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Empowering Student with Drone: A DDR Approach to Expanding the Physics Body of Knowledge and Enhancing Stem Education

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Abstract

This study investigates the integration of drone technology into the Malaysian secondary school physics curriculum using a Design and Development Research (DDR) approach to enhance student engagement and proficiency in STEM subjects. Traditional teaching methods often fail to engage students with fundamental physics concepts, resulting in disinterest and difficulty in understanding. Drone technology offers a practical, interactive learning platform that aligns with STEM goals, fostering problem-solving skills, creativity and a deeper understanding of physics principles. The study's primary aim is to develop a comprehensive body of knowledge (BOK) for drone technology in physics that tailored to Malaysian secondary schools. This involves assessing teacher needs, identifying key physics concepts related to drone technology and evaluating the BOK's effectiveness and usability. The research is conducted in three phases: needs assessment, design and development and evaluation. The needs assessment phase involves semi-structured interviews with teachers to identify challenges and expectations regarding drone technology in physics education. The design and development phase uses the Nominal Group Technique (NGT) to prioritize key BOK

components and the Fuzzy Delphi Method (FDM) refines and validates the content through expert feedback. The evaluation phase surveys teachers and students to assess the BOK's usability, engagement and impact on teaching and learning. Essential physics concepts identified include aerodynamics, energy and power, kinematics and dynamics, electromagnetism and control systems. Integrating drones into physics education can enhance student engagement and comprehension by making abstract concepts more tangible and relatable. However, challenges such as resource constraints, teacher readiness and curriculum alignment must be addressed. The study concludes that drone technology can significantly transform physics education, promoting contextual and interdisciplinary learning and preparing students for future technological challenges by bridging theoretical knowledge and practical problem-solving.
Keywords: Drone Technology, Design and Development Research (DDR), Active Learning, Body of Knowledge

Introduction

STEM (Science, Technology, Engineering and Mathematics) education plays an essential role in equipping students with the skills and knowledge required to thrive in a world increasingly dominated by technology. It fosters critical thinking, problem-solving and creativity skills that are vital not only for personal and academic success but also for societal progress (Hebebci & Usta, 2022; Norris et al., 2023). However, despite the growing emphasis on STEM, many students face significant challenges in understanding core concepts, particularly in physics which is fundamental to many technological advancements (Guilding et al., 2023; Hemme et al., 2023). This difficulty in grasping abstract physics concepts often leads to a lack of engagement, reducing students' overall interest and proficiency in STEM subjects. Physics, in particular is frequently perceived as a difficult and abstract subject which contributes to the disengagement of students from STEM related fields.

In Malaysia, the secondary school curriculum reflects this global challenge, where students often complete physics tasks and experiments without fully comprehending the scientific principles behind them (Ruwiyah et al., 2021; Shahari and Phang, 2023). This gap in understanding hinders the effectiveness of STEM education, leading to students having surface-level knowledge without the deep conceptual grasp needed for future scientific or technological endeavors. This issue is compounded by traditional teaching methods that focus more on theoretical knowledge and less on interactive or practical applications, making it difficult for students to relate what they learn to real-world phenomena.

To address these challenges, integrating drone technology into physics education offers a promising solution. Drones, as modern technological tools, provide hands-on learning experiences that can bridge the gap between theoretical concepts and practical understanding. When students interact with drones, they are exposed to real-life applications of physics principles such as aerodynamics, energy conversion and motion dynamics (Chun, 2021; Espinola et al., 2019; Et. al., 2021; Yeung et al., 2024). This practical involvement makes abstract concepts more tangible, thereby enhancing students' engagement and deepening their understanding of the subject matter. Furthermore, the use of drone technology in education promotes active learning, which is known to improve retention and comprehension of scientific knowledge.

This integration of drone technology into the curriculum aligns seamlessly with the broader goals of STEM education. One of the primary objectives of STEM education is to develop students' ability to solve complex problems, think critically, and innovate creatively. Drones provide a platform for students to apply their physics knowledge in real-world contexts, encouraging them to experiment, analyze and adapt skills that are fundamental to STEM learning (Alqahtani et al., 2021; Gyasi et al., 2021). For instance, students can explore how principles of lift, thrust, and drag operate in drone flight, or how energy efficiency is optimized in drone motors, thereby fostering a deeper understanding of both physics and technology.

