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Intelligent Seed Hub: Smart IoT for Enhancing Teaching and Learning Practices in Seed Science and Technology

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ABSTRACT

This project aims to enhance the quality and efficiency of the teaching and learning process (PdP) by developing an Internet of Things (IoT)-enabled seed germination rack, known as the Intelligent Seed Hub (ISH). This Problem-Solving Project (PPM) was implemented using the Design Thinking 101 method, which involves six main processes: Empathise, Define, Ideate, Prototype, Test, and Implement. The innovation was developed through a structured process involving brainstorming, persona profiling, SMART analysis, user behaviour assessment (5W1H), SCAMPER, and the House of Quality. The objectives were to increase seed germination rates by up to 80% and to shorten the time required for uniform germination to less than five days. The ISH underwent four phases of testing and demonstrated significant improvements: seed germination rates increased up to 23.8% for green beans and 37.6% for rice. The germination period was reduced, respectively, from seven days to four days for green beans and to five days for rice. In addition, these outcomes contributed to improved seedling quality, reduced laboratory and labour costs and increased user satisfaction and confidence. The long-term impact of the ISH innovation includes cost savings in operational expenses, enhanced support for subject-related projects and research and efficient utilisation of laboratory space. With a Technology Readiness Level (TRL) of 6, the ISH innovation is ready for broader implementation and standardisation across UiTM branch campuses. Furthermore, the invention has received intellectual property protection from MyIPO, underscoring its originality and reinforcing its potential for innovation, commercialisation, and broader market adoption.

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1. INTRODUCTION

The integration of technology in education has significantly enhanced the teaching and learning process (T&L) through efficient, data-driven pedagogical approaches. The implementation of the Internet of Things (IoT) enables real-time data collection, monitoring, and control across various fields, including agriculture (Atzori et al., 2010). In Malaysia, the agricultural sector faces escalating challenges, including labour shortages, inefficient resource use, and a pressing need for more sustainable practices (Zainal Abidin et al., 2024). Therefore, this innovation project introduces the Intelligent Seed Hub (ISH), an IoT-enabled seed germination rack designed to support and enrich T&L activities in seed science and technology. Technology efficiently promotes ideal seed germination by automating the monitoring of environmental factors such as temperature, humidity, and soil moisture. It also serves as an engaging and hands-on learning tool that enhances students' understanding of agricultural technology and environmental management.

The use of IoT in agriculture has been shown to improve germination growth by maintaining ideal growing conditions and minimising human error, ultimately leading to higher seedling success rates and improved crop productivity (Zhang et al., 2019; Jayaraman et al., 2016). The implementation of smart agriculture with educational innovation empowers learners to grasp concepts through practical experience, while also promoting STEM education and fostering sustainable farming practices (Wee & Ting, 2023). However, selecting an innovative product for development requires a clear understanding of current challenges, user needs, and technological feasibility. In the context of educational and agricultural enhancement, it is crucial to identify a product that not only solves real problems but also aligns with teaching and learning objectives.

The ISH was chosen for development based on its potential to address multiple gaps in conventional seed germination methods, such as the lack of real-time monitoring, inconsistent environmental control and limited student engagement in hands-on agricultural learning. By integrating IoT technology, this product offers a smart, automated solution that enhances both plant growth outcomes and the quality of practical education. This IoT-enabled system not only provides real-time data monitoring and automated control of factors such as temperature, humidity, and soil moisture but also supports innovation-driven teaching and learning activities. The increasing importance of precision agriculture and sustainable farming practices underscores the relevance of such a tool, making it a valuable innovation for both classroom and field applications (Gubbi et al., 2013; Wolfert et al., 2017). The decision to develop the ISH was further supported by criteria such as cost-effectiveness, scalability, ease of use, and its potential to increase students' knowledge through the integration of IoT and mobile technologies into the learning process. In addition, students are ready and interested in using pervasive technologies within their formal education (Stojanović et al., 2023).

