education sciences

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Flipped Micro-Modules for Teaching Sustainable Engineering Practices

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Abstract: With the aim of assisting students in acquiring the practical knowledge required for sustainable engineering practices, a new intervention method in the form of flipped micro-modules was developed. The perceived quality of the flipped micro-modules and their relationship with the students' attitudes towards using them were then evaluated using an extended technology acceptance model (TAM-extended model). The quality of the flipped micro-modules was measured based on three aspects: the quality of the framework, the quality of the content, and the quality of the operation. The findings revealed that the students considered the framework of the flipped micro-modules to be the most important aspect. The findings also demonstrated that the flipped micro-modules have the potential to improve engineering education and prepare students for future sustainable engineering practices.

Keywords: flipped classroom; micro-modules; intervention; TAM-extended model; sustainable engineering education

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Citation: Hou, H.; Zhang, H.; Wang, Y. Flipped Micro-Modules for Teaching Sustainable Engineering Practices. *Educ. Sci.* **2023**, *13*, 784. https://doi.org/10.3390/educsci13080784

Academic Editor: Valery Vodovozov

Received: 7 July 2023
Revised: 24 July 2023
Accepted: 30 July 2023
Published: 1 August 2023

1. Introduction

The pedagogical landscape in higher education has undergone significant changes in recent years, embracing new technologies and innovative teaching methods such as project-based learning, gamified learning, learning in virtual immersive environments, flipped classrooms, and blended learning. In particular, engineering education has also adapted to these trends to better equip students with the knowledge and skills required for their future practices. Traditional in-class learning approaches emphasize more on delivering theoretical principles, which often leads to a lack of practical experience. One challenge for current engineering graduates is to effectively recognize and solve the practical problems they encounter in their careers.

Sustainable engineering education is a critical aspect of preparing future engineers for the challenges of sustainable development. This refers to the process of teaching and learning about engineering practices that focus on environmental protection, social responsibility, and economic viability [1]. The goal is to prepare engineers to design, develop, and implement solutions that are sustainable and meet the needs of the present generation without compromising the ability of future generations to meet their own needs. Sustainable engineering education can provide future engineers with the knowledge and skills needed to achieve these aims.

Engineers who are trained in sustainable engineering practices are better equipped to design products, systems, and processes that have minimal impact on the environment and promote the well-being of society while also being economically feasible. However, current engineering students may not have a clear understanding of the resource constraints and may lack the necessary knowledge and skills to implement sustainable engineering practices [2]. As a result, it is essential for engineering curriculums to include sustainable engineering practice-related knowledge to better equip students with the knowledge and skills they need to contribute to sustainable development.

With increasing recognition of the importance of sustainable engineering education, many universities are attempting to incorporate it into their engineering curricula. Despite this, numerous challenges still exist, such as the absence of a clear definition of sustainable engineering education, the time-consuming process of updating courses, and the lack of systematic integration of sustainability knowledge with engineering practice. Therefore, it is important to identify relevant and practical content for sustainable engineering and find an effective way to integrate it into the existing engineering curriculum.

There are several pedagogical tools and methods designed specifically for teaching engineering practices. The purpose of these tools is to equip students with hands-on experience and the skills necessary for success in engineering fields. These pedagogical methods include project-based learning, field trips and site visits, internships, and co-op programs. This study proposes the development of micro-modules and their incorporation into flipped classroom pedagogy to facilitate sustainable engineering education among university students with an engineering academic background.

This paper presents a case study-based design and implementation process of a flopped micro-module pedagogy. It aims to evaluate engineering students' acceptance of using the flipped micro-module application in existing curriculums and discusses how this pedagogical approach facilitates learning of sustainable engineering knowledge. In this study, a micro-module is defined as self-contained instructional unit that concentrates on diverse types of sustainable engineering practices. The micro-modules were intended to provide the students with concise and targeted learning materials and activities, enabling them to engage in deeper learning and to implement their knowledge in practical situations. Each micro-module utilized in this study was comprised of animated videos, questionnaires, and online discussion forums, all of which were accessible via a university online education management system (Blackboard). Based on two engineering management courses, one undergraduate-level and one postgraduate-level course, three micro-modules were developed and integrated into the course delivery process. Both qualitative and quantitative data were collected to answer the following research questions:

(1) How do engineering students perceive the quality of the flipped micro-modules, and what are their acceptance levels of the new pedagogical method?

(2) What is the implication of this study for the future development of flipped micro-modules for supporting sustainable engineering practice education?

1.1. Technology-Led Pedagogies in Higher Education

The integration of various technologies into the curriculum has significantly improved learning effectiveness and students' learning experience. With the advent of advanced technologies such as videos, virtual reality/augmented reality, apps, artificial intelligence (AI), and cloud analytics [3–5], technology-led pedagogies have been developed to support different learning behaviours, processes, and habits [6,7]. While different learning theories, such as cognitive learning theory, constructivist learning theory, behavioral learning theory, and humanistic learning theory, provide insights into how individuals engage in the learning process, many researchers have adapted these theories to integrate technologies to enhance learners' abilities to comprehend new knowledge, create engaging learning experiences, and provide a space for learners to explore new knowledge and engage in critical thinking.

The integration of technologies in higher education has resulted in the development of various teaching models and digital tools, which are widely used in educational practices. For example, almost all higher education institutions use learning management systems (LMS) to manage, deliver, and track course materials and student progress. This type of technology provides teachers with valuable data about student learning and performance, allowing them to make informed decisions about instructional design and teaching strategies [8]. In recent years, AI tutors have been integrated at the course level by some instructors. They can provide personalized feedback and guidance to students based on their strengths and weakness, allowing for a more effective learning experience [9]. Virtual and augmented reality (VR/AR) technologies are used to provide immersive and interactive learning experiences that engage students and help them to understand complex concepts in a more intuitive way [10]. With the proliferation of social media, social media-based learning has also become a new digital learning format. Social media platforms can be used to deliver course materials, increase interactions between students and teachers, and foster learning communities [11].

Technology-led pedagogies, such as project-based learning, gamified learning, flipped classrooms, and blended learning, can align with various learning theories, as they provide opportunities for students to actively engage with and construct their understanding of the knowledge.

Project-based learning enables students to apply the concepts they learned to real-world problems. It has been applied to help students engage in real problem-solving and knowledge construction, and to develop more professional and transferable knowledge [12–14]. Gamified learning is another example of using technologies to enhance students' motivation and enable the learning process to become more engaging [15]. Blended learning is a teaching approach that combines traditional face-to-face instruction with technology-enhanced elements. The goal of blended learning is to leverage the strengths of both face-to-face and online learning to create a more personalized, engaging, and effective learning experience for students. In blended learning, students are often given more control over their learning pace and direction, and teachers can use technology to support and enhance student learning [16,17]. In recent years, the flipped classroom has been developed and put into practice with support technologies. It encourages student-centric active learning and is a dynamic way of learning, enabling students to work more closely with their classmates and instructors.

1.2. A Comparison of Different Technology-Led Pedagogies

The literature suggests that project-based learning, gamified learning, blended learning, and flipped classrooms can all be used for delivering practicum content [13,18–20]. Subhash and Cudney [15] pointed out that gamified learning may distract students' focus from the course content, as the students would focus more on the game mechanism. In other words, the students may focus on winning the game instead of learning the knowledge embedded in the game [21]. In addition, project-based learning approaches are usually time-consuming and require considerable resources to design and implement student-centric projects [13]. The literature suggests that blended learning and flipped classroom approaches are considered to be more appropriate for teaching practicum content compared with other methods. First, they promote active learning by having students engage with course material before class. Secondly, in-class time is dedicated to practical applications and problem-solving, fostering hands-on experience. Thirdly, flipped classrooms offer flexibility, allowing students to learn at their own pace and reinforce understanding. Fourthly, they efficiently use class time by shifting theoretical content delivery outside of class. Fifthly, instructors can provide immediate feedback and support during in-class activities. Lastly, flipped classrooms facilitate the integration of sustainable engineering practice education, preparing students for future challenges in a supportive and interactive environment.

