Transforming Rural Education Through Smart Aquaculture: Developing Future-Ready Skills, Career Awareness and Entrepreneurial Mindsets

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ABSTRACT

This study examines the potential of technology-enhanced school-based aquaculture to support future-ready skills, career awareness, and entrepreneurial mindsets among rural high school students in Malaysia. As digital technologies increasingly transform agricultural practices and employment opportunities, integrating technological applications into agricultural education may provide students with meaningful exposure to emerging competencies and economic possibilities. A quantitative exploratory case study was conducted at Pulau Nyior High School, Kedah, involving 30 Agricultural Science students who participated in a catfish farming initiative supported by Internet of Things (IoT) monitoring technology. Data were collected using a structured questionnaire comprising 30 items measured on a five-point Likert scale and analyzed using descriptive statistics. The instrument demonstrated high overall internal consistency (Cronbach's alpha = 0.976). The findings revealed positive student perceptions of technology-enhanced learning, particularly understanding the role of technology in improving agricultural efficiency (M = 4.10) and applying STEM concepts to practical aquaculture activities (M = 4.10). Students also reported positive perceptions of their ability to identify agricultural business opportunities (M = 4.20), interest in applying acquired skills to establish businesses (M = 4.17), and confidence in starting small businesses (M = 4.07). However, confidence in independently establishing a home-based aquaculture project was comparatively lower (M = 3.80), suggesting