Moreover, the integration of drones into physics education helps prepare students for future technological challenges. As drones become increasingly utilized in various industries ranging from agriculture to logistics, healthcare and environmental monitoring familiarity with drone operations and the underlying physics principles equips students with the skills they need to participate in and contribute to these emerging fields. In addition to enhancing students' technical abilities, the practical application of drone technology in education also contributes to their overall STEM proficiency, preparing them for careers in science, engineering and technology (Makransky & Mayer, 2022).

Despite the potential benefits of using drones in education, there remains a gap in the development of a structured BOK that systematically integrates drone technology with core physics concepts. Existing research and educational approaches have largely focused on the technical aspects of drones without fully exploring their pedagogical value in teaching fundamental physics. This gap is especially apparent in the Malaysian educational context where drone technology has yet to be fully incorporated into the teaching of physics. There is a need for a comprehensive BOK that serves as a guideline for teachers, helping them not only cover the technical aspects of drone operation but also connect these operations to fundamental physics principles, thereby enhancing student understanding and engagement.

Literature Review

To understand the phenomenon of surface learning in the Malaysian secondary school curriculum, it is essential to consider both educational theories and contextual factors influencing the learning process. Theoretical frameworks such as constructivist theories by scholars like Piaget and Vygotsky, highlight the importance of active engagement and social interaction in the construction of knowledge. These theories suggest that students learn best through hands-on experiences and interactions with their environment, emphasizing a deeper, conceptual understanding of material (Moore & Piaget, 1971). Piaget's cognitive development theory also argues that learning is an active process where students construct knowledge through exploration and manipulation of their surroundings. This is contrasted by surface learning which aligns more closely with behaviorist theories where the focus is on observable outcomes and behaviors, with less attention given to students' cognitive processes (Chambers et al., 2020; Goddard, 2017; Rodrigues Neto & Pereira, 2020).

In the context of Malaysia, the National Curriculum Framework serves as a guideline for science education, aiming to develop students' knowledge, skills and attitudes essential for lifelong learning. Despite its well-intentioned objectives, the implementation of this framework often results in surface learning due to the focus on standardized testing and performance metrics (Rahman et al., 2020). High-stakes examinations which dominate the

Malaysian education system, create an environment where memorization is prioritized over conceptual understanding. This examination-driven culture pushes teachers to cover large amounts of content quickly, often at the expense of fostering deeper comprehension among students.

The over-reliance on rote memorization is a significant factor contributing to surface learning in Malaysian secondary schools. As highlighted by Rahman et al. (2020), students often memorize facts and formulas solely for the purpose of passing exams, rather than developing a meaningful understanding of scientific concepts. This method results in short-term retention of information without the ability to apply knowledge to new situations, thus preventing deep learning from taking place. Furthermore, the traditional teaching methods commonly used in classrooms, such as lecturing and direct instruction, do not engage students in critical thinking or inquiry-based learning which are essential for understanding the real-world applications of scientific principles (Tan & Wong, 2019).

Surface learning is often a consequence of educational practices that prioritize content coverage over conceptual understanding. Ong et al. (2021) highlight the effectiveness of the 5E Inquiry Learning Model in promoting deeper learning among Malaysian students, suggesting that traditional teaching methods may not adequately engage students in meaningful scientific inquiry. This aligns with the findings of (Idris & Bacotang, 2023), who argue that a robust STEM education system is crucial for preparing students to meet the demands of the rapidly changing technological landscape, emphasizing the need for educational reforms that foster deeper engagement with scientific concepts. The Malaysian secondary school curriculum has been criticized for its emphasis on high-stakes assessments which can inadvertently promote surface learning. Idris & Bacotang (2023) discuss the challenges and obstacles facing STEM education in Malaysia, noting that the current assessment practices often lead students to focus on memorization rather than understanding. This is echoed by (Nasri et al., 2023) who identify gender-biased issues within the hidden curriculum that affect student engagement in science, suggesting that a lack of awareness about these factors can further exacerbate surface learning.