While sustainable engineering practices are more often delivered on a lecture basis or a case basis rather than a course basis, both blended learning and flipped classrooms are suitable for delivering the content. Blended learning and flipped classrooms are instructional approaches that combine traditional face-to-face teaching with online learning elements. They both emphasise active learning and personalised learning, integrating online and in-person teaching components. Both offer a high level of flexibility in learning. Blended learning integrates online and face-to-face activities throughout the course, and students engage in both activities simultaneously or in a structured sequence throughout the learning process. Typically, the online component occurs before the in-person class session in a flipped classroom. In order to prepare for the in-person activities, the students must access pre-recorded lectures and other online materials outside of class. The latter is considered more appropriate for integrating information about sustainable engineering practices into students' learning processes. The students have access to practice-based sustainable engineering cases prior to class, and they can readily connect the practice (learned outside of the classroom) with the theories discussed in class if they have gained the knowledge prior to class. Using the flipped classroom approach to teach sustainable engineering practices, the "off-classroom and in-class" scenarios are distinct in terms of "learning place" but are also well integrated, as the two categories of content can complement each other to improve the students' comprehension.

1.3. Flipped Classroom Pedagogy in the Discipline of Engineering Education

According to previous studies, social science, computer science, and engineering are the top three education areas in which flipped classrooms have been widely applied [22,23]. So far, this method has been applied to subjects like manufacturing technology [24], digital circuits [25], and energy engineering [26]. The effectiveness and advantages of this pedagogy in previous applications have been validated: 83% of the participants preferred the flipped classroom approach over the traditional didactic teaching approach, as it provides more chances for teachers and learners to communicate with each other, making the sessions more informative [24]. In an experiment involving 41 engineering students conducted in reference [25], it was found that the flipped classroom approach can allow more content to be covered than the traditional teaching method, enabling the students to have more first-hand practice. It can connect both theoretical knowledge and problem-based learning exercises [27].

One of the biggest challenges that fresh graduates from existing engineering programs are facing is that their knowledge in dealing with engineering practices, especially related to sustainable engineering practices, is lacking. Traditional lecture-based teaching cannot satisfy the current needs of sustainable engineering education. Flipped classrooms can solve this problem, as they enable several levels of flexibility. First, students are allowed to engage in learning during off-classroom time and participate in designed learning activities based on their own pace. Second, different forms of content can be used to facilitate learning, such as online videos, VR platforms, online games, online Q&A, etc. To a certain extent, this has enriched students' perception of the knowledge. Third, the flipped classroom pedagogy provides interaction flexibility. On one hand, online e-learning platforms can be used to enable student and teacher communication, while on the other hand, the classroom has been "flipped", allowing students and teachers to have more time to discuss the "pre-learned" knowledge during class time. The teachers can understand their students' learning outcomes and track their progress directly and efficiently [25].

However, the flipped classroom approach is not perfectly versatile. In Castedo et. al.'s case study [26], the flipped classroom approach was found to have some positive effects on learning, but its efficacy was highly influenced by the students' attitudes. In other words, the students' attitudes towards the flipped classroom approach highly affected their learning outcomes. Thus, to evaluate the effectiveness of a flipped classroom education model, it is necessary to assess the students' attitudes or their acceptance of the pedagogical approach.

1.4. How to Flip the Classroom to Support Sustainable Engineering Practice Teaching

In order to answer the question of how to flip the classroom to support sustainable engineering practice teaching, it is necessary to develop a package of systematic teaching materials and relevant activities to facilitate both in-class and off-classroom learning. As suggested by AI-Abdeli [28], a clear and structured framework of flipped classroom design shall be established in order enable a smooth transition and implementation of a flipped classroom. AI-Abdeli [28] has adopted a three-stage (before class, in class, and after class) flipped-class model, which outlines the framework of the flipped classroom used in his teaching.

Sustainable engineering practices are a relatively vague concept that needs to be broken down into small units to illustrate practical scenarios. Thus, micro-modules are considered an effective tool to incorporate the flipped classroom approach in sustainable engineering practice teaching. Micro-modules focus on engaging students in deeper learning and increasing the practicability of knowledge under real-world circumstances. They can provide learners with bite-sized, easily digestible information and activities that promote active engagement and the application of new knowledge, allowing them to build on their prior knowledge and experiences.

Integrating micro-modules into a flipped classroom that teaches sustainable engineering practices involves a strategic and thoughtful approach to maximize their effectiveness in facilitating active learning and practical application. The major steps for integrating micro-modules into a flipped classroom include: (1) identifying the key topics and sub-topics related to sustainable engineering practices that need to be covered in the course; (2) developing the micro-modules for each sub-topic; (3) assigning the micro-modules as pre-class assignments; (4) integrating pre-class learning in in-class activities (e.g., focusing on creating active learning activities that build upon the knowledge presented in the micro-modules; (5) collecting the students' feedback [14].

2. Materials and Methods

This study was conducted in three stages. In the first stage, 3 micro-modules containing 6 animation video clips were developed. In the second stage, the developed micro-modules were incorporated into two existing courses to facilitate course delivery. In the third stage, the students' acceptance of the flipped micro-modules was evaluated based on a TAM-extended theoretical model. The details are elaborated in the following sub-sections.

2.1. Development of the Micro-Modules

Key topics were identified to facilitate sustainable engineering education to guide the micro-module content design (Figure 1), including economic/management, technology, business, entrepreneurship, and ethics/law. A total of 3 micro-modules were developed. These three sub-topics were selected and defined based on the key topics identified under sustainable engineering education. They were then incorporated into the course, with each micro-module consisting of a quiz, online forum discussion, and two video clips: one teaching key concepts/theories/frameworks, and the other one demonstrating a practical case. Within the semester of Fall 2022 (from September 2022 to January 2023), two engineering management-related courses (one at the undergraduate level and the other at the postgraduate level) from a university in Hong Kong were selected to adopt the flipped micro-modules.

The first course taught the project procurement principles and practical methods used in the construction and facility management sectors. The contents included "tendering and estimating", "contractual arrangement and management", "resolution of disputes", "application of management science principles" and "techniques for project management, planning, and control". The second course taught economics knowledge and its application in facilities management.

Aligning with the teaching objectives of these two courses, three micro-modules were developed to facilitate students' understanding of (1) sustainable engineering management practices in construction projects, (2) basic ethics in project procurement and outsourcing practice, (3) decision-making science and decision-making tools used in lean facilities management. These three micro-modules fell under the "economic/management perspective" and "ethical/law perspective" categories indicated in Figure 1—key topics identified to facilitate sustainable engineering education. In the development process, a web-based animation design platform called Vyond was used to develop 6 animation video clips with video lengths between $2'08''$ and $6'26''$. The micro-modules were incorporated into the corresponding lectures, and the detailed implementation process will be given in the following sections.

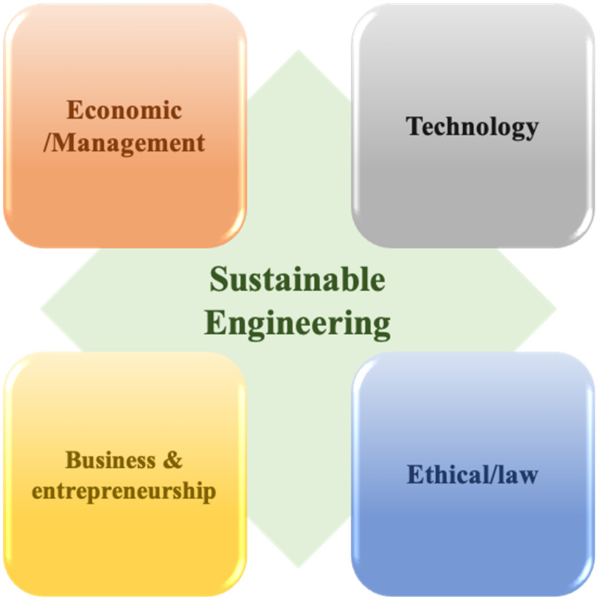

Figure 1. Key topics identified to facilitate sustainable engineering education.

