Enhancing Technology Acceptance Through Drone-Based STEM Activities: A TPCK Framework Approach

Pongpatai Kitrungloadjanaporn[1,2,3], Darapond Triampo[1,2,4], Narin Nuttavut[1,2,5], and Wannapong Triampo[1,2,5,*]

[1]School of Bioinnovation and Bio-based Product Intelligence, Faculty of Science, Mahidol University, Bangkok, Thailand
[2]MUSC Centre for Excellence in STEM Education, Faculty of Science, Mahidol University, Bangkok, Thailand
[3]Institute for Innovative Learning, Mahidol University, Bangkok, Thailand
[4]Department of Chemistry, Faculty of Science, Mahidol University, Bangkok, Thailand
[5]Department of Physics, Faculty of Science, Mahidol University, Bangkok, Thailand
Email: pongpatai.kit@mahidol.ac.th (P.K.); darapond.tri@mahidol.edu (D.T.); narinnuttavut@gmail.com (N.N.); wtriampo@gmail.com (W.T.)
*Corresponding author
Manuscript received July 21, 2025; revised September 29, 2025; accepted October 9, 2025; published March 19, 2026

***Abstract*—Drone-based Science, Technology, Engineering, and Mathematics (STEM) learning offers a practical means of connecting theory with real-world applications, enhancing student engagement meaningfully. This study investigates its impact on students' technology acceptance using the Technology Acceptance Model (TAM) and examines differences by gender and school type in Thailand. Three modules were developed through the Technological Pedagogical Content Knowledge (TPCK) framework, covering drone fundamentals, operational skills, and applications such as agricultural survey or natural disaster management. A mixed-methods approach involved pre- and post-questionnaires from 130 high school students across different school types. Findings show significant improvement in all TAM areas—usefulness, ease of use, attitude, and intention—following the intervention, with minimal differences between genders and school backgrounds. The results demonstrate that drone-based STEM not only strengthens technology acceptance but also broadens access to engaging technology-enhanced education. These insights emphasize the value of integrating drone-based activities into future STEM curricula for both educators and policymakers.**

***Keywords*—drone-based learning, Science, Technology, Engineering, and Mathematics (STEM) education, technology acceptance, innovation learning, equitable access**

I. Introduction

Drones, or Unmanned Aerial Vehicles (UAVs), are gaining popularity due to their versatility and growing accessibility. Equipped with features such as automated flight, remote control, and advanced imaging sensors, drones are now applied in diverse domains, including agriculture, disaster response, logistics, and media production [1–6]. Their ability to capture data in inaccessible or hazardous environments also underscores their value beyond industrial contexts. Increasingly, drones have been introduced into education, especially in STEM—science, technology, engineering, and mathematics classrooms.

Integrating drone technology into schools offers students opportunities that extend beyond theoretical study of science and engineering, deepening their engagement and developing practical skills. Hands-on activities, such as exploring flight dynamics or solving community challenges like farmland monitoring and disaster planning, help transform abstract concepts into tangible learning experiences. The Technological Pedagogical Content Knowledge (TPCK) framework provides a robust foundation for this integration by aligning content, pedagogy, and technology meaningfully.

Existing research highlights the benefits of drone-based learning, including enhanced motivation, critical thinking, and technology confidence [7, 8]. For example, the TechViwoEDU Project demonstrated that low-cost drones can effectively promote computational thinking, problem decomposition, and algorithmic reasoning, even in rural schools [9, 10]. These skills are not only academically beneficial but are also essential for future STEM careers.

However, integrating drones into education poses several challenges. Teachers often lack research-based guidance, along with the pedagogical and technological knowledge required to design meaningful activities. Safety regulations, liability concerns, and financial costs for equipment, maintenance, and training further constrains implementation, particularly in under-resourced areas [11, 12].

In response, this study presents a series of drone-based STEM modules grounded in the TPCK framework. These modules aim to teach scientific concepts, build technological fluency, foster collaboration, and spark interest in real-world problem solving. To better understand the effectiveness, this research employed the Technology Acceptance Model (TAM) to explore students' perceptions of drone-based STEM learning and its potential for advancing technology-integrated education.

II. Literature Review

A. Drones in Education

Drones have emerged as a powerful tool in STEM education, offering interactive and hands-on learning experiences that align with broader shifts toward Industry 4.0 technologies. These tools are transforming how students learn by making the experience more immersive, and relevant to the digital age [13]. Their increasing accessibility and ease of use make them effective for engaging students in real-world applications and inspire future careers in fields like robotics, programming, and environmental science [14]. Drone-based learning has shown to foster project-based learning, teamwork, technical skills, and creative thinking [15]. For example, the Drone Education Program in Sarawak helped students improve flight operation and video editing skills, increasing their engagement in STEM [16].

In rural areas, drones have also helped bridge the digital

doi: 10.18178/ijiet.2026.16.3.2554

divide by significantly increasing student interest in STEM from 53.4% to nearly 90% [17]. Similarly, Sattar and Nawaz [10] showed that coding drones in a simulated wildfire response scenario paired with inquiry-based learning sparked students' creative, analytical, and technical thinking. Moreover, drones played a key role in integrating Artificial Intelligence (AI) and programming into education. For example, Wang *et al.* [18] used Python and the You Only Look Once (YOLO) image recognition package in drone activities to teach students on computational thinking and AI fundamentals. Zhang and Stewart [19] highlighted how drone programming helped students break down problems and apply mathematical algorithms.

While drone education nurtures programming, robotics, and engineering competencies, as well as agricultural literacy and systems thinking [20, 21], it also strengthens soft skills like adaptability, teamwork, and project management, shaping well-rounded individuals for complex challenges. Drones also serve as a platform for innovation and creativity, where students are encouraged to design, build, and test their own projects, developing divergent thinking and reflective problem-solving which are key aspects of 21st-century learning [22]. Despite these benefits, drone-integrated education is still in its early stages. High equipment costs, inconsistent performance of low-cost alternatives, and insufficient training are persistent barriers. These challenges point out the need for structured, research-based approaches that guide educators in effective drone adoption [23].