The effectiveness of science education is heavily influenced by teacher preparedness and pedagogical approaches. Zakaria et al. (2021), emphasize the importance of effective communication and feedback mechanisms among science and mathematics teacher educators to ensure the successful implementation of innovative curricula. Furthermore, the findings of Krishnan et al. (2023), indicate that socio-economic factors significantly impact students' academic achievement in STEM subjects, suggesting that teachers must be equipped to address diverse student backgrounds and learning needs. Professional development initiatives that focus on inquiry-based learning and critical pedagogy are essential for equipping teachers with the necessary skills to foster deeper learning among students. Jaafar & Maat (2020), argue that despite efforts to promote higher-order thinking skills (HOTS), teacher-centered approaches still dominate Malaysian classrooms, hindering the development of critical thinking abilities in students.

In conclusion, the literature underscores the need for reforms in teaching strategies and assessment practices to move away from surface learning and foster deeper, more meaningful engagement with science. Shifting towards inquiry-based learning, enhancing teacher professional development, and integrating formative assessments can help students build a more profound understanding of scientific concepts, ultimately improving their scientific literacy and preparing them for future challenges.

Objective

The objective of this study is to design and develop a comprehensive drone technology physics BOK for Malaysian secondary schools, aiming to enhance students' engagement and proficiency in STEM disciplines. This objective is achieved through a systematic process that includes three key stages: assessing teachers' needs, identifying core elements and developing content and evaluating the curriculum's usability.

Firstly, the study examines the needs and requirements of teachers regarding the integration of drone technology into physics education. This involves understanding the current challenges and opportunities faced by educators. Secondly, it identifies the essential topics, skills and concepts that should constitute the BOK for drone technology within the secondary school co-curriculum. This step ensures a comprehensive and structured educational framework. Thirdly, the study collaborates with subject matter experts to construct the content, ensuring it is pedagogically sound and aligned with the identified needs and core components. The goal is to create an engaging and informative curriculum that fosters a deeper understanding of physics through practical drone applications. Finally, the study evaluates the BOK usability and impact on teaching strategies in secondary schools.

By achieving these objectives, the study aims to develop a robust and comprehensive drone technology BOK that significantly enhances physics education and contributes to the overall improvement of STEM education in Malaysian secondary schools. The ultimate goal is to empower students' analytical and problem-solving skills, preparing them for success in a technology-driven world.

Method

This study employs the Design and Development Research (DDR) approach pioneered by Richey and Klein (2007). Richey & Klein (2007) state that the use of the DDR approach is highly systematic, involving the processes of design, development and evaluation based on empirical research. According to Richey (2004), there are two types of research in development studies: Type One which focuses on the design, development and evaluation of specific products and Type Two, which addresses the design, development and evaluation of models. This study utilized a multi-method research design, implemented across three distinct phases to ensure thorough data collection, analysis and the development of a BOK for incorporating drone technology into physics education.

Table 1
Overview of Phases and Methodologies for Developing the Body of Knowledge (BOK) in Drone Technology for Physics Education

Phase	Description	Methods/Techniques
Phase 1: Needs Analysis	Semi-structured interviews were conducted to assess teachers' needs and challenges regarding the integration of drone technology into physics teaching. This allowed for flexible, in-depth exploration of their perspectives.	- Semi-structured interviews - Open-ended questions focusing on challenges, expectations and benefits of using drone technology in physics education.
Phase 2: Design and Development	The BOK for drone technology in physics was designed using the Nominal Group Technique (NGT) to identify and prioritize key components. The Fuzzy Delphi Method (FDM) was used to refine and validate the BOK content	- NGT: Group brainstorming, contribution, and ranking to reach consensus on key curriculum components. - FDM: Iterative rounds of expert feedback to refine the BOK content and achieve consensus.
Phase 3: Usability Evaluation	The usability of the developed BOK was evaluated via a survey administered to both teachers and students. The survey assessed the ease of use, clarity, engagement, and overall impact of the BOK on teaching and learning.	- Usability questionnaire containing quantitative and qualitative items - Survey focusing on ease of use, clarity, content engagement, and the effectiveness of the BOK in classroom settings.