2.2. Implementation of the Flipped Micro-Modules

As shown in Figure 2, each micro-module was incorporated and implemented in four steps. First, before the class, the first videos, together with relevant reading materials, were uploaded to the university's learning management platform for students to learn (Part 1 in Figure 2). Second, during the class, the instructor started with a brief review of the first video to refresh the students' memory, followed by a discussion and other in-class activities. Third, after the class, a second video illustrating a case was uploaded, followed by an online quiz and online forum (Parts 2, 3, and 4 in Figure 2). The online quiz tested the contents of the two videos to examine the students' learning progress and outcomes. An online forum was implemented to strengthen instructor–student communication and to encourage the students to learn from each other. A total of 101 students (66 undergraduates and 35 graduate students) participated in the entire flipped classroom learning process, which included viewing the pre-class and post-class videos, completing the online exams, and participating in the online forum. The students enrolled in the courses were required to participate in the flipped classroom activities, and their participation was marked using a university online education management system (Blackboard). To encourage the students to participate in the flipped classroom activities, the quiz scores were used as an assessment method for the course.

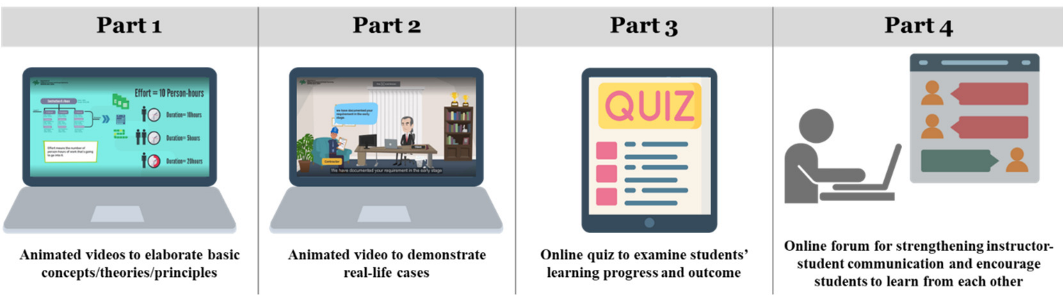

Figure 2. Micro-module framework.

At the end of the course, the students were encouraged to participate in an evaluation survey on a voluntary basis. Section 3.4 elaborates on the details of the questionnaire design and survey implementation.

2.3. Assessment of the Students' Acceptance of the Flipped Micro-modules Using an Extended TAM Model

Since Fred Davis proposed the Technology Acceptance Model (TAM) in 1989 [29], it has been widely adopted and used to measure the acceptance of different media [30]. The adaptation of TAM is highly associated with the purpose of use and the technologies to be evaluated [31,32]. Some TAM-extended models have been developed to predict people's intention to use a system and their usage behaviour, thereby incorporating constructs such as voluntariness, job relevance, output quality, and experience [33]. The fundamental theoretical framework of TAM consists of three core factors: perceived usefulness (PU), perceived ease of use (PEU), and attitudes toward using (ATU). The framework also illustrates interactive effects that PU and PEU have on ATU and the relationship between PEU and PU.

An extended TAM model was developed for assessing the students' acceptance of the micro-modules and the flipped classroom approach, as shown in Figure 3. The goal of the assessment was to understand how the students responded to the intervention method and identify areas that may require adjustments or improvements in the teaching strategy. The formative assessment will provide insights into the learning process to improve teaching and learning.

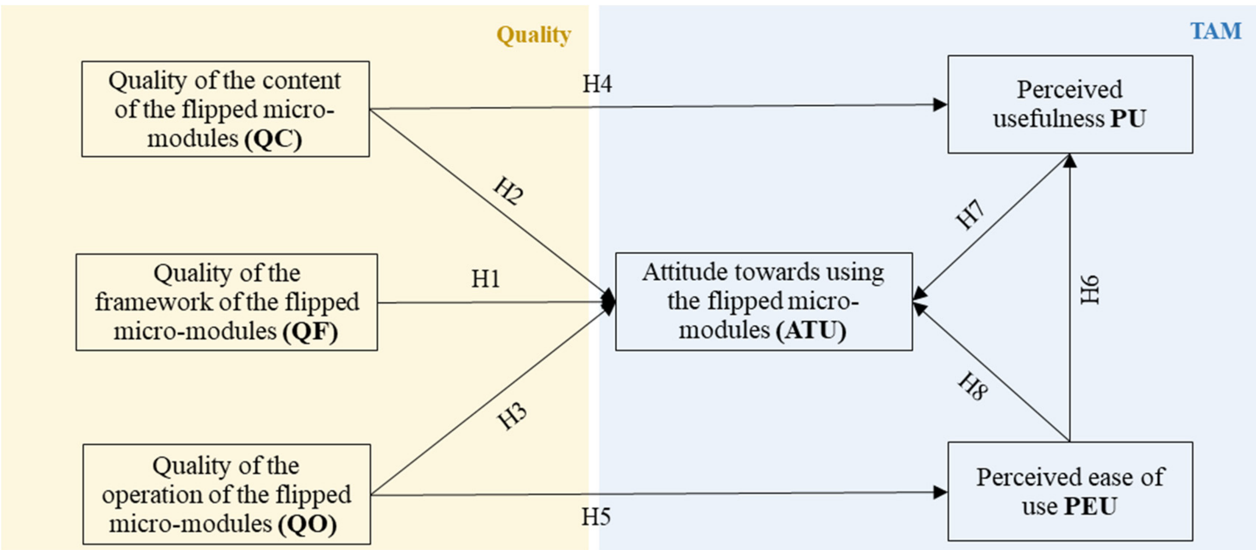

Figure 3. Proposed TAM-extended model. Note: "H" stands for hypothesis.

According to Fathema et al. [34], the system quality (quality related to the features, contents, interaction capability, etc.) can influence the PU, PEU, and ATU. Therefore, in addition to the original TAM, the quality of the micro-modules was considered to be another important factor that affected the ATU in this study. It was integrated into the extended TAM, assuming that the quality of the micro-module would affect the PU, PEU, and ATU.

The quality of the micro-modules was measured by the quality of the framework of the flipped micro-modules (QF), quality of the content of the flipped micro-modules (QC), and the quality of the operation of the flipped micro-modules (QO). QF refers to the logic and structure of the micro-module framework, including previewing the videos before the lecture, in-class teaching and discussions, after-class quizzes, and online forum participation. QC refers to the content of the micro-modules, including the selection of the topic/knowledge and the structure and presentation of the knowledge in each video. QO refers to students' experiences in the operating system, including accessing the learning materials, the process of watching the videos, and the instruction information for accessing the micro-modules.

These are hypotheses that were tested in this study. Hypotheses H1, H2, and H3 related to the impact of the quality of the framework, content, and operation of the flipped micro-modules on the ATU. Hypotheses H4 and H5 related to the impact of the quality of the content and operation on the PU and PEU, respectively. Hypotheses H6 and H8 related to the interplay between the PEU, PU, and ATU. In other words, the hypotheses tested the relationships between different factors that influenced the acceptance of flipped micro-modules as a learning tool.