Problem-solving actions require strategic approaches through creative thinking. It involves exploring new ideas and finding unique, effective solutions to address users' challenges. The objectives of this innovation project were to increase the seed germination percentage and to shorten the number of days required for uniform germination. From an educational perspective, it also helps to ensure a smoother T&L that aligns with existing lesson plans. The novelty of this study lies in the strategic integration of IoT into agricultural education through the development of the ISH, an IoT-enabled germination system designed to advance T&L in seed science and technology. Unlike conventional germination systems, the ISH functions as both an agricultural and pedagogical innovation, linking theory with real-time data-driven experimentation. Students engage in experiential learning by monitoring temperature, humidity, and soil moisture via an interactive interface. This promotes scientific inquiry, problem-solving, and digital literacy, aligning with IR4.0 educational goals while enhancing agricultural productivity and learning outcomes.

2. METHODOLOGY

2.1 Project Selection Method & Analysis

The selection of this innovation project was carried out systematically using several structured methods to ensure that the chosen solution meets students' real needs and aligns with the program's objectives. Four approaches were used to select the innovation project. The first approach is a Brainstorming Session, in which ideas were generated through a group process to explore various possibilities for innovation based on challenges faced in T&L for the seed science and technology subject. The challenges were stated as follows: i) Students are unable to access the laboratory on holidays as it is closed and no staff are on duty, resulting in a lack of intensive monitoring during that period, which resulted in low seed germination percentage; ii) The existing germination rack does not have a proper drainage system in the laboratory, causing water accumulation or overflow issues that hinder seed growth. Then, the Persona Profile Analysis was conducted through interviews with instructors and students in the seed science and technology field to understand the characteristics, needs, and pain points of target students and to ensure the product would deliver practical value to students. Next, the project goals were evaluated using the SMART criteria (Specific, Measurable, Achievable, Realistic, Timely) to ensure that the innovation's objectives were realistic, focused, and aligned with faculty goals. Lastly, the Data Analysis Matrix was developed to compare and evaluate alternative solutions or ideas based on multiple criteria, such as percentage of seed germination, the lack of an irrigation system, and the less ergonomic aspects of the conventional germination rack (existing), on a 10-point scale. This matrix helped select the most viable and effective innovation to develop.

2.2 Problem- Solving Action

Problem-solving requires strategic thinking driven by creativity. It involves exploring new ideas and identifying unique and effective solutions. The main goal is to address users' challenges by developing innovative solutions. In this project, the strategy used is Design Thinking 101. The first phase was empathetic, whereas the second phase aimed to gain a deep understanding of the users. In this strategy, empathy was developed through a questionnaire administered to users about their experiences with conventional seed germination racks. In the context of open-ended survey questions, which are typically used in qualitative research, a sample size of around 30-40 participants is often considered sufficient, especially if the population is not too large (Creswell & Poth, 2018). Therefore, in this study, 37 respondents completed the online form via "Google Form" on 5th July 2024.

The 5W1H (What, Who, Why, Where, When, and How) method, as shown in Figure 1, and user behaviour observation were applied to identify the problems encountered when using the existing germination rack. The ideation phase focuses on generating as many ideas as possible to solve the defined problems. Creative techniques such as SCAMPER and House of Quality (HoQ) were used during this stage to develop potential solutions.

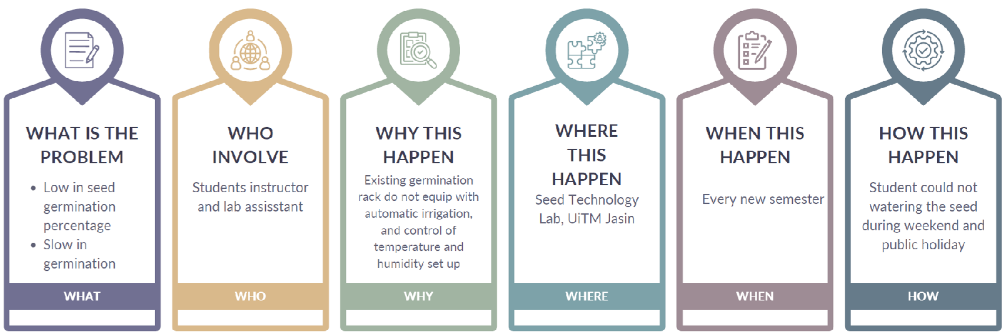

Fig 1 *The process of determination: Define element (5W1H)*
Source: Author (2026)

