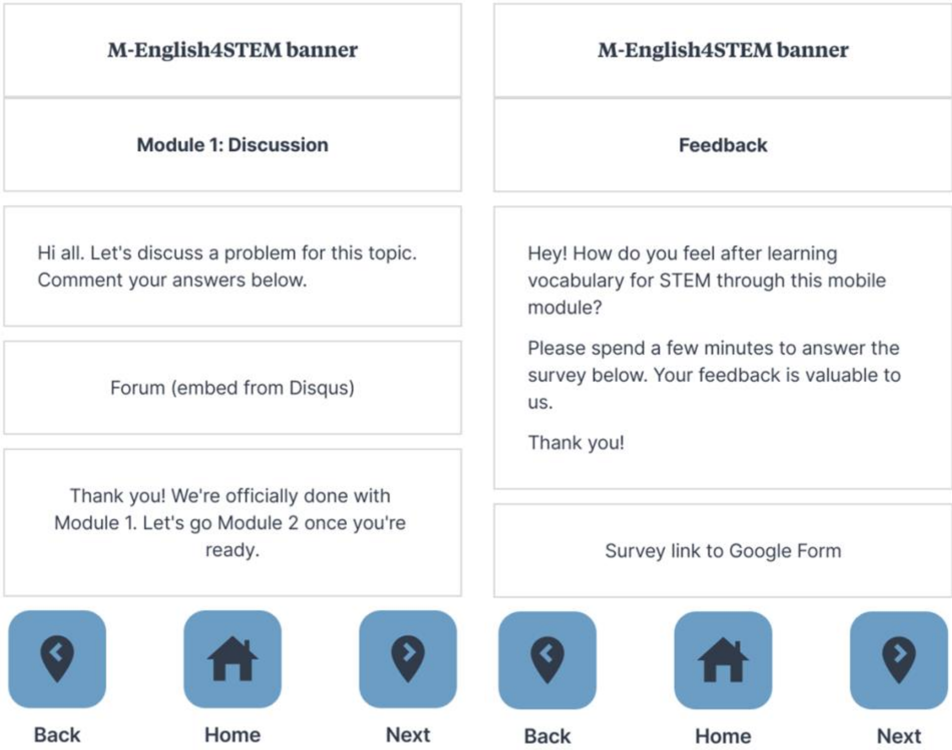
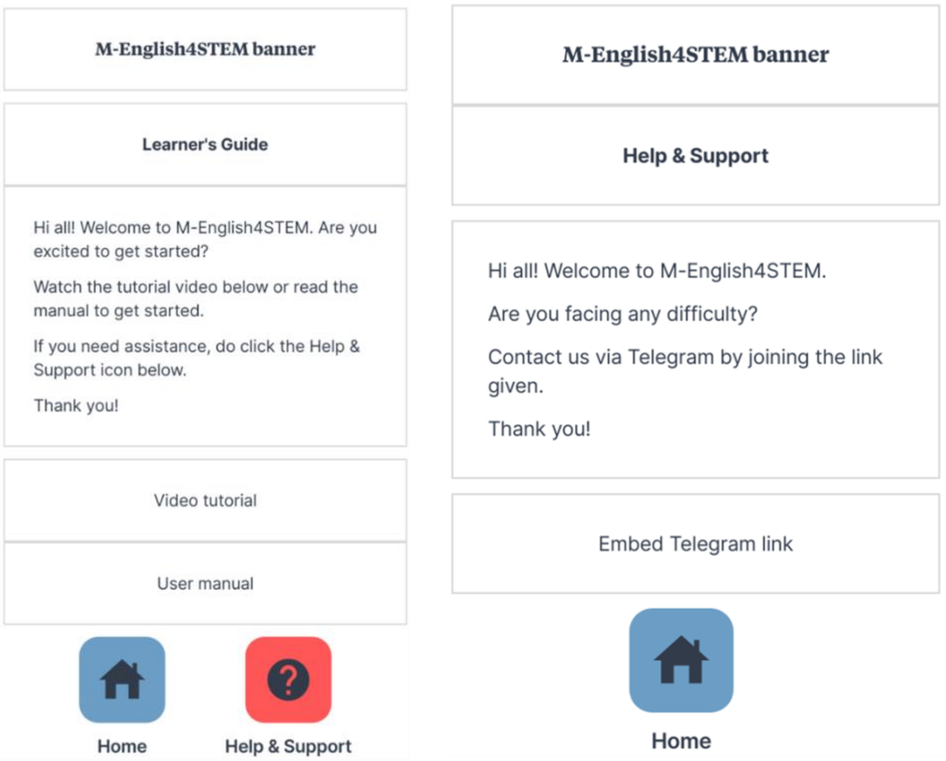


Figure 11.