H1: *The quality of the framework of the flipped micro-modules has a significant impact on students' attitudes toward using the flipped micro-modules.*

H2: *The quality of the content of the flipped micro-modules has a significant impact on students' attitudes toward using the flipped micro-modules.*

H3: *The quality of the operation of the flipped micro-modules has a significant impact on students' attitudes toward using the flipped micro-modules.*

H4: *The quality of the content of the flipped micro-modules has a significant impact on students' perceived usefulness.*

H5: *The quality of the operation of the flipped micro-modules has a significant impact on students' perceived ease of use.*

H6: *Students' perceived ease of use has a significant impact on their perceived usefulness.*

H7: *Students' perceived usefulness has a significant impact on their attitudes toward using the flipped micro-modules.*

H8: *Students' perceived ease of use has a significant impact on their attitudes toward using the flipped micro-modules.*

2.4. Data Collection and Analysis

A questionnaire survey was conducted to collect data based on the proposed TAM-extended model. The questionnaire consisted of 34 questions (Appendix A), which could be divided into three parts. Part 1 consisted of 29 7-point Likert scale questions (ranging from 1—strongly disagree to 7—strongly agree) measuring the six constructs (PU, PEU, QO, QC, QF, and ATU, at least 4 items under each construct). Part 2 consisted of 4 questions to collect background information about the student participants, and part 3 provided an open-ended question asking the students' opinions on the micro-modules. The survey was hosted using Microsoft Forms and was completed by 101 students from two engineering courses. Prior to the official launch of the survey, a pilot survey was conducted to evaluate the questionnaire's readability. The survey obtained human subject ethics application review approval (No. HSEARS20221217003) from the first author's university. The background information of the respondents is shown in Table 1.

Table 1. Background information of the student participants.

Attributes	Distribution	Respondents % (n = 101)
Gender	Male Female	73% (74) 27% (27)
Education level	Master students Undergraduate student (Year 3 and Year 4)	35% (35) 64% (66)
Study mode	Full-time student Part-time student	86% (87) 14% (14)
Whether previously attended any courses that adopted micro-modules	Yes No	46% (46) 54% (55)

The collected data were analysed using structural equation modelling (SEM) and the partial least squares (PLS) method due to their suitability for small sample sizes, ability to handle non-normal distributions, and strong exploratory and explanatory aspects [35]. The PLS-SEM method was adopted to test the proposed TAM-extended model and the relationships between the theoretical constructs.

3. Results

Smart PLS 3.3.9 was used for analyzing the correlations described in the proposed model. Before carrying out the PLS-SEM analysis, IBM SPSS Statistics 26.0 was used to conduct common method variance bias tests, and both softwares were used for associated validity and reliability checks to assess the data quality and consistency of the structural model.

3.1. Model Testing and Analytic Results

3.1.1. Validity and Reliability Tests

This study used the Kaiser–Meyer–Olkin sampling adequacy measure (KMO) and Bartlett's sphericity test to determine whether the data were suitable for factor analysis. The KMO measure of sample adequacy was found to be 0.853, beyond the 0.6 threshold value. The Bartlett test revealed a significance value of 0.000, below the threshold value of 0.005. These results showed that the sample was sufficient for factor analysis (Table 2).

Table 2. KMO and Bartlett's test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.853
Bartlett's Test of Sphericity	Chi-Square	2743.231
	Degrees of freedom	561
	p-value	0.000

The constructs relating to the extended TAM were validated, and the measured items of the variables and their factor loadings were also examined in this study. The results showed that the Cronbach alphas for all the constructs were greater than 0.7: PU (0.856), PEU (0.781), QC (0.869), QO (0.773), QF (0.858), and ATU (0.923), indicating that the measurement items had strong internal consistencies and reliabilities (Table 3). Regarding the factor loadings, as suggested by [35], items with factor loadings below 0.70 were removed from the model to improve the model and path strength, given that the averages and standard deviations were within the acceptable range. Table 3 shows that both PEU1 and PEU4 had factor loadings less than 0.70 (PEU1: 0.654, PEU4: 0.699). Strictly speaking, both items should have been removed to enhance the model's explanatory power. Considering that PEU4 (0.699) was slightly below 0.7 and that it represented a unique dimension of the PEU construct that was theoretically relevant and meaningful, it was retained in the model. In some cases, even though their factor loading was below the conventional threshold, their inclusion might have contributed valuable insights into the users' perceptions of ease of use that could not be captured by other items. PEU1 (0.654) was eliminated to enhance the model's explanatory power and path strength, as the statistical results indicated that it could not adequately represent the PEU construct.

Table 3. Factor loading and Cronbach's alpha of the measurement instruments and constructs.

Construct	Measurement Item	Factor Loading	Cronbach's Alpha (α)
Perceived usefulness (PU)	PU1	0.831	0.856
	PU2	0.883	
	PU3	0.732	
	PU4	0.798	
	PU5	0.740	
Perceived ease of use (PEU)	PEU1	0.654	0.781
	PEU2	0.770	
	PEU3	0.748	
	PEU4	0.699	
	PEU5	0.766	
Quality of the content of the flipped micro-modules (QC)	QC1	0.778	0.869
	QC2	0.876	
	QC3	0.842	
	QC4	0.778	
	QC5	0.777	
Quality of the operation of the flipped micro-modules (QO)	QO1	0.774	0.773
	QO2	0.711	
	QO3	0.808	
	QO4	0.772	
Quality of the framework of the flipped micro-modules (QF)	QF1	0.802	0.858
	QF2	0.766	
	QF3	0.786	
	QF4	0.805	
	QF5	0.828	
Attitudes toward using the flipped micro-modules (ATU)	ATU1	0.791	0.923
	ATU2	0.879	
	ATU3	0.883	
	ATU4	0.900	
	ATU5	0.915	

3.1.2. Analysis of the Measurement Model

In the current study, the extended TAM model had six variables, all of which were reflective measurement models. It was necessary to ensure that the indicators accurately measured each of the structures under consideration and evaluated the indicators' validity and reliability. With Cronbach's alpha values greater than 0.70, a composite reliability more significant than 0.60, and an average variance extracted from the model (AVE) more than 0.50, all the thresholds were satisfied (Table 4), indicating the model and its development had internal consistency, reliability, and convergent validity. Additionally, for adequate discriminant validity, the bold numbers in Table 5 were greater than the corresponding non-bold numbers, indicating that the data achieved good discriminant validity.

Table 4. Construct internal consistency reliability and convergent validity.

Construct	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
PU	0.856	0.897	0.638
PEU	0.750	0.842	0.572
QC	0.869	0.906	0.658
QO	0.773	0.853	0.593
QF	0.858	0.897	0.636
IU	0.923	0.942	0.765

Table 5. Discriminant validity.

Construct	PU	PEU	QC	QO	QF	IU
PU	0.799					
PEU	0.682	0.756				
QC	0.613	0.723	0.811			
QO	0.502	0.635	0.678	0.770		
QF	0.595	0.745	0.619	0.744	0.798	
IU	0.530	0.732	0.528	0.541	0.586	0.875

3.1.3. Analysis of the Structural Model

The structural model was then analyzed to assess its prediction performance. The explained variance (R^2) and predictive correlation of the model (Stone-Geisser's Q^2) were evaluated. According to Table 6, the structural model predicted a PU variance of 0.495, a PEU variance of 0.414, a QC variance of 0.382, a QO variance of 0.639, and an ATU variance of 0.554. The PU, PEU, QC, QO, and ATU constructs all had Q^2 values above zero, showing a predictive correlation. The predictive power of the model was confirmed by the Q^2 and R^2 values. Figure 4 visually presents the full PLS-SEM analysis results.

Table 6. Assessments of relevance between the constructs in the structural model.

Construct	R^2	R^2 Adjusted	Q^2
PU	0.495	0.485	0.298
PEU	0.414	0.408	0.230
QC	0.382	0.375	0.241
QO	0.639	0.632	0.353
ATU	0.554	0.530	0.410

Notes: R^2 and Q^2 were used to evaluate the model's accuracy and predictive correlation, respectively. R^2 values indicate the amount of variance in the endogenous constructs that can be explained by the exogenous constructs. A value of 0.67 or higher was considered substantial, while values between 0.33 and 0.19 were considered moderate and weak, respectively. The Q^2 values, on the other hand, were used to evaluate the predictive relevance of the exogenous constructs using a blindfolding procedure. A Q^2 value greater than 0 indicates a predictive correlation.

The results of the bootstrapping procedure with 5000 resamples indicated that all of the path coefficients except for H7 were significant, with a 95% confidence interval (t-value greater than 1.645 and a *p*-value less than 0.05) (Table 7). This supports the hypotheses H4, H5, H6, H8, H9, H10, and H11.