The development of the prototype can be divided into three main components: (1) Structural Development of the Innovation, (2) Software Programming, and (3) IoT Configuration. The prototype development process begins with benchmarking against existing equipment, sketching the prototype, fabrication, wiring, system programming in the Arduino IDE, IoT configuration, and testing. Product testing was conducted to ensure the prototype functioned as intended. The list of tests carried out included IoT functionality testing, water pump testing, and the calibration of soil moisture and temperature settings. Briefing and sharing sessions regarding the innovation were conducted by the project team with both students and industry representatives, including hands-on use of the ISH.

3. RESULT AND DISCUSSION

The IoT has developed as a transformative technology, particularly in seed science and technology, offering innovative solutions to enhance productivity and sustainability. The key features of the innovative germination rack, known as the Intelligent Seed Hub (ISH), were equipped with a watering and drainage system, enclosed germination space with controlled conditions, grow lights that provide uniform illumination, integrated with an automatic temperature control system, a combination of real-time and remote data monitoring and control (Figure 2).

Fig. 2 *Intelligent Seed Hub (ISH)- Innovative germination rack equipped with IOT system*
Source: Author (2026)

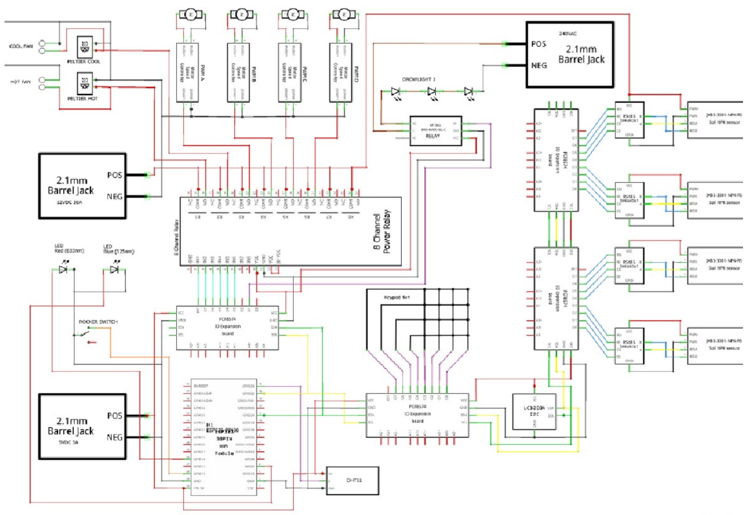

Fig 3 *Schematic diagram of ISH using Fritzing Software*
Source: Author (2026)

The schematic diagram of ISH using Fritzing Software is shown in Figure 3. The design, wiring, and safety had received three formal certifications from qualified authorities: Maintenance of the innovation product certified by a Licensed Electrical Machinery Supervisor, Product design verified by a Mechanical Engineer, and Wiring and electrical system approved by an Electrical Engineer (Figure 4).