The learner's guide and help and support pages



Based on Figures 6 to 11, the storyboard of the overall app was drafted. The other modules (modules 2 to 8) followed the same storyboard as module 1. After the storyboard was designed and presented, the mobile app development occurred.

Discussion

In the design stage of the Design and Development Phase, content analysis was carried out to identify the vocabulary to be used in the app. Based on content analysis for seven sources, 402 words were identified. According to the Malaysian standard for upper secondary students, the vocabulary matched the CEFR B1 level. Out of 402, 97 words were selected and categorised into eight topics.

Berelson (1952), the pioneer of content analysis, mentioned that the choice of texts depends on the research objectives and the researchers themselves. The content analysis was carried out in this phase to ensure that the vocabulary chosen is adequate and suitable for STEM learners by reviewing seven sources' content (Abidin & Hashim, 2021; Md Nawawi et al., 2021; Ministry of Education, 2020; Ong et al., 2021). The seven sources are: 1) GSCE (General Certificate of Secondary Education) Science, 2) GSCE Information Communications Technology (ICT), 3) GSCE Digital Technology, 4) GSCE Mathematic, 5) KSSM Form 4 Science, 6) KSSM Form 4 Maths and 7) Pitch like a Pro (Open learning resource which has been evaluated).

Since English for STEM is not yet available in Malaysia, authentic resources need to be designed. Thus, these sources were chosen as GCSE contents, and the CEFR B1 syllabus is the standardised level for upper-secondary learners in Malaysia (Abidin & Hashim, 2021; Md Nawawi et al., 2021; Ministry of Education, 2013). The focus of ME4STEM is for upper secondary learners because they can choose their stream of studies (Ministry of Education 2013), rendering the specificity and importance of introducing specific terms and jargon suited to their chosen stream. Hence, for ME4STEM, these seven sources were selected to look into a broader range of vocabulary.

The words from these seven sources were matched to the Malaysian CEFR B1 syllabus to ensure that the vocabulary was neither difficult nor easy. As Bloom (1986) supports, language acquisition should start with familiar words that learners already know before adding to another level. In ME4STEM, the additional level was included in the vocabulary usage in solving STEM-related problems via discussion. Thus, content analysis is essential to show that the contents in ME4STEM were not created without foundation.

After looking at the contents, the design of ME4STEM embeds mastery learning, cognitive constructivism, social constructivism, problem-based learning, and the cognitive theory of multimedia learning. The theories serve as fundamental to the elements in ME4STEM. The mastery learning theory by Bloom (1986) was used as the foundation, whereby each unit in the module begins with a learning video (instruction), followed by practice and mini-assessment. Mastery learning gives a systematic approach to learning, which encourages learners to learn concepts by themselves independently. This finding is supported by Komalawardhana et al. (2021), who mentioned that students could master the concepts via mastery learning as it introduces the lesson in an organised way. Due to that, ME4STEM is underpinned by the constructs in mastery learning, encouraging more exposure to English for STEM vocabulary concepts to learners.

Additionally, ME4STEM embeds the review construct from cognitive constructivism by Piaget (1974). The review element is crucial because it enhances the cognitive abilities of learners to remember the vocabulary learnt. The review element is placed before the mini-assessment in ME4STEM to improve learners' vocabulary retention. One notable feature of this review element in ME4STEM is that it includes images with captions rather than videos. The rationale for only using images with captions is to avoid information overload (Mayers, 2014), which could hinder the retention of learners. As supported by Kanellopoulou et al. (2019), excessive video usage does not guarantee vocabulary retention. Thus, the researcher decided to use images with captions in the review section of ME4STEM, providing ease of use for learners.