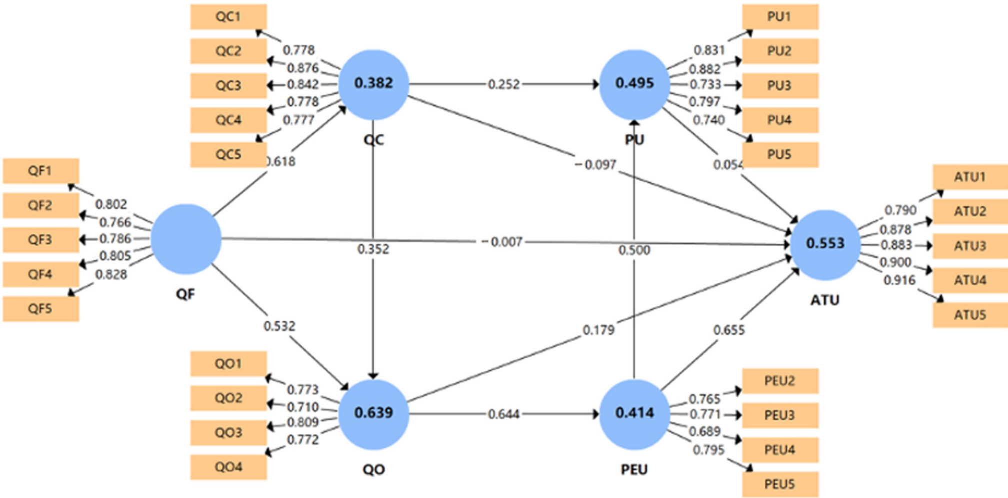

Figure 4. Analysis results.

Table 7. Path analysis for hypothesis testing.

Hypothesis	Path Coefficient (β)	Sample Mean	T Statistics	*p*-Values	Decision
H1 QF → ATU	−0.007	0.001	0.142	0.961	Not Supported
H2 QC → ATU	−0.097	−0.118	0.118	0.412	Not Supported
H3 QO → ATU	0.179	0.209	0.127	0.157	Not Supported
H4 QC → PU	0.252 *	0.249	0.100	0.012	Supported
H5 QO → PEU	0.644 ***	0.661	0.079	0.000	Supported
H6 PEU → PU	0.500 ***	0.511	0.104	0.000	Supported
H7 PU → ATU	0.054	0.061	0.108	0.613	Not Supported
H8 PEU → ATU	0.655 ***	0.636	0.147	0.000	Supported
H9 QF → QC	0.618 ***	0.628	0.076	0.000	Supported
H10 QC → QO	0.352 **	0.357	0.103	0.001	Supported
H11 QF → QO	0.532 ***	0.534	0.093	0.000	Supported

Note: * Significance codes: 0.05; ** Significance codes: 0.01; *** Significance codes: 0.001.

Despite the *p*-value for H7 being within the 0.1 threshold, as indicated in Table 7, it was considered acceptable and was kept in the model, as it was an essential construct of the original Technology Acceptance Model (TAM) and played a crucial role in the development of educational intervention tools.

Figure 5 visually presents the full TAM-extended model results. The results show the interplay between different aspects of the quality of the micro-modules and their indirect effects on the students' attitudes towards using the flipped micro-modules. Furthermore, the quality of the micro-module contents affected both PU and PEU of the flipped micro-modules. This highlights the importance of developing high-quality micro-module content for effective use in flipped micro-modules.

The modelling results revealed positive and statistically significant correlations between QC and QO, QF and OC, and OF and QC. This indicates that when the framework of the micro-modules was of high quality (QC), it had a positive effect on the quality of the content (QC) and the quality of operation (QO). In addition, the results revealed another significant relationship: the QO significantly influenced the ATU (attitude towards using) via the PEU (perceived ease of use). This indicates that the quality of operation, such as the simplicity of navigating the micro-modules, gaining access to the materials, and interacting with the online forums, had a direct impact on the students' perceptions of the micro-modules' usability. The students' attitudes towards using micro-modules as a learning resource were positively affected when they were simple to access and navigate.

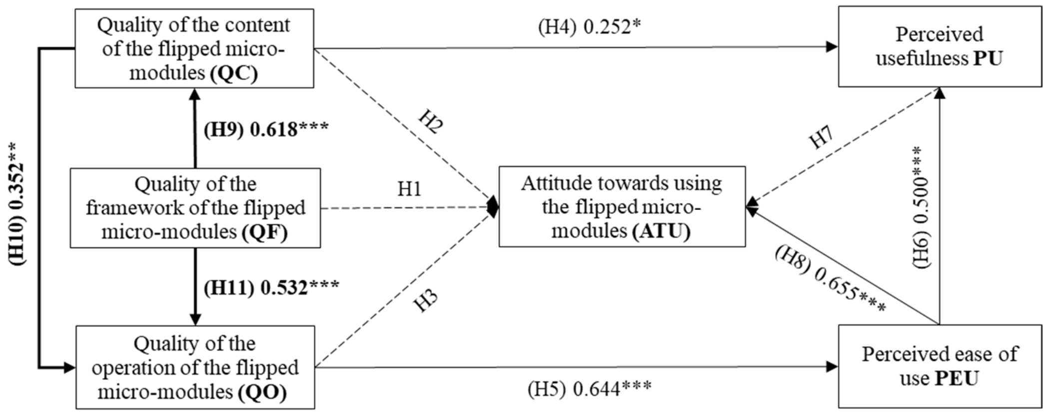

Figure 5. Structural equation modelling results. Note: * Significance codes: 0.05; ** Significance codes: 0.01; *** Significance codes: 0.001.

3.2. Comparison of the Survey Results between Undergraduate and Postgraduate Students

Figure 6 shows the perception comparison between the undergraduate and postgraduate students from the two engineering management courses. The rating between undergraduate and postgraduate students on the six constructs of micro-modules, PU, PEU, QC, QO, QF, and ATU, ranged from 5 to 6 (out of 7 on the Likert scale). This indicates that the students agreed that the micro-modules performed well in terms of their framework, content, and operation. Furthermore, the students perceived the flipped micro-modules as useful and relatively simple to use, and showed a positive attitude towards technology utilization.

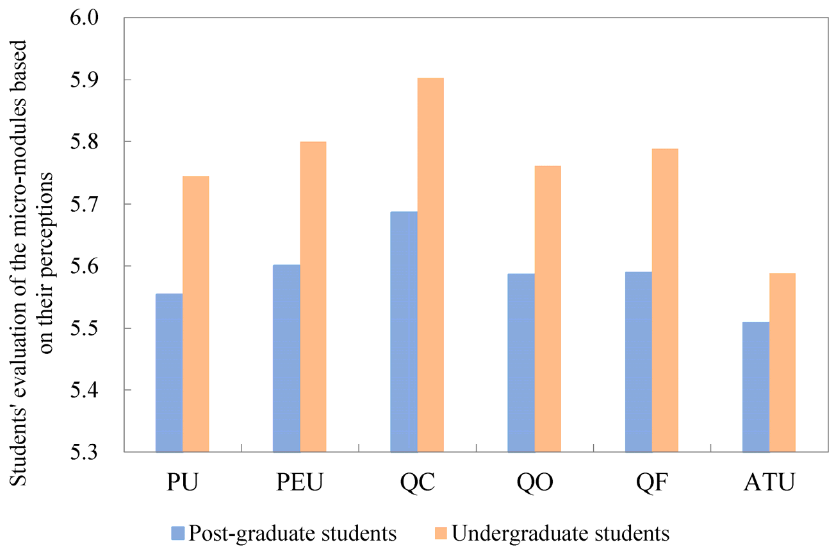

Figure 6. Comparison of undergraduate and postgraduate students' perceptions of the micro-modules. Note: Likert scale 1–7, with 1 as the lowest and 7 as the highest level.