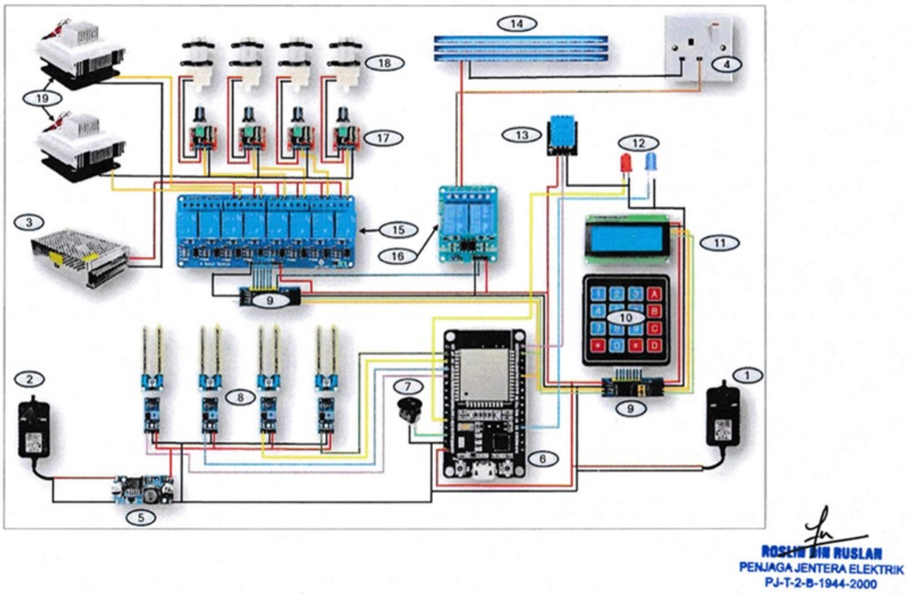

Fig. 4 *Maintenance of the innovation product certified by a Licensed Electrical Machinery Supervisor.*
Source: Author (2026)

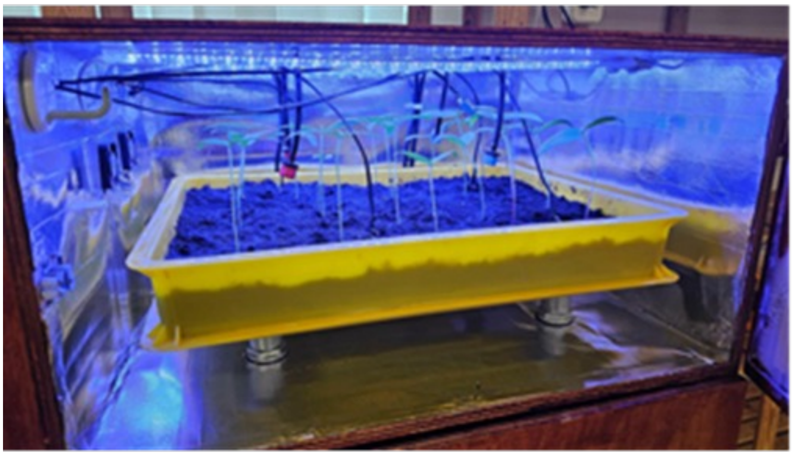

Fig. 5 *Successful germination process by using ISH*
Source: Author (2026)

The ISH has demonstrated the ability to improve the overall germination percentage for two seed types used in the PdP process (Figure 5). Table 1 presents a comparison of recorded germination percentages for the ISH and the conventional germination rack. This innovation meets the 80% germination standard set by ICAR – National Rice Research Institute (for rice) and CGIAR (for mung beans) under the course code AGR519 (Crop Physiology) at the Faculty of Plantation and Agrotechnology (FPA).

Table 1
The comparison of the germination percentage of the conventional germination rack versus the ISH

Germination Rack	Bean seed (%)	Rice seed (%)
Conventional germination	76.2	52.4
Intelligent Seed Hub (ISH)	100	90
Increment (%)	23.8	37.6

The duration (in days) for uniform seed germination has been shortened for two seed types (green bean and rice) used in the PdP process at FPA for course code AGR519, with a practical requirement of achieving uniform germination in 5 days or less and the germination time (in days) recorded after testing the ISH versus the conventional germination rack as shown in Table 2. The germination period was reduced from seven days to four days for green beans and to five days for rice. It showed that using ISH achieved germination 42.8% faster than the existing germination rack. Meanwhile, for rice seed, the germination was faster, about 28.6%. As a result of this study, ISH has been shown to enhance germination percentage and reduce the number of days to germination.

Table 2
The comparison of germination days of the conventional germination rack versus the ISH

Germination Rack	Bean seed (days)	Rice seed (days)
Conventional germination	7	7
Intelligent Seed Hub (ISH)	4	5
Increment (%)	42.8	28.6

Student feedback indicated that 55.5% seedling uniformity was attained when using ISH during the AGR519 practical sessions. An increase of 64.1% in the average uniform germination rate using rice seeds was achieved. This uniform germination contributes to the production of healthy, high-quality seedlings, meeting practical requirements and ultimately facilitating a smoother PdP. The level of customer satisfaction with the use of ISH increased significantly, with a 68.9% improvement in seed germination rate and a 51.8% reduction in the time required for uniform seed germination, as measured on a 5-point Likert scale (Joshi et al., 2015). IoT, laptops, and mobile devices, in particular, help students develop and strengthen fundamental competencies. It improves students' ability to learn quickly, thoroughly, and effectively. A study by Skordeli (2019) on the pedagogical potential of IoT found that it can offer more personalised learning opportunities for students. This allows instructors to provide more in-depth feedback to their students.