B. Technological Pedagogical Content Knowledge

The Technological Pedagogical Content Knowledge (TPCK) framework assimilates three essential types of knowledge: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK) to support effective teaching with digital tools [24]. Unlike traditional approaches that treat these areas separately, TPCK emphasizes their intersection and how this assimilation enhances learning. Mishra and Koehler [25] reported that TPCK is vital for teaching with technology because it helps teachers understand not just what to teach, but how and why certain concepts may be difficult or easy for students to grasp when technology is involved. Through TPCK, teachers can consider how digital tools might solve learning challenges, while reflecting on what students already know and how to build on that foundation. Moreover, TPCK enables educators to design active, student-centered activities that develop collaboration, critical thinking, and problem-solving skills [26], while also building confidence in technology use [27].

TPCK further allows teachers to accommodate diverse learning styles by leveraging multiple modalities such as simulations, games, and interactive media [28]. By promoting intentional and reflective teaching, the framework helps educators select appropriate technologies that support their learning goals rather than allowing students to be distracted by flashy or overly complex tech [25]. Together, drones in education and the TPCK model provide a foundation for innovative, technology-enhanced pedagogy. However, effective integration requires overcoming practical barriers and equipping teachers with the knowledge to design purposeful, contextually relevant learning experiences. Fig. 1 shows the TPCK model, illustrating the overlapping nature of content, pedagogy, and technology, and how their integration supports effective teaching.

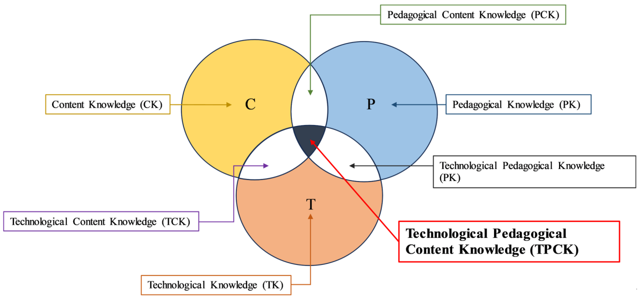

Fig. 1. Technological Pedagogical Content Knowledge (TPCK) model.

III. Materials and Methods

A. Materials

This study employed the Tello Education (Tello EDU), a lightweight and easy-to-use drone specifically designed for educational purposes. Its compact design and beginner-friendly features make it ideal for introducing students to hands-on, interactive learning experiences. A key advantage of Tello EDU is its compatibility with various coding languages, including Scratch, Python, Swift, and block-based programming, allowing users to choose the platform that best matches their skill level.

For beginners, the drone's block-based programming interface offers a simplified, drag-and-drop system that reduces the complexity of coding while introducing fundamental programming concepts. As noted by Cavadas [29], this accessibility makes Tello EDU an excellent entry point for learning both programming and drone technology. The Tello EDU app complements the drone by offering a wide range of commands and flight options. Its intuitive, block-based coding environment allows learners to build instructions by assembling colorful visual blocks. Due to its adaptability, ease of use, and strong educational value, Tello EDU serves as a powerful tool in both classroom settings and informal learning environments where students can explore technology in a fun and practical way [29].

B. Participants, Ethical Approval, and Informed Consent

This study involved 130 high school students aged between 14 and 17 years, selected from four different types of schools: international schools, science-focused public schools in the capital, rural provincial schools, and schools in the greater metropolitan area.

Table 1. The distribution of students by grade level and age

Grade Level	Age 14	Age 15	Age 16	Age 17	Total
Grade 9	11	-	-	-	11
Grade 10	2	58	20	1	81
Grade 11	-	1	26	7	44
Grade 12	-	-	1	3	4

Purposive sampling was employed to select schools that had previously participated in our STEM outreach activities, ensuring administrative readiness, teacher collaboration, and familiarity with STEM-related activities. Such criteria ensured that the research could be conducted efficiently and that participants were adequately prepared to engage in technology-based learning. In this study, one school was selected from each category. Table 1 summarizes the distribution of students by grade level and age.

Among the total 130 participants, 83 were males and 47 were females. While all students had some prior knowledge about drones through classroom discussions or online content, none had direct operational experience. All participants engaged in drone-based STEM activities and subsequently completed a Technology Acceptance Model (TAM) questionnaire to assess their perceptions of technology use. This diverse selection allowed examination of drone-based STEM learning across varied educational contexts and levels of technology accessibility.

Ethical considerations were carefully addressed in the design and implementation of this study to ensure compliance with ethical standards regarding both student safety and data privacy. Since the participants were minors, both parental/legal guardian's written informed consent and institutional approval were obtained prior to the activities. All drone flights were conducted under controlled conditions, complying with national safety regulations to minimize risks. No personal data or identifying information were collected during the activities; only aggregated, anonymized responses to questionnaires were analyzed. Ethical approval was granted by the Institutional Review Board (IRB) of Mahidol University (Approval No. MU-CIRB 2023/205.2606).

C. Research Measurement

Data were collected using a paper-based questionnaire adapted from the Technology Acceptance Model (TAM) [30]. The same questionnaire was administered before and after the STEM activities to assess changes in students' perceptions of drone technology in education. The questionnaire focused on four main constructs:

1) Perceived Usefulness (PU): the students' belief that drone-based STEM activities enhanced their understanding and ability in STEM subjects, reflecting whether students found the experience meaningful and beneficial for their learning.
2) Perceived Ease of Use (PEU): the extent to which students found drone use simple and accessible, indicating whether they felt confident operating drones and completing tasks without feeling overwhelmed.
3) Attitude Toward Use (ATT): students' overall feelings toward using drones in STEM learning, including their level of interest, enjoyment, and engagement, or even any hesitation or discomfort they may have felt.
4) Behavioral Intention (BI): the students' willingness and intention to continue using drone technology in the future. A high score here suggests that students see value in drone technology beyond the current activity and are open to integrating it into future learning experiences.