Compared to the postgraduate students, the undergraduate students indicated a higher level of agreement on the measurement items for every construct. This means that the undergraduate students showed a higher level of acceptance of the flipped micro-modules. Additionally, the variation trends through the six constructs were of high homogeneity between the undergraduate and postgraduate students. Overall, the QC received the highest rating, followed by the PEU, QF, QO, and PU. The ATU received the lowest rating among all the students.

3.3. Comparison of the Survey Results between Students with and without Previous Experience of Using Micro-Modules

Figure 7 shows the perception comparison between students with and without previous experience of using micro-modules. First, nearly half of the students (46 out of 101) declared that they had previous experience using micro-modules. These 46 students may have attended another course taught by the same instructor (the first author), who also implemented micro-modules in that course. However, the design of the micro-modules used in the other course was much simpler. The students were asked to view a video before class, and no additional activities were implemented. This explains why the students with previous experience using micro-modules provided slightly lower ratings compared with those who had not used micro-modules before. It is also possible that some of these students may have also participated in micromodule-related learning activities elsewhere. Second, in general, the students with previous experience using micro-modules exhibited higher ratings on all the PU, PEU, QC, QO, and ATU assessments. Thirdly, the students with previous experience rated QO significantly higher than those who had never used micro-modules. This indicates that the students with previous experience were better able to access the learning materials, view videos, and participate in the online activities (quiz, online forum). According to the ratings on the ATU, the students with previous experience also indicated a greater intent to utilise the micro-modules in the future. This comparison is meaningful, suggesting that once a student has used micro-modules in the past, he or she tends to have a more favourable perception of their quality and a higher level of acceptability. Thus, strengthening the applicability of micro-modules contributes to the promotion of their use.

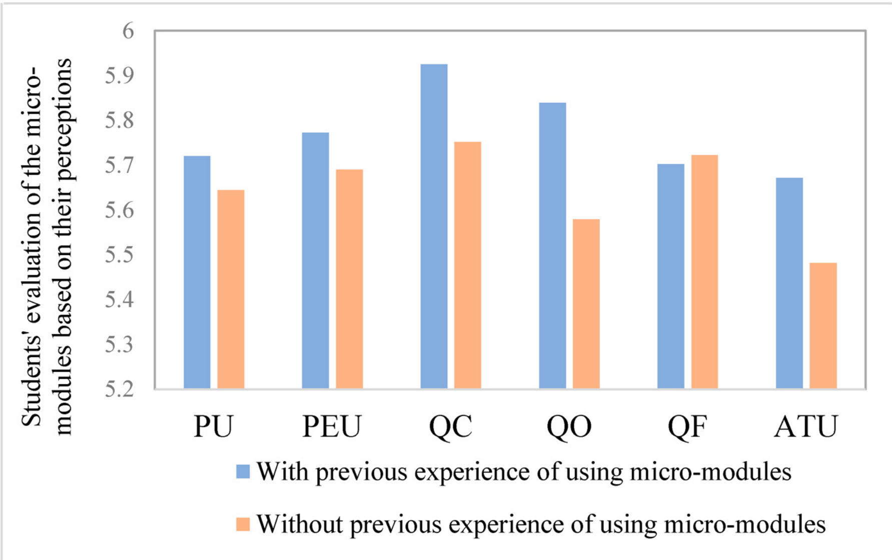

Figure 7. Comparison of the survey results between students with and without previous experience using micro-modules. Note: Likert scale 1–7, with 1 as the lowest and 7 as the highest level.

3.4. Qualitative Findings of the Survey

An open-end question was asked at the end of the questionnaire survey: "Please share with us your comments regarding your learning experience with the flipped micro-modules". Approximately 95% of the respondents provided answers to the question. Excluding invalid answers such as "N/A", "No comment", and answers expressing a general attitude, such as "good", "very good", and "I like the micro-modules", the responses containing specific information were extracted and summarized in the following table (Table 8).

Table 8. Coding results regarding the students' comments on the flipped micro-modules.

Quality of the Micro-Modules	Framework	Content	Operation
Representative keywords extracted from the responses	"The micro modules are supplementary to the lectures in terms of the structure"	"Easier to memorize (the content)"	"Provide more flexibility for students to learn"
	"Self-direct study mode is structured"	"Easier to understand"	"Using process is flexible"
	"I see good connections between micro-modules and lectures"	". . . provide a clear way to learn the concept"	"Insufficient guidelines on what to do"
	"pre-viewing and post-viewing activities are useful"	"The micro-modules enhanced my understanding"	"Need some time to adapt to the new method"
	"They make learning more convenient and effective"	"They are interesting and very attractive"	"The process of using the micro-modules is a bit complicated"
		"Pace and duration of the videos are appropriate"	

The key responses were categorized in Table 6 based on the three aspects of the flipped micro-module quality: framework, content, and operation. Comments on the framework and contents of the flipped micro-modules were overall positive, while there were some comments that suggested insufficiencies of the operation of the flipped micro-modules, such as "the micro-modules don't provide sufficient guidelines on what to do". The qualitative findings echoed the survey findings, in that the perception of the QO was rated the lowest among the three aspects (see Figure 6).

4. Discussion

The quantitative and qualitative analyses in this study provide three aspects of implications for the development of flipped micro-modules in the context of sustainable engineering education.

4.1. Systematic Framework for Developing Sustainable Engineering Practices Micro-Modules

This study proposed three aspects to measure the quality of flipped micro-modules: QF, QC, and QO. They were proven to be valid in measuring the overall quality of flipped micro-modules (shown in Table 3). The inter-relationships among the three quality aspects were reflected in the structural model (Table 5).

The modelling results showed that the quality of the framework (QF) of the flipped micro-modules was the most important quality aspect, as it had a significant impact on both the quality of the content of the flipped micro-modules (QC) and the quality of the operation of the flipped micro-modules (QO). This suggests that a systematic framework is necessary for guiding the development of the micro-modules. By having a well-structured framework in place, the development of flipped micro-module materials could be guided toward meeting specific goals or objectives related to sustainable engineering.

The results also showed that the QF and QC of the micro-modules had a significant impact on the QO, and the QO was found to be the mediator between QF/QC and PEU (Figure 5). This implies that even with a well-structured framework and well-designed content, an operation protocol or system is important, as it enables students to access the micro-modules and use them smoothly. In other words, a user-friendly platform is critical for enhancing students' perceptions of the overall quality of flipped micro-modules.

4.2. The Mediating Effect of Perceived Ease of Use and Perceived Usefulness

This study originally proposed that the QC, QF, and QO have direct and significant impacts on the ATU. However, these three hypotheses were not supported. This means that the students' attitudes were unlikely to be directly affected by any single aspect of the flipped micro-modules. Their perceptions regarding the quality of the flipped micro-modules were proved to be closely related to their perception of whether the flipped micro-modules were useful and relevant to their learning, and the usefulness and content relevance could be affected by all three aspects of the micro-modules' quality.

Furthermore, H7 was not supported based on the modelling results. The perceived usefulness (PU) did not have a significant impact on the students' attitudes towards using the flipped micro-modules (ATU). This could have been due to various reasons, such as the students' prior experiences with using similar education materials, their motivation for learning, or the overall context in which the micro-modules were used. In addition, the results of this study highlight the importance of considering multiple factors when evaluating the effectiveness of flipped micro-modules and understanding students' attitudes toward using them. While the PU is often considered an important factor in determining the success of education materials, it is not the only factor that influences students' ATU. Further research may be necessary to better understand the complex interplay between the factors that contribute to students' attitudes toward using these types of educational materials.

The mediating roles of the PEU and PU imply that the students' perceptions of the quality of the micro-modules (QC, QF, and QO) influenced their perceived ease of use and usefulness, which, in turn, affected their attitudes towards using the micro-modules (ATU). In other words, the students' perception of how well-designed, organized, and easy to navigate the micro-modules were, as well as their perception of the relevance and benefit of the content presented, shaped their overall attitude towards engaging with the micro-modules as an effective learning tool. While mediating roles of the PEU and PU have been commonly studied in technology acceptance research [36–38], this study highlights their importance in the field of higher education, specifically in the context of flipped micro-modules for sustainable engineering practices. Understanding the mediating effects of PEU and PU can provide valuable insights for educators and instructional designers to optimize the design and delivery of the micro-modules to enhance students' learning experiences and acceptance of this innovative pedagogical approach.