The use of the ISH has streamlined the PdP process. At present, practical sessions can be conducted according to the planned lesson schedule without delays, while the preparation of practical laboratory reports is also more efficient. Instructors can assess assignments and provide feedback within the designated timeframe. Survey feedback indicates that 100% of users are satisfied and motivated to continue using the ISH, highlighting its effectiveness as an educational tool that supports hands-on learning and efficient lab practical sessions. Tsipianitis et al. (2025) found that IoT integration positively impacts learning by strengthening STEM skills through hands-on interaction with real-world data and fostering higher-order thinking skills such as problem-solving and collaboration.

As seed quality is closely related to germination rate and tolerance to biotic and abiotic stresses, it is crucial for seedling development. The good, healthier seedling can be used in other lab practical sessions on different topics. The implementation of ISH has contributed to 53.8% cost savings for the faculty in the first quarter of 2024 by reducing seedling purchase expenses. By automating the seed germination process, ISH provides an ideal environment for healthy seedling growth without the need for continuous manual supervision. This reduces reliance on labour, thereby lowering overall operational costs. In addition, the use of ISH aligns with the faculty's recommendation to implement cost-saving measures of up to 30%, making it a sustainable and economically valuable innovation for institutional use.

NASA developed the Technology Readiness Level (TRL) in the 1970s to assess the maturity of a technology throughout the research, development, and deployment phases. Referring to the TRL framework, the ISH is currently at Level 6. At this stage, the prototype has undergone field testing, and the test results successfully met the project objectives. The IoT element used in the system, BLYNK, is also functioning well and remains stable while accessed via mobile phones, computers, and on-site applications.

It is recommended that ISH be implemented in other agriculture-related courses beyond AGR519 to enhance practical learning across the curriculum, particularly in subjects such as plant physiology, agronomy, and sustainable farming practices. A larger-scale version of ISH could be developed for field trials or institutional nurseries to assess its effectiveness in real-world farming environments further. With IoT capabilities, not only students but also farmers will be able to optimise operations and improve yields at a lower cost, reducing costs for consumers (Fadziso, 2018).

4. CONCLUSION

The innovation of the Intelligent Seed Hub (ISH) represents a transformative step in modernising agricultural education through the strategic integration of IoT technologies. Aligned with the 12th Malaysia Plan (RMK-12) and Sustainable Development Goals (SDGs) 2 and 4, this innovation reinforces national priorities on food security, sustainable agriculture, and equitable access to quality education. ISH has proven effective in accelerating germination time, increasing germination success rates, and producing more uniform seedlings while simultaneously reducing operational costs. Its capacity to meet practical course requirements demonstrates high suitability for experiential and competency-based learning models in seed science and technology. Furthermore, the initiative directly supports UiTM's institutional aspiration to foster a digitally enabled, research-driven, and future-ready campus ecosystem. The scalability of ISH offers strong potential for wider implementation across other agricultural disciplines, training centres, and community-based farming programmes. With further refinement and policy support, ISH could be integrated into national curriculum frameworks, institutional smart farming laboratories, or rural-based technology transfer initiatives. Overall, ISH serves not only as an instructional tool but also as a replicable model for sustainable innovation, bridging academic research with real-world agricultural advancement.

5. CO-AUTHOR CONTRIBUTION

Author 1 developed the main project idea, prepared the literature review, and wrote the write-up of this article. Co-Authors 2 through 5 contributed to the development of ISH by selecting, designing, fabricating, and testing this innovation project.

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7. FUNDING

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8. CONFLICT OF INTEREST

The authors declare no conflict of interest in this article.

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