The questionnaire was translated into Thai and validated by three experts in educational technology for accuracy and cultural relevance. It comprises 13 items, where PU = 3, PEU = 3, ATT = 4, and BI = 3 items. All items were rated on a five-point Likert scale, ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Reliability analysis of pre-test data yielded Cronbach's alpha values above the accepted threshold of 0.70 for all constructs (PU = 0.87, PEU = 0.85, ATT = 0.88, and BI = 0.89), indicating a high level of internal consistency.

For statistical analysis, descriptive statistics were used to summarize central tendencies and variability, while the Shapiro–Wilk Test assessed the normality of data distribution. Wilcoxon Signed-Rank Test was employed to compare pre- and post-activity scores, Mann–Whitney U Test to analyze gender-based differences, Kruskal–Wallis H Test to compare students' technology acceptance across different school types, and Cronbach's alpha to assess the questionnaire reliability.

The drone-based STEM activities were organized into three modules, each with a unique title designed to spark curiosity and encourage student engagement. In addition to introducing the content, these titles built a sense of anticipation and thematic connection throughout the learning process. The modules are listed as follow:

- Module 1 "Drone Spark"

This first module introduced real-world drone applications in areas such as environmental monitoring, wildlife tracking in forest areas, traffic observation, infrastructure inspection (like signal towers) offshore oil rig surveys, media production, video shooting, photography, emergency medical supplies delivery during traffic congestion, online shopping goods transportation, fire extinguishing in high-rise buildings, and fertilizer and pesticides dispersion on farms.

To get students thinking, the session opened with a brainstorming question—"Do you know how drones are used in real life?"—to activate students' prior knowledge, engage them in discussion, and build critical thinking skills. Follow which students learned about drone safety regulations and legal guidelines based on standards from the Civil Aviation Authority of Thailand. Key topics included safety protocols, privacy concerns, and ethical drone use. The goal was to help students operate drones effectively and understand the accompanying responsibilities.

In essence, Module 1 laid the foundation, providing both technical context and ethical grounding before students move on to hands-on flying activities.

- Module 2 "Drone Adventure"

Building on the theoretical knowledge from Module 1, students engaged in hands-on drone operation in this module by learning basic hardware setup, flight mechanics (throttle, roll, pitch, yaw), and how these concepts relate to movement along the X, Y, and Z axes [31, 32]. Simple terms were used to help students understand how changes in propeller speed influence direction and stability. Consequently, students were guided through connecting their drones to a mobile device via the official drone flight app to bridge theory and practice while providing students the skills needed for upcoming autonomous flight missions. To reinforce their learning, students completed the following flight missions:

Mission 1: Students practiced flying drones individually in a safe, supervised space, each limited to one full battery cycle (12 min). As part of this task, they took team selfies with the drone and shared them in a group chat to encourage peer interaction and digital sharing. This activity helped build confidence with the controls and added a fun social element.

Mission 2: Students participated in a relay-style team challenge, where each team of four took turns piloting the drone along a designated four-point course. Here, each handoff must happen only after a successful landing, with the drone's base aligned at least 50% on a marked landing zone. The entire mission had to be completed within 5 minutes, pushing teams to collaborate efficiently. Students recorded flight videos and helped teammates with navigations, strengthening spatial reasoning and communication skills.

- Module 3 "Drones Care for the Community"

The final module simulated a disaster-relief mission, requiring students to design lightweight delivery mechanisms like baskets or trays for transporting supplies such as medicine, food, and first-aid kits to areas cut off by flooding. Using simple materials like colored paper, teams applied engineering design, prototyping, and aerodynamic testing to ensure stability. Each group conducted test flights with their delivery prototypes, tweaking designs to improve balance and aerodynamic performance. After iterative refinements, four students per team worked together in a timed relay mission to fly across three drop zones. Within a 5 min time limit, they must deliver their cargo and return to base. This scenario required teams to think and act quickly while coordinating under pressure, as students needed to calculate optimal drop-off positions, manage flight time and battery usage, adapt to environmental conditions, such as wind or heat, and collaborate efficiently under strict time constraints.

This module provided the foundation for judging the activities as authentic and challenging problem-solving tasks, rather than simple demonstrations. The real-world tasks were further validated through concrete design requirements. Here, the application of engineering design principles, testing aerodynamic stability, and adapting prototypes based on real-time performance were demanded. Moreover, the disaster-relief context reflected societal needs, thereby enhancing both authenticity and difficulty. These tasks represented interdisciplinary situations that students might realistically encounter in STEM practice.

Together, the three modules aligned with the TPCK framework by combining technological, pedagogical, and content knowledge, while also strengthening students' Behavioral Intention (BI) to continue exploring drone technology in meaningful contexts, as reflected in the results.

IV. Result and Discussion

The findings demonstrated a statistically significant improvement in all four constructs of the Technology Acceptance Model (TAM) following participation in the drone-based STEM activities. Among these, Behavioral Intention to Use (BI) showed the greatest increase, with mean score rising from 4.17 to 4.51, suggesting heightened motivation and interest in applying drone technology in future learning contexts. Increases in Perceived Usefulness (PU) and Perceived Ease of Use (PEU) indicate that students recognized drones as academically relevant and user-friendly, while the positive shift in Attitude Toward Use (ATT) reflects stronger engagement and enjoyment in STEM learning (Fig. 2).