4.3. Future Development of Flipped Micro-Modules to Support Sustainable Engineering Practice Education

The use of micro-modules in flipped classroom learning is not a new learning approach, but developing micro-modules to deliver practical knowledge of sustainable engineering is still considered to be innovative. In the traditional flipped classroom, instructors typically record lectures or instructional videos covering theoretical content, and students are expected to watch these videos before coming to class [39]. In this study, instead of lengthy pre-recorded lectures, micro-modules were introduced. These micro-modules were bite-sized, self-contained units of content that were focused on specific sub-topics related to sustainable engineering practices. The micro-modules consisted of animated videos and quizzes used to present the content in an engaging and interactive manner. Additionally, online forums were organised as part of the micro-modules. The students also accessed online forums to foster discussions and interactions related to the micro-module topics.

Given the increasing demand for sustainable solutions and the need to address pressing environmental and social issues, it is important to continually assess and improve sustainable engineering education to ensure that students are equipped with the practical skills and knowledge they need to succeed in their careers. In accordance with the study's objective of preparing students for future sustainability challenges, the micro-modules in this research were designed to explicitly address sustainable engineering practices. Using a meta-analysis methodology, Lo and Hew [40] investigated the effect of flipped classrooms on student achievement in engineering education. On the basis of a sample size of

2590 students, they discovered that self-paced learning and more problem-solving activities were the two most frequently reported advantages that promoted student learning. This study effectively echoes these two crucial perspectives. Sustainable engineering practices were chosen to be reinforced using a pedagogical method that allowed students to learn at their own pace, namely the flipped classroom method, in order to foster the students' problem-solving skills.

This study has significant potential for the future development of flipped micro-modules for supporting sustainable engineering practice education. First, the flipped micro-modules can be integrated with other resources, such as online simulations or VR technologies, to provide a more comprehensive and immersive learning experience, together with chances for hands-on practice. Second, the flipped micro-modules can be expanded to cover a wider range of sustainable engineering practices, such as renewable energy systems, sustainable transportation, and sustainable building design. Third, the flipped micro-modules can be developed to personalize the learning experience for each student. With the help of artificial intelligence and machine learning algorithms, it can better fit students' prior knowledge and learning preferences. Lastly, the flipped micro-modules can be designed to provide students with ongoing assessment and feedback to help themselves and their teachers to track their progress and identify areas for improvement. This is also supported by Yelamarthi and Drake's [25] research conclusion that flipped learning pedagogy can help teachers to better understand their students' learning progress. By continually improving the flipped micro-modules, it is possible to create a more effective and engaging learning experience.

5. Conclusions

This study developed a new intervention method in the form of flipped micro-modules and evaluated its effectiveness using a TAM-extended model, aiming to address the insufficiency of current engineering education in assisting students in mastering the practical knowledge required for sustainable engineering practices. The results of the study indicated that the flipped micro-modules are effective for sustainable engineering practice education. This study also identified areas for future development, such as integrating the flipped micro-modules with other learning resources, expanding their coverage to other sustainable engineering topics, and providing ongoing assessment and feedback to students.

The limitations of this study lie in, firstly, the sample size, which might be too small to generalize the findings to a larger population and may limit the representativeness of the results and conclusions. Second, the study lacked a control group, which could have allowed for a more rigorous comparison between the flipped micro-modules versus the traditional teaching method. To address these two limitations, future studies need to be conducted to measure the long-term impact of the flipped micro-modules on students' sustainable engineering practices using a larger sample size.

Author Contributions: Conceptualization, H.H.; methodology, H.H.; software, H.H., H.H.; validation, H.H., H.Z. and Y.W.; formal analysis, H.H., H.Z. and Y.W.; investigation, H.H., H.Z.; resources H.H.; data curation, H.H.; writing—original draft preparation, H.H., H.Z.; writing—review and editing, H.H., H.Z.; visualization, H.Z. and Y.W.; project administration, H.H.; funding acquisition, H.H. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by Funding for Strategic Plan Initiatives to Enhance the Student Learning Experience through the Use of Interactive Pedagogies, The Hong Kong Polytechnic University (Funding number: SPF21-22/A1/BEEE01).

Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the Human Subjects Ethics Sub-Committee of The Hong Kong Polytechnic University (protocol code HSEARS20221217003).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available from the corresponding author upon request. The data are not publicly available due to privacy restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Questions in the Survey Questionnaire

Categories	Questions
Perceived usefulness	**Q1**: The micro-modules enhance my practical knowledge in the engineering management **Q2**: The micro-modules make it easier for me to learn knowledge from the practical world **Q3**: I can easily remember the knowledge after viewing the animated videos **Q4**: The micro-modules support the in-classroom teaching **Q5**: The micro-modules are useful for delivering practical engineering management knowledge
Perceived ease of use	**Q6**: There was no problem for me to access the micro-modules and view the animated videos **Q7**: It is easy for me to figure out the way to learn knowledge through the micro-modules **Q8**: Learning how to operate the micro-modules (e.g., playing the animated videos) is easy for me **Q9**: I can conduct individual learning using micro-modules at my own pace **Q10**: It would be easy for me to become skilled at using micro-modules to learn knowledge
Quality of the content of the micro-modules	**Q11**: The visual contents in the animated videos are well presented **Q12**: The knowledge is well structured and explained in the animated videos **Q13**: The voice-over explanation/narration in the animated videos is easy to understand **Q14**: The animated videos demonstrate useful knowledge—the knowledge is relevant to the lecture topics and can connect students with the practical world **Q15**: The storytelling of the animated videos is logical and easy to follow
Quality of operation of the micro-modules	**Q16**: Blackboard is a suitable platform for hosting the micro-modules **Q17**: The animated videos are fast to be loaded online **Q18**: The instructional information on the micro-modules is clear **Q19**: The micro-modules provide mobility for me to learn knowledge
Quality of the micro-module framework	**Q20**: The micro-modules complement the lecture notes **Q21**: I can well examine my learning process through the micro-modules **Q22**: The framework/structure of each micro-module is logical **Q23**: Each micro-module embraces a clear topic **Q24**: Each micro-module presents a cohesive and systematic framework
Intention to use	**Q25**: I will choose to learn with micro-modules to supplement my in-class learning activities **Q26**: If a course has equipped with micro-modules, I will seek opportunities to access micro-modules for learning knowledge **Q27**: I hope other courses can also use micro-modules to support learning and teaching activities **Q28**: I will definitely participate in micro-modules for knowledge learning If I am given a chance **Q29**: I plan to participate in micro-modules for learning knowledge in the future
Demographical Characteristics	**Q30**: Gender **Q31**: Study Mode **Q32**: Year of Study **Q33**: Have you ever participated in learning activities in the form of micro-modules before?
Open-ended Question	**Q34**: Share with us your comments regarding learning with micro-modules

References

1. Gagnon, B.; Leduc, R.; Savard, L. Sustainable development in engineering: A review of principles and definition of a conceptual framework. *Environ. Eng. Sci.* **2009**, *26*, 1459–1472. [CrossRef]
2. Davidson, C.I.; Hendrickson, C.T.; Matthews, H.S.; Bridges, M.W.; Allen, D.T.; Murphy, C.F.; Allenby, B.R.; Crittenden, J.C.; Austin, S. Preparing future engineers for challenges of the 21st century: Sustainable engineering. *J. Clean. Prod.* **2010**, *18*, 698–701. [CrossRef]
3. Popenici, S.A.D.; Kerr, S. Exploring the impact of artificial intelligence on teaching and learning in higher education. *Rese. Prac. Technol. Enhanc. Learn.* **2017**, *12*, 22. [CrossRef] [PubMed]
4. Anderson, A. *Virtual Reality, Augmented Reality and Artificial Intelligence in Special Education: A Practical Guide to Supporting Students with Learning Differences*; Routledge: New York, NY, USA, 2019.