Aside from cognitive constructivism, ME4STEM also embeds social constructivism by Vygotsky (1997). In vocabulary learning, mainly via a mobile app, there is a need to embed social elements so that the app is not monotonous. Therefore, ME4STEM included a discussion section in each unit to allow learners to interact with their peers. Learners who scaffold learning with other learners tend to learn better as they are more comfortable and confident in voicing their thoughts (Amna Saleem et al., 2021; Tomak, 2022). Though previous studies focused on the social aspect of mobile learning (Jacobs & Renandya, 2021; Tomak, 2022), this research included problem-based learning alongside social constructivism so that learners could discuss STEM-related problems in the app using the language components learnt. This adds value to ME4STEM, which previous studies have not looked upon yet. Hence, the design and development of ME4STEM have undergone thorough planning and review, which means that ME4STEM is feasible for STEM learners.

The problem-based learning instruction, which refers to posing problem-based tasks or questions for learners, was embedded in the discussion section. In relation to the discussion element, the problem-based learning instruction by Barrows (1996) was also embedded. However, one feature of problem-based learning, creating an authentic problem (Barrows, 1996), is the primary construct included in ME4STEM. The authenticity of the problem-based questions plays an essential role because learners need to be able to solve the issues by thinking critically. Also, since ME4STEM is a language-based app, learners need to construct their thoughts using words introduced in the unit. This encourages higher-order thinking skills, which benefit the learners. In line with past studies, problem-based learning instructions provide an autonomous learning environment, encouraging learners to participate actively and increasing their self-efficacy (Alemi et al., 2021; Jasti & Pavani, 2021). Due to problem-based learning, ME4STEM's design contributes to a conducive mobile learning environment, giving learners full autonomy.

Finally, aside from learning theories, the design of ME4STEM is underpinned by Mayers's Cognitive Theory of Multimedia Learning (CTML) (2014). This theory is essential in designing multimedia instructions in ME4STEM. The constructs of using audio, words, and visuals in CTML serve as the foundation of ME4STEM. Due to that, each unit in ME4STEM has one video in the learning video (instruction) section, which includes explaining words represented by images and subtitles. Subtitles are essential in CTML because they help learners better remember words (Asllani & Paçarizi, 2021; Teng & Zhang, 2021). Other media elements in ME4STEM include images and games created from external sources.

Though external sources are used to develop games for ME4STEM, the content is still authentic and specific, suited to the needs of learners. ME4STEM incorporates mastery learning and cognitive constructivism, allowing learners to review the vocabulary learnt, enhancing their understanding and memory (Piaget 1974). With the ESP approach accompanied by mastery learning and cognitive constructivism, ME4STEM introduces vocabulary in a meaningful way, whereby learners first would learn the words, practice them in sentences, review them with images and finally assess themselves in texts. Therefore, the elements in ME4STEM are underpinned by various learning theories to ensure that the mobile module is feasible and could provide desirable outcomes for learners to improve their English for STEM vocabulary.

Conclusion

This study applied Design and Development Research (DDR) to design, develop and evaluate an English for STEM mobile module. This study reported the design stage and embedding mastery learning theory as the main structure of the learning content in the app. The theories of cognitive constructivism, social constructivism, and problem-based learning underpinned the mobile application's overall structure. The arrangement of contents in this mobile module starts with a learning video, practice, review, mini-assessment, language exploration, and discussion, providing a systematic and holistic methodological design. The methodological design of this app implies that DDR could be enriched by incorporating learning theories and learner-centred approaches, which could encourage more course developers to adhere to this methodology.

The learning components were designed based on the learning theories. Each component in the mobile app was underpinned by mastery learning theory (learning video, practice, mini-assessment), cognitive constructivism (review), social constructivism and problem-based learning (discussion), and English for Specific purposes language forms and functions (language exploration). These elements implied the importance of reviewing and having a solid structure in mobile learning, ensuring learners could learn more systematically.

Hence, this study implied that theoretical foundations are vital in designing and developing a mobile app. Integrating multiple learning theories in the design and development of a mobile application gives more learning opportunities and ensures that the mobile app is holistic and feasible to be sustained.

This study included self-paced learning activities and materials for English vocabulary for upper-secondary STEM learners. In the future, it is hoped that future research could highlight more skills such as listening, speaking, reading, and writing to complement the vocabulary in ME4STEM. These skills could be embedded in ME4STEM, encouraging learners to practice with answers given because learners who prefer to learn by themselves feel more motivated to learn when they can get immediate feedback. Immediate feedback from the mobile app encourages learners to learn as they do not have to wait for the teachers to mark their work.

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