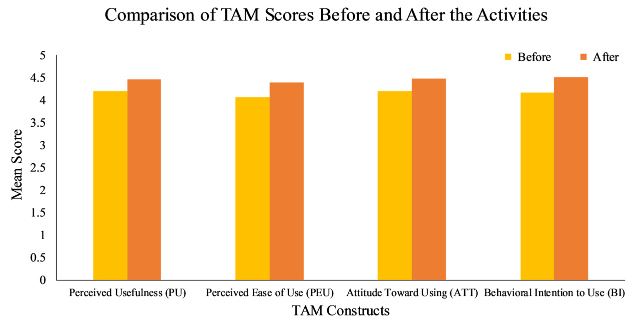

Fig. 2. Comparison of TAM scores before and after the activities.

Prior to hypothesis testing, the Shapiro–Wilk test confirmed distributional assumptions. Paired-samples t-tests were applied to normally distributed constructs (PEU and ATT), while Wilcoxon signed-rank tests were used for non-normally distributed constructs (PU and BI). For school type comparisons, a Kruskal–Wallis H test was conducted. All statistical tests were two-tailed with the significance set at $p < 0.05$.

A. Descriptive Analysis of Technology Acceptance Across Age Group

As presented in Table 2, descriptive analysis revealed consistently high scores across all age cohorts (14–17 years), with means exceeding 4.0 on every construct. Students aged 17 showed the highest means for PU (Mean = 4.73, SD = 0.42), PEU (Mean = 4.61, SD = 0.61), ATT (Mean = 4.64, SD = 0.53), and BI (Mean = 4.70, SD = 0.51). In contrast, students aged 14 reported slightly lower values (PU Mean = 4.28, ATT Mean = 4.38), though their BI remained relatively high (Mean = 4.49).

Table 2. Mean, standard deviation, and Kruskal–Wallis results of TAM by age group

Construst	Age 14 (n = 11)		Age 15 (n = 81)		Age 16 (n = 44)		Age 17 (n = 4)		Total (N = 130)		χ^2 (df = 3)	p-value
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
PUaf	4.28	0.38	4.51	0.47	4.42	0.60	4.73	0.42	4.47	0.52	6.186	0.103
Peuaf	4.41	0.41	4.45	0.51	4.26	0.67	4.61	0.61	4.39	0.58	4.330	0.228
ATaf	4.38	0.46	4.50	0.53	4.46	0.53	4.64	0.53	4.48	0.52	2.064	0.559
BIaf	4.49	0.40	4.55	0.52	4.43	0.54	4.70	0.51	4.51	0.52	3.896	0.273

Kruskal–Wallis results revealed no significant differences among the four age groups in PU (χ^2 = 6.186, df = 3, p = 0.103), PEU (χ^2 = 4.330, df = 3, p = 0.228), ATT (χ^2 = 2.064, df = 3, p = 0.559), or BI (χ^2 = 3.896, df = 3, p = 0.273). These outcomes suggest that hands-on, drone-based STEM activities promoted technology acceptance equally across different age cohorts. Consistent with prior studies by Sze *et al.* [16] and Yang *et al.* [33], where experiential, project-based approaches appear to mitigate age-related disparities by engaging learners in authentic, problem-solving tasks.

B. Descriptive Analysis of Technology Acceptance Across School Types

Table 3 displays results of deeper insights into students' perceptions, where descriptive statistics were calculated for each TAM construct across four types of schools, namely Metropolitan schools, international schools, Science-focused public schools, and Rural schools. Across all school types, the mean scores exceeded the neutral midpoint of 3.00, indicating generally positive perceptions towards drone-based STEM learning. This suggests that students consistently recognized the educational value of drone technology, irrespective of school type, thereby highlighting its inclusivity and potential to enrich diverse learning environments.

Table 3. Mean and standard deviation of TAM constructs by school type

Constructs	Over all		School in the Greater Metropolitan Area		International school		Public school in the Capital focused on Science and Mathematics		Rural school	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
PU	4.47	0.52	4.31	0.62	4.30	0.55	4.60	0.46	4.56	0.44
PU1	4.57	0.56	4.44	0.64	4.36	0.57	4.68	0.53	4.67	0.47
PU2	4.42	0.66	4.19	0.88	4.30	0.63	4.57	0.55	4.49	0.55
PU3	4.44	0.65	4.30	0.78	4.26	0.62	4.57	0.65	4.51	0.55
PEU	4.39	0.58	4.25	0.72	4.42	0.54	4.47	0.60	4.40	0.47
PEU1	4.55	0.61	4.41	0.69	4.65	0.57	4.57	0.65	4.56	0.55
PEU2	4.22	0.78	4.04	0.90	4.22	0.74	4.38	0.83	4.21	0.67
PEU3	4.41	0.72	4.30	0.99	4.39	0.66	4.46	0.69	4.44	0.59
ATT	4.48	0.52	4.42	0.51	4.36	0.56	4.63	0.46	4.47	0.55
ATT1	4.55	0.64	4.41	0.69	4.52	0.73	4.68	0.53	4.53	0.63
ATT2	4.53	0.64	4.59	0.50	4.30	0.76	4.49	0.69	4.65	0.57
ATT3	4.39	0.66	4.33	0.62	4.13	0.76	4.65	0.54	4.35	0.69
ATT4	4.46	0.66	4.33	0.73	4.48	0.59	4.70	0.46	4.33	0.75
BI	4.52	0.51	4.44	0.59	4.48	0.50	4.59	0.44	4.51	0.54
BI1	4.48	0.66	4.41	0.75	4.43	0.66	4.57	0.65	4.49	0.79
BI2	4.37	0.78	4.33	0.78	4.35	0.83	4.38	0.76	4.40	0.79
BI3	4.69	0.54	4.59	0.69	4.65	0.49	4.84	0.37	4.65	0.57

Table 4. Effect of drone-based STEM activities on students' technology acceptance

Construct	Pre-test (M ± SD)	Post-test (M ± SD)	Test	Statistic	*p*-value	Effect Size (r)	95% CI
PU	4.20 ± 0.69	4.47 ± 0.52	Wilcoxon	$Z = -3.43$	0.001	0.30 (medium)	[0.165, 0.335]
PEU	4.08 ± 0.70	4.39 ± 0.58	Paired t-test	$t\,(129) = -4.08$	< 0.001	0.34 (medium)	[−0.46, −0.16]
ATT	4.20 ± 0.67	4.48 ± 0.52	Paired t-test	$t\,(129) = -4.02$	< 0.001	0.33 (medium)	[−0.42, −0.14]
BI	4.18 ± 0.66	4.52 ± 0.51	Wilcoxon	$Z = -4.70$	< 0.001	0.41 (medium-large)	[0.170, 0.500]

Note: CI means Confidence Interval.