5. Baxter, G.; Hainey, T. Student perceptions of virtual reality use in higher education. *J. Appl. Res. High. Educ.* **2019**, *12*, 413–424. [CrossRef]
6. Han, J.; Geng, X. University students' approaches to online learning technologies: The roles of perceived support, affect/emotion and self-efficacy in technology-enhanced learning. *Comput. Educ.* **2023**, *194*, 104695. [CrossRef]
7. Zhang, X.; Zhou, M. Information and digital technology-assisted interventions to improve intercultural competence: A meta-analytical review. *Comput. Educ.* **2022**, *194*, 104697. [CrossRef]
8. Bradley, V.M. Learning Management System (LMS) use with online instruction. *Int. J. Technol. Educ.* **2021**, *4*, 68–92. [CrossRef]
9. Zawacki-Richter, O.; Marín, V.I.; Bond, M.; Gouverneur, F. Systematic review of research on artificial intelligence applications in higher education—Where are the educators? *Int. J. Educ. Technol. High. Educ.* **2019**, *16*, 39. [CrossRef]
10. Hou, H.; Wu, H. Technology for real estate education and practice: A VR technology perspective. *Prop. Manag.* **2020**, *38*, 311–324. [CrossRef]
11. Chugh, R.; Ruhi, U. Social media in higher education: A literature review of Facebook. *Educ. Inf. Technol.* **2018**, *23*, 605–616. [CrossRef]
12. Martín, P.; Potočnik, K.; Fras, A.B. Determinants of students' innovation in higher education. *Stud. High. Educ.* **2017**, *42*, 1229–1243. [CrossRef]
13. Guo, P.; Saab, N.; Post, L.S.; Admiraal, W. A review of project-based learning in higher education: Student outcomes and measures. *Int. J. Educ. Res.* **2020**, *102*, 101586. [CrossRef]
14. Hou, H.; Lai, J.H.K.; Wu, H. Project-based learning and pedagogies for virtual reality-aided green building education: Case study on a university course. *Int. J. Sustain. High. Educ.* **2023**, *24*, 1308–1327. [CrossRef]
15. Subhash, S.; Cudney, E.A. Gamified learning in higher education: A systematic review of the literature. *Comput. Hum. Behav.* **2018**, *87*, 192–206. [CrossRef]
16. Delialioğlu, Ö. Student engagement in blended learning environments with lecture-based and problem-based instructional approaches. *J. Educ. Technol. Soc.* **2012**, *15*, 310–322.
17. Rasheed, R.A.; Kamsin, A.; Abdullah, N.A. Challenges in the online component of blended learning: A systematic review. *Comput. Educ.* **2020**, *144*, 103701. [CrossRef]
18. Markopoulos, A.P.; Fragkou, A.; Kasidiaris, P.D.; Davim, J.P. Gamification in engineering education and professional training. *Int. J. Mech. Eng. Educ.* **2015**, *43*, 118–131. [CrossRef]
19. Elmer, S.J.; Carter, K.R.; Armga, A.J.; Carter, J.R. Blended learning within an undergraduate exercise physiology laboratory. *Adv. Physiol. Educ.* **2016**, *40*, 64–69. [CrossRef]
20. Rosenbusch, K. Technology intervention: Rethinking the role of education and faculty in the transformative digital environment. *Adv. Dev. Hum. Resour.* **2020**, *22*, 87–101. [CrossRef]
21. Topalli, D.; Cagiltay, N.E. Improving programming skills in engineering education through problem-based game projects with Scratch. *Comput. Educ.* **2018**, *120*, 64–74. [CrossRef]
22. González-Zamar, M.-D.; Abad-Segura, E. Global Evidence on Flipped Learning in Higher Education. *Educ. Sci.* **2022**, *12*, 515. [CrossRef]
23. Förster, M.; Maur, A.; Weiser, C.; Winkel, K. Pre-class video watching fosters achievement and knowledge retention in a flipped classroom. *Comput. Educ.* **2022**, *179*, 104399. [CrossRef]
24. Mavromihales, M.; Holmes, V. Delivering manufacturing technology and workshop appreciation to engineering undergraduates using the flipped classroom approach. *Int. J. Mech. Eng. Educ.* **2016**, *44*, 113–132. [CrossRef]
25. Yelamarthi, K.; Drake, E. A flipped first-year digital circuits course for engineering and technology students. *IEEE Trans. Educ.* **2014**, *58*, 179–186. [CrossRef]
26. Castedo, R.; López, L.M.; Chiquito, M.; Navarro, J.; Cabrera, J.D.; Ortega, M.F. Flipped classroom—Comparative case study in engineering higher education. *Comput. Appl. Eng. Educ.* **2019**, *27*, 206–216. [CrossRef]
27. Prevalla, B.; Uzunboylu, H. Flipped learning in engineering education. *TEM J.* **2019**, *8*, 656.
28. Al-Abdeli, Y.M. Flipped classes: Drivers for change, transition and implementation. In *The Flipped Classroom: Practice and Practices in Higher Education*; Springer: Singapore, 2017; pp. 193–209.
29. Davis, F.D. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q.* **1989**, *13*, 319–340. [CrossRef]
30. Mustofa, R.H.; Pramudita, D.A.; Atmono, D.; Priyankara, R.; Asmawan, M.C.; Rahmattullah, M.; Mudrikah, S.; Pamungkas, L.N.S. Exploring educational students acceptance of using movies as economics learning media: PLS-SEM analysis. *Int. Rev. Econ. Educ.* **2022**, *39*, 100236. [CrossRef]
31. Liu, I.F.; Chen, M.C.; Sun, Y.S.; Wible, D.; Kuo, C.-H. Extending the TAM model to explore the factors that affect intention to use an online learning community. *Comput. Educ.* **2010**, *54*, 600–610. [CrossRef]
32. Scherer, R.; Siddiq, F.; Tondeur, J. The technology acceptance model (TAM): A meta-analytic structural equation modeling approach to explaining teachers' adoption of digital technology in education. *Comput. Educ.* **2019**, *128*, 13–35. [CrossRef]
33. Venkatesh, V.; Davis, F.D. A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Manag. Sci.* **2000**, *46*, 186–204. [CrossRef]
34. Fathema, N.; Shannon, D.; Ross, M. Expanding the Technology Acceptance Model (TAM) to examine faculty use of Learning Management Systems (LMSs) in higher education institutions. *J. Online Learn. Teach.* **2015**, *11*, 210–232.

35. Hair, J.F.; Ringle, C.M.; Sarstedt, M. Partial least squares structural equation modeling: Rigorous applications, better results and higher acceptance. *Long Range Plan.* **2013**, *46*, 1–12. [CrossRef]
36. Akour, I.; Alshare, K.; Miller, D.; Dwairi, M. An exploratory analysis of culture, perceived ease of use, perceived usefulness, and internet acceptance: The case of Jordan. *J. Internet Commer.* **2006**, *5*, 83–108. [CrossRef]
37. Eze, N.U.; Obichukwu, P.U.; Kesharwani, S. Perceived usefulness, perceived ease of use in ICT support and use for teachers. *IETE J. Educ.* **2021**, *62*, 12–20. [CrossRef]
38. Chen, L.; Aklikokou, A.K. Determinants of E-government adoption: Testing the mediating effects of perceived usefulness and perceived ease of use. *Int. J. Public Admin.* **2020**, *43*, 850–865. [CrossRef]
39. Akçayır, G.; Akçayır, M. The flipped classroom: A review of its advantages and challenges. *Comput. Educ.* **2018**, *126*, 334–345. [CrossRef]
40. Lo, C.K.; Hew, K.F. The impact of flipped classrooms on student achievement in engineering education: A meta-analysis of 10 years of research. *J. Eng. Educ.* **2019**, *108*, 523–546. [CrossRef]