Throughout these phases, the DDR approach ensured a systematic process of needs analysis, design and development and evaluation, aligning the educational content with the specific learning objectives of the Malaysian secondary school physics curriculum.

Results

The need analysis revealed a significant gap in teachers' knowledge of drone technology and its potential to enhance physics education. Teachers highlighted the need for structured content that effectively links drone operations with core physics principles. The fundamental physics concepts embedded in drone technology are crucial for bridging the gap between theoretical knowledge and practical application in physics education. This study aimed to identify and explore these essential physics concepts, particularly in alignment with the Malaysian secondary school curriculum (DSKP Physics Form 4 and Form 5). The findings were based on a combination of document analysis, open-ended surveys and expert interviews with the results discussed in relation to the initial research questions. The analysis of the DSKP Physics curriculum for Form 4 and 5 identified several key physics concepts essential for understanding drone technology, including:

Aerodynamics

One of the core concepts is aerodynamics which involves understanding how air interacts with drones in flight. Aerodynamics is the study of the behavior of air as it interacts with solid objects such as drones. Students can explore the four essential forces which is lift, allows the drone to rise; thrust, which moves it forward; drag, which resists motion and weight, the force of gravity that pulls the drone downward. These principles help students grasp the science of flight and link drone operations to broader topics in aerodynamics.

Lift

Lift is the upward force that counteracts the weight of the drone and allows it to rise into the air. It is generated primarily by the drone's rotors or wings. According to Bernoulli's principle, as the speed of air increases over the curved upper surface of a rotor blade, the pressure decreases, creating lift. The angle of attack or the angle between the rotor blade and the oncoming air, also significantly influences lift generation. Students can experiment with varying rotor designs and angles of attack to observe changes in lift, thereby gaining practical insights into aerodynamic efficiency.

Thrust

Thrust is the forward force produced by the drone's motors and propellers, propelling it through the air. Thrust is generated by the rotation of the propellers which push air downwards, resulting in an equal and opposite reaction that propels the drone upwards and forwards in accordance with Newton's third law of motion. By adjusting the speed of the motors, students can explore how thrust affects the drone's velocity and maneuverability, providing a hands-on understanding of propulsion systems.

Drag

Drag is the aerodynamic resistance that opposes the drone's forward motion. It is a critical factor that affects the efficiency and speed of flight. There are two primary types of drag which is parasitic drag that arises from the shape and surface area of the drone and induced drag, which is related to the generation of lift. Students can investigate how design modifications, such as streamlining the drone's body or altering its surface texture, can reduce drag and enhance flight performance.

Weight

Weight is the force exerted by gravity on the drone, pulling it downward. It is a crucial factor that must be balanced by lift for sustained flight. The weight of the drone is determined by its mass and the acceleration due to gravity. Understanding the relationship between weight and lift is essential for effective drone operation. Students can conduct experiments to assess how varying payloads affect the drone's ability to achieve lift thereby reinforcing the importance of weight management in drone design.

Energy and Power

Another key concept is energy and power, which focuses on how drones convert electrical energy from batteries into mechanical energy that drives the propellers. This process allows drones to generate lift and thrust, offering students a practical way to understand energy transfer and efficiency. Through real-world examples, students can explore how the energy stored in a drone's battery powers its movement and how power efficiency impacts flight duration.

Kinematics and Dynamics
The study of kinematics and dynamics in drones introduces students to motion and forces such as velocity, acceleration and the application of Newton's laws. For instance, students can analyze how Newton's laws of motion apply to drone flight, observing how forces cause the drone to accelerate or remain in motion. This hands-on exploration makes complex principles like force, mass, and acceleration more accessible and engaging for students.

Electromagnetism
Electromagnetism is another fundamental physics concept applied in drone technology particularly in communication and navigation. Drones rely on radio waves for remote control and GPS for navigation, allowing students to understand how electromagnetic waves are used in technology. This also offers a practical demonstration of signal transmission and the electromagnetic spectrum, illustrating the role of these concepts in real-world applications like drone operations.