In terms of PU, the highest scores were observed in students from science-focused public schools (Mean = 4.60, SD = 0.46) and rural schools (Mean = 4.56, SD = 0.44), suggesting that students in these educational settings perceived drones as highly effective for STEM learning enhancement. Regarding PEU, international school students demonstrated high confidence (PEU1: Mean = 4.65, SD = 0.57), while students from science-focused public schools also reported a strong perception of ease (PEU3: Mean = 4.46, SD = 0.69). These results imply familiarity with technology in the classroom and facilitate smoother adaptation to drone-based activities.

In terms of ATT, students' attitudes were particularly positive in science-focused public schools, with high scores on ATT2 (Mean = 4.49, SD = 0.69) and ATT4 (Mean = 4.70, SD = 0.46), suggesting that tech-rich contexts encourage engagement and motivation. Similarly, BI scores were consistently high across all school types, with BI3 peaking in science-focused public schools (Mean = 4.84, SD = 0.37), marking a strong intention to continue drone-based learning.

Table 4 summarizes the statistical significance of pre- and post-activity scores. Here, results of the Wilcoxon Signed-Rank test revealed statistically significant increase in all TAM constructs following the activities:

- PU: mean score rose from 4.20 to 4.47 ($Z = -3.431$, $p = 0.001$, indicating enhanced recognition of drones' contribution to STEM learning.
- PEU: mean score increased from 4.08 to 4.39 ($t\,(129) = -4.08$, $p < 0.001$), showing greater confidence in handling the technology after hands-on practice.
- ATT: mean score rose from 4.20 to 4.48 ($t\,(129) = -4.02$, $p < 0.001$, reflecting more positive attitudes toward educational drone integration.
- BI: recorded the largest mean increase from 4.18 to 4.52, ($Z = -4.70$, $p < 0.001$), underscoring students' motivation to continue exploring drone technology beyond the classroom activities.

Overall, these findings affirm the effectiveness of drone-integrated STEM learning in shaping students' future engagement with educational technology. The rise in BI and ATT scores points out growing enthusiasm, positive emotional response, and increased motivation. In essence, the activities not only helped students learn but also fostered a mindset that embraces innovation and ongoing interaction with emerging tools like drones.

C. Effect of Drone-Integrated STEM Activities on Students' Technology Acceptance Across School Types

To evaluate the impact of drone-integrated STEM activities on students' acceptance of technology, both parametric and non-parametric tests were applied to pre- and post-test scores across four key TAM constructs. The analysis included 130 students across all school types, encompassing both male and female participants (Table 4). A Shapiro–Wilk test was first performed to assess data normality. Results indicated that PU and BI deviated from normality, while PEU and ATT met the assumption. Accordingly, Wilcoxon signed-rank tests were used for PU and BI, while paired-samples t-tests were applied for PEU and ATT. Across all constructs, significant raise were observed between pre- and post-test measures:

- PU: increased from 4.20 (SD = 0.69) to 4.47 (SD = 0.52),
  $Z = -3.43$, $p = 0.001$, $r = 0.30$, 95% CI = [0.165, 0.335].
- PEU: increased from 4.08 (SD = 0.70) to 4.39 (SD = 0.58), $t\,(129) = -4.08$, $p < 0.001$, $r = 0.34$, 95% CI = [−0.46, −0.16].
- ATT: increased from 4.20 (SD = 0.67) to 4.48 (SD = 0.52), $t\,(129) = -4.02$, $p < 0.001$, $r = 0.33$, 95% CI = [−0.42, −0.14].

- BI: increased from 4.18 (SD = 0.66) to 4.52 (SD = 0.51), $Z = -4.70$, $p < 0.001$, $r = 0.41$, 95% CI = [0.170, 0.500].

Collectively, these results confirm statistically robust and practically meaningful gains across all TAM constructs. Importantly, no statistically significant differences were detected between students from international schools, science-focused public schools, rural schools, and metropolitan schools, suggesting comparable levels of acceptance among diverse educational contexts.

To further examine school type effects, a Kruskal–Wallis H test was conducted (Table 5). Findings revealed no statistically significant differences in PEU, ATT, or BI, while PU approached significance ($p = 0.053$) but did not reach the conventional threshold of $p < 0.05$. Overall, the intervention proved equally effective across school contexts, reinforcing the inclusivity and scalability of drone-based STEM education. Students, regardless of background, exhibited similar levels of enthusiasm, confidence, and intention to continue engaging with drone technology in future learning.

Table 5. School outcomes in TAM after drone-based STEM activities

Construct	Schools	N	Mean	SD	*p*-value	Interpretation
PUaf	School in the Greater Metropolitan Area	27	4.32	0.62	0.053	Not significant
	International school	23	23	4.30		
	Public school in the Capital focused on Science and Mathematics	37	4.60	0.46		
	Rural school	43	4.56	0.44		
PEUaf	School in the Greater Metropolitan Area	27	4.25	0.72	0.577	Not significant
	International school	23	4.42	0.54		
	Public school in the Capital focused on Science and Mathematics	37	4.47	0.60		
	Rural school	43	4.40	0.47		
ATTaf	School in the Greater Metropolitan Area	27	4.42	0.51	0.199	Not significant
	International school	23	4.36	0.56		
	Public school in the Capital focused on Science and Mathematics	37	4.63	0.46		
	Rural school	43	4.47	0.55		
BIaf	School in the Greater Metropolitan Area	27	4.44	0.59	0.776	Not significant
	International school	23	4.48	0.50		
	Public school in the Capital focused on Science and Mathematics	37	4.59	0.44		
	Rural school	43	4.51	0.54		

D. *Effect of Drone-Integrated STEM Activities on Male and Female Students' Technology Acceptance*

To explore whether gender influenced students' acceptance of drone-integrated STEM activities, data from male ($n = 83$) and female ($n = 47$) participants were analyzed separately.

A Shapiro–Wilk test, appropriate for small to moderate sample sizes, revealed that responses from both groups were not normally distributed with all *p*-values below 0.05 (e.g., PU for males: $W = 0.902$, $p = 0.000$; PU for females: $W = 0.919$, $p = 0.003$). Consequently, the Mann–Whitney U test was selected to compare gender differences. As summarized in Table 6, no statistically significant differences emerged between genders across all four TAM constructs. However, PU approached significance ($U = 1561.000$, $Z = -1.955$, $p = 0.051$), suggesting a possible variation in how males and females perceived the usefulness of drones-based STEM activities. These outcomes suggest that the activity was equally effective for both genders, supporting the inclusivity of the activity design. By aligning content, pedagogy, and technology, the activity enabled all students to build confidence and technological competence. Research by Choi and Hong [34] supports this conclusion, showing that TPCK-informed instruction tends to neutralize gender gaps in technology adoption. For example, in TPCK-based science programs for preservice teachers, female participants demonstrated growth in instructional confidence and skills, eventually matching their male peers. Likewise, Yepes *et al.* [23] reported that high school drone-based STEM programs led to equal engagement and outcomes for both male and female students.

These findings are consistent with broader literature, suggesting that well-structured, hands-on tech learning experiences offer balanced benefits across gender lines [35]. Ensuring equal access is particularly important, as research has shown that girls who gain strong Information and Communication Technology (ICT) skills during their school years are significantly more likely to pursue STEM careers [36]. Additionally, Jang *et al.* [37] and Mailizar *et al.* [38] demonstrated that teachers with strong Technological Pedagogical Content Knowledge a variation of TPCK (TPACK) competencies positively influenced students' PU thereby enhancing motivation and behavioral intention toward technology adoption. Similarly, several studies confirmed that strong TPCK/TPACK competencies directly predict improved student responses in PU, PEU, ATT, and BI [33, 39]. Altogether, these findings emphasize that combining robust pedagogy with technological fluency is key to boosting student acceptance of educational technology, supporting the effectiveness of drone-based STEM learning.

Table 6. Gender outcomes in TAM after drone-based STEM activities

Contruct	Gender	N	Mean	SD	Z	*p*-value	Interpretation
PUaf	Male	83	4.41	0.54	−1.955	0.051	Not significant
	Female	47	4.60	0.45			
PEUaf	Male	83	4.32	0.64	−1.630	0.103	Not significant
	Female	47	4.53	0.44			
ATTaf	Male	83	4.45	0.53	−1.139	0.255	Not significant
	Female	47	4.55	0.51			
BIaf	Male	83	4.48	0.55	−0.829	0.407	Not significant
	Female	47	4.58	0.45			

E. Qualitative Research Results

In the qualitative phase of the study, following the self-assessment based on TAM, students responded to five open-ended questions addressing (1) challenges and obstacles encountered, (2) perceptions of the activity, (3) suggestions for improvement, (4) achieved learning outcomes, and (5) potential applications of drones in real-life contexts. These responses provided insights into students' experiences, complementing the quantitative findings in Table 7.

Table 7. The results of open-ended questions after conducting drone-based STEM activities

Theme	Findings	Example Student Quotes
Challenges & Barriers	Students encountered difficulties in controlling drones (precision, landing, switching pads), technical limitations (lag, limited camera), time constraints, and group coordination issues.	"Strong winds made it difficult to control the drone." / "Skill in controlling the drone of each individual." / "Limited time." / "The camera in the drone is limited so it's hard to land on the target."
Perceptions of Activities	Students described the activities as fun, exciting, and engaging. They saw them as opportunities for teamwork, problem-solving, and learning new technology.	"The activity promoted teamwork and problem-solving." / "It's a fun activity, I haven't touched a drone for over 8 years now. It's fun to control it again." / "The event was so much fun and helped me learn a lot about drones."
Suggestions for Improvement	Students suggested having more time, more drones to ensure equal participation, and more diverse/challenging missions. Many also expressed that they would like similar activities to be organized again.	"Maybe we could have more time to learn about the technology in detail." / "We want enough drones so everyone can use them longer." / "There should be more diverse activity stations and missions."
Learning Outcomes	Students reported gaining knowledge of drone flight and control, teamwork and communication, planning and critical thinking, and problem-solving skills. They also noted increased understanding of real-world applications.	"Before I had no idea how to control a drone. Now I do." / "I know how to use and fly the drone." / "I learned teamwork and critical thinking skills during the mission."
Applications of Drones	Students envisioned drones being applied in agriculture, environmental monitoring, safety and rescue, logistics/delivery, industry, education, and media production.	"See that drones are more than security; they can be used for agriculture, discovery and more." / "Drones can be used instead of risking a human's life." / "It can be used for delivery and also for stopping wildfires." / "Use in agriculture and industry."

Collectively, these qualitative results portray both challenges and opportunities of drone-based STEM learning. Despite technical and logistical barriers, students expressed enthusiasm, identified meaningful learning outcomes, and recognized the broader societal value of drone technology.