Control System
Finally, control systems in drones use feedback mechanisms such as gyroscopes and accelerometers to maintain stability and balance. These sensors provide real-time data, enabling drones to adjust to changes in position or external forces. By learning how drones stabilize themselves through closed-loop control systems, students gain insights into modern engineering principles and how control mechanisms work in various technologies.

Integrating core physics concepts with drone technology provides a powerful framework for enhancing student engagement and understanding. By making abstract principles more tangible and relevant, educators can create a more effective learning environment that prepares students for future challenges in science and technology. The use of drones as a teaching tool exemplifies the potential for innovative educational practices that bridge the gap between theory and application.

Discussions
The integration of drone technology into physics education has the potential to significantly transform both the teaching and learning processes by offering students real world applications of abstract physics concepts. Traditionally, physics has been taught through a combination of theoretical explanations and formula-based learning which can sometimes feel disconnected from practical use cases for students. By introducing drones into the classroom, educators can provide a tangible link between these theoretical concepts and their applications in technology. Students gain the opportunity to engage directly with core physics principles such as aerodynamics, energy transfer, motion and control systems in a hands-on and interactive environment. This shift from passive learning to active participation not only enhances understanding but also improves long-term retention of knowledge. This practical approach resonates with constructivist learning theories, particularly those advocated by Vygotsky (1978), which emphasize that students build knowledge more effectively when they are actively involved in the learning process through hands-on experiences.

Understanding the fundamental physics behind drone operations is crucial for students as it bridges the gap between abstract scientific concepts and their real-world applications. For instance, when students learn about aerodynamics and the forces of lift, thrust, drag and weight, they can immediately see these principles at work as they observe or control a drone in flight. Similarly, concepts like energy conversion and kinematics, which may seem difficult to grasp in a textbook become more accessible when students can see how electrical energy from a drone's battery is converted into mechanical energy to propel it forward. This direct engagement with physics principles through drone technology helps students not only to better understand complex topics but also to appreciate the practical importance of physics in modern technology.

The development of BOK in this study further underscores the importance of linking theory with practice. The BOK offers a structured framework for educators to teach physics concepts in a way that aligns with the real-world applications of drone technology. The availability of these resources allows teachers to more effectively convey complex physics principles by contextualizing them within drone operations, thus making the material more relatable and understandable for students. This approach leads to increased student engagement, as drones provide a dynamic, hands-on tool that makes learning more exciting. The introduction of drone technology into the physics curriculum can also act as a catalyst for sparking greater interest in STEM fields. With growing demand for skills in STEM disciplines in the global job market, early exposure to technology-based learning experiences like drones can inspire students to pursue careers in these fields thus aligning educational outcomes with industry needs.

Despite these promising results, the study also identified a critical need for ongoing professional development for teachers to ensure the successful integration of drone technology into physics education. Teachers are often the key drivers of student success, but to fully realize the potential of drones in the classroom, they must be equipped with the appropriate knowledge, skills, and pedagogical strategies. Many educators may be unfamiliar with drone technology or uncertain about how to effectively incorporate it into their lessons. Without sufficient training, teachers may struggle to utilize drones as a meaningful learning tool, potentially limiting the educational benefits that drones can provide. This underscores the importance of sustained support and professional development programs aimed at helping teachers integrate drone technology into their teaching practices confidently and competently.

Moreover, the implementation of drones in education requires schools and educational institutions to invest not only in the technology itself but also in creating an infrastructure that supports its use. This includes ensuring that schools have access to drones, appropriate space for flight demonstrations and a curriculum that effectively incorporates drone-related activities into the teaching of core physics concepts. With the right training and resources, teachers can transform their classrooms into interactive learning environments that motivate students to explore and engage with physics in new and exciting ways.

Conclusion

This study has underscored the significant educational potential of integrating drone technology into physics instruction. By bridging the gap between theoretical physics concepts and their real-world applications, drones offer an interactive and engaging learning tool that transforms the classroom environment. The development of a comprehensive BOK tailored to the Malaysian secondary school physics curriculum successfully demonstrated how drones can make abstract concepts such as aerodynamics, energy transfer, motion and control systems more accessible and engaging for students. This practical, hands-on approach not only deepens students' understanding of complex physics topics but also enhances their long-term retention of knowledge. Moreover, it fosters a heightened interest in STEM fields, helping to prepare students for future technological challenges and career opportunities.

The study also highlighted the crucial need for continuous professional development and institutional support for educators. While drones provide a valuable tool for enhancing physics education, their successful integration into classrooms requires teachers to have a solid understanding of drone operations, physics concepts, and effective pedagogical strategies. Without adequate training and resources, the full educational benefits of using drones may not be fully realized. Therefore, it is essential for schools and educational institutions to invest in sustained professional development programs that equip teachers with the skills and confidence needed to implement drone technology effectively in their lessons.

An important aspect of this study was the utilization of the DDR approach, which brought several advantages to the research process. The DDR approach is systematic and structured, encompassing the stages of needs analysis, design, development and evaluation. This ensured that the creation of the BOK was grounded in a thorough understanding of the needs and challenges faced by teachers and students. The use of multiple methods including semi-structured interviews, surveys and expert feedback, enabled the collection of robust, empirical data that informed each phase of the BOK development. This data-driven approach allowed for continuous refinement of the content, ensuring that the final BOK was both relevant and practical for real-world classroom use.

Additionally, the DDR approach facilitated collaboration and consensus-building through techniques such as the Nominal Group Technique (NGT) and the Fuzzy Delphi Method (FDM). These methods encouraged active participation and contributions from educators and experts, enabling the identification and prioritization of key components for the BOK. This collaborative process resulted in a well-rounded, consensus-driven framework that reflected the shared insights of the stakeholders involved. Furthermore, the iterative nature of DDR allowed for flexibility, enabling the BOK to be refined and adapted based on ongoing feedback, making it more responsive to the evolving needs of teachers and students.

In summary, the DDR methodology was instrumental in the successful development of the BOK for drone technology in physics education. By offering a systematic, flexible, and data-driven approach, DDR ensured that the educational framework was grounded in empirical evidence and aligned with the needs of the curriculum. The study highlights the potential of drone technology to enhance physics education while emphasizing the importance of teacher training and institutional support to ensure its effective implementation. With these elements in place, the integration of drones can significantly improve students' understanding of fundamental physics concepts and inspire a new generation of learners to pursue careers in STEM fields.

Recommendations

Based on the findings of this study, several recommendations can be made to further enhance the integration of drone technology into physics education and expand its impact on teaching and learning. Firstly, while this study focused on Malaysian secondary schools, the findings may have limited generalizability to other educational contexts. Future research should broaden the scope by designing and developing drone modules for physics education in more diverse settings, including different countries, educational levels and curricula. By expanding the study to encompass broader contexts, researchers can better understand how drone technology can be adapted to different educational systems and student needs, ensuring that its benefits are accessible to a wider audience.

Secondly, there is a need to continue developing instructional materials and strategies that emphasize active learning through drone technology. The BOK developed in this study provides a solid foundation for linking drone operations with core physics concepts but further refinement and expansion of these materials should be explored. Specifically, developing additional modules or resources that address more advanced physics topics or interdisciplinary connections could enhance students' overall learning experience. These materials should focus on fostering critical thinking, problem-solving and collaboration among students, which are essential skills for STEM careers.

Thirdly, the study highlighted the importance of ongoing professional development for teachers. To ensure the effective integration of drones into physics classrooms, schools and educational institutions should provide sustained training programs that equip teachers with both the technical knowledge of drone operations and the pedagogical skills needed to incorporate drones into their teaching practices. Institutions should also consider establishing support networks where teachers can share best practices and collaborate on drone-related projects, thereby enhancing their capacity to use drone technology effectively in the classroom.

Finally, future research and educational initiatives should not only aim to improve the use of drones in the Malaysian context but also contribute to global advancements in STEM education. The insights gained from this study can serve as a guide for other countries and educational systems looking to incorporate innovative technologies like drones into their curricula. By continuing to explore the educational benefits of drones and expanding their application in classrooms worldwide, researchers and educators can drive progress in both drone technology and physics education on an international scale.

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