V. CONCLUSION

This study found that drone-integrated STEM activities, designed using the Technological Pedagogical Content Knowledge (TPCK) framework, significantly improved students' acceptance of technology. Using the Technology Acceptance Model (TAM) as the evaluative lens, all four constructs—Perceived Usefulness (PU), Perceived Ease of Use (PEU), Attitude Toward Use (ATT), and Behavioral Intention to Use (BI)—showed statistically significant gains. Among these, BI demonstrated the most notable increase, indicating that students were not only engaged but also motivated to continue using drone technology in future learning experiences. Importantly, positive results were consistent across genders and school types, reinforcing the inclusivity and broad applicability of this approach.

The findings accentuate the value of integrating emerging technologies like drones into STEM education, especially when supported by the TPCK structured framework. By blending content knowledge with hands-on experience and collaborative problem-solving, the activities enhanced students' confidence in technology use, teamwork, and engagement with STEM learning. This approach provides educators with an effective pathway to promote equitable, engaging, and future-ready STEM education. Moreover, this model shows potential to foster more balanced gender engagement in technology use and expand access to digital skills critical for students navigating increasingly tech-driven academic and career landscapes.

Nevertheless, certain limitations should be noted. First, the sample size of 130 students from four school types may not capture the broader diversity of educational settings. Second, the study measured only short-term outcomes, leaving the long-term sustainability of effects uncertain. Third, while male and female students engaged comparably, the absence of baseline gender data prevents conclusions about narrowing gender gaps. In addition, enthusiasm may have been influenced by the novelty of interacting with a new technology rather than the instructional design alone. Despite these limitations, the model holds potential for broader application. The integration of emerging technologies within the TPCK framework could extend beyond STEM to fields such as social sciences, humanities, and language learning. For example, using drones for geographic mapping, digital storytelling, or interactive simulations.

Future research should employ longitudinal designs to examine long-term impacts on academic achievement, digital literacy, and career aspirations. Studies should also investigate how socioeconomic status, school resources, and prior technology exposure shape outcomes. For large-scale sustainable implementation, issues of cost, teacher training, equipment maintenance, and safety requirements must be addressed through adequate resources, professional development, and institutional support. Expanding to under-resourced schools, particularly in rural areas, will be essential for ensuring equitable access and scalability.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Pongpatai Kitrungloadjanaporn, Darapond Triampo, and Wannapong Triampo were responsible for data collection,

research conduct, data analysis, and manuscript writing. Narin Nuttavut contributed to research conduct, data analysis, and manuscript writing. All authors have read and approved the final version of this manuscript.

ACKNOWLEDGMENT

The authors wish to thank Assoc. Prof. Dr. Patcharin Panjaburee for her valuable guidance on statistical analysis. The authors would also like to extend their appreciation to all participating schools for granting permission to conduct the activities involved in this study.

REFERENCES

[1] A. Rejeb, A. Abdollahi, K. Rejeb *et al.*, "Drones in agriculture: A review and bibliometric analysis," *Comput. Electron. Agric.*, vol. 198, 107017, 2022.

[2] S. Park and Y. Choi, "Applications of unmanned aerial vehicles in mining from exploration to reclamation: A review," *Minerals*, vol. 10, no. 8, 663, 2020.

[3] V. C. Hollman, "Drone Photography and the Re-aestheticisation of Nature," *Decolonising and Internationalising Geography: Essays in the History of Contested Science*, Switzerland: Springer Cham, ch. 1, pp. 57–66, 2020.

[4] B. Mishra, D. Garg, P. Narang *et al.*, "Drone-surveillance for search and rescue in natural disaster," *Comput. Commun.*, vol. 156, pp. 1–10, 2020.

[5] V. Garg, S. Niranjan, V. Prybutok et al., "Drones in last-mile delivery: A systematic review on efficiency, accessibility, and sustainability," *Transp. Res. Part D: Transp. Environ.*, vol. 123, 103831, 2023.

[6] J. F. M. Sánchez, O. G. Hurtado, and R. M. P. Chaves, "Economic drones in education," *Elementary Education Online*, vol. 20, no. 6, pp 1291–1298, 2021.

[7] J. Ryu, S. LaPaglia, and R. Walters, "Idaho drone league (iDrone) to stimulate STEM workforce," *J. STEM Educ.: Innov. Res.*, vol. 21, no. 2, pp. 35–41, 2020.

[8] T. F. Slater, "Identifying implementation strategies for integrating drones into STEM and career technology education CTE programs," *Educ. Sci.*, vol. 14, no. 1, 105, 2024.

[9] J. T. Amenyo and W. Kpo, "Leveraging programmable educational drones for learning STEM, computational thinking and higher order thinking in schools in rural villages," *Drones: Various Applications*, Croatia: IntechOpen, ch. 1, pp. 45–67, 2024.

[10] F. Sattar and M. Nawaz, "Developing computational thinking in STEM education with drones," in *Proc. 2023 IEEE Global Eng. Educ. Conf. (EDUCON)*, 2023, pp. 1–5.

[11] S. Naab and E. Weigel, "A bird's-eye view of using drones in the classroom," *Am. Biol. Teach.*, vol. 83, no. 6, pp. 407–410, 2021.

[12] G. Albeaino, R. Eiris, M. Gheisari *et al.*, "Development of a VR-based drone-mediated building inspection training environment," in *Proc. Computing in Civil Engineering 2021*, 2021, pp. 1401–1408.

[13] P. Pergantis and A. Drigas, "The effect of drones in the educational process: A systematic review," *Educ. Sci.*, vol. 14, no. 6, 665, 2024.

[14] T. Karachalios, C. Karachristos, T. Kouvara *et al.*, "From classroom to sky: The Drones4STEM initiative in secondary education," in *Proc. 2024 IEEE Global Engineering Education Conf. (EDUCON)*, 2024, pp. 1–5.

[15] R. C. Y. Yeung, C. H. Yeung, D. Sun *et al.*, "A systematic review of drone integrated STEM education at secondary schools (2005–2023): Trends, pedagogies, and learning outcomes," *Computers & Education*, vol. 212, 104999, 2024.

[16] S. N. Sze, P. Phang, W. K. Tiong et al., "Digital drone education in sarawak: Enhancing STEM learning through hands-on training for school students," *J. Adv. Res. Appl. Sci. Eng. Technol.*, vol. 53, no. 2, pp. 1–9, 2025.

[17] N. J. N. Jemali, A. A. Rahim, M. R. M. Rosly et al., "Adopting drone technology in STEM education for rural communities," in *Proc. IOP Conf. Ser.: Earth Environ. Sci.*, 2022, 012017.

[18] S. I. C. Wang, E. Z. F. Liu, Y. Y. Huang et al., "When drone meets AI education: Boosting high school students' computational thinking and AI literacy," in *Proc. 2024 Pacific Neighborhood Consortium Annu. Conf. and Joint Meetings (PNC)*, 2024, pp. 45–52.

[19] S. Zhang and C. Stewart, "Computational thinking curriculum for unmanned aerial systems," in *Proc. 2019 IEEE National Aerospace and Electronics Conf. (NAECON)*, 2019, pp. 122–125.

[20] D. Stewardson, C. Ortiz, L. K. Narine et al., "Engaging Utah educators to teach 21st-century skills using drones," *Outcomes and Impact Quarterly*, vol. 3, no. 2, 3, 2023.

[21] J. Pusppanathan, I. Zulkapri, N. D. Nawi *et al.*, "Service learning implementation: Empowering engineering students via drone tech for EDU-4IR program," in *Proc. AIP Conf.*, 2022, 030014.

[22] F. Gratani and L. Giannandrea, "Towards 2030. Enhancing 21st-century skills through educational robotics," *Front. Educ*, vol. 7, 955285, 2022.

[23] I. Yepes, D. A. C. Barone, and C. M. D. Porciuncula, "Use of drones as pedagogical technology in STEM disciplines," *Informatics in Education*, vol. 21, no. 1, pp. 201–233, 2022.

[24] R. M. Cacho, "TPCK assessment of pre-service teachers toward enhancing teacher educators' modeling," *Asian J. Educ. e-Learning*, vol. 2, no. 5, pp. 349–356, 2014.

[25] P. Mishra and M. J. Koehler, "Technological pedagogical content knowledge: A framework for teacher knowledge," *Teachers Coll. Rec.: The Voice of Scholarship in Education*, vol. 108, no. 6, pp. 1017–1054, 2006.

[26] M. J. Koehler, P. Mishra, and W. Cain, "What is technological pedagogical content knowledge (TPACK)?" *Journal of Education*, vol. 193, no. 3, pp. 13–19, 2017.

[27] C. Angeli and N. Valanides, "Epistemological and methodological issues for the conceptualization, development, and assessment of ICT–TPCK," *Computers & Education*, vol. 52, no. 1, pp. 154–168, 2009.

[28] C. S. Chai, J. H. L. Koh, and C. C. Tsai, "A review of technological pedagogical content knowledge," *Educational Technology & Society*, vol. 16, no. 2, pp. 31–51, 2013.

[29] J. A. J. Cavadas, "Using drones for educational purposes," M.S. thesis, Department of Network Engineering, Universitat Politècnica de Catalunya, Barcelona, Spain, 2019.

[30] T. Teo, "Modelling technology acceptance in education: A study of pre-service teachers," *Comput. Educ.*, vol. 52, no. 2, pp. 302–312, 2009.

[31] D. Tezza, S. Garcia, and M. Andujar, "Let's learn! An initial guide on using drones to teach STEM for children," in *Proc. International Conf. on Human-Computer Interaction*, 2020, pp. 530–543.

[32] T. Bresciani, "Modelling, identification and control of a quadrotor helicopter," M.S. thesis, Dept. of Automatic Control, Lund Univ., Lund, Sweden, 2008.

[33] J. Yang, Q. Wang, J. Wang et al., "A study of K–12 teachers' TPACK on the technology acceptance of e-schoolbag," *Interact. Learn. Environ.*, vol. 29, no. 7, pp. 1062–1075, 2021.

[34] Y. Choi and S. H. Hong, "Effect of a science-based TPACK program for elementary preservice teachers according to their gender," *Contemporary Issues in Technology and Teacher Education*, vol. 22, no. 3, pp. 542–578, 2022.

[35] E. Ulbrich, M. Tejera, A. Schmid *et al.*, "Fostering the four C's: A gendered perspective on technology use in STEAM education," *Educ. Sci.*, vol. 15, no. 5, 528, 2025.

[36] F. Hertweck and J. Lehner, "The gender gap in STEM: (Female) teenagers' ICT skills and subsequent career paths," *PLOS ONE*, vol. 20, no. 1, e0308074, 2025.

[37] J. Jang, Y. Ko, W. S. Shin *et al.*, "Augmented reality and virtual reality for learning: An examination using an extended technology acceptance model," *IEEE Access*, vol. 9, pp. 6798–6809, 2021.

[38] M. Mailizar, M. Hidayat, and A. Al-Manthari, "Examining the impact of mathematics teachers' TPACK on their acceptance of online professional development," *J. Digit. Learn. Teach. Educ.*, vol. 37, no. 3, pp. 196–212, 2021.

[39] L. Hsu, "Examining EFL teachers' technological pedagogical content knowledge and the adoption of mobile-assisted language learning: A partial least square approach," *Computer Assisted Language Learning*, vol. 29, no. 8, pp. 1287–1297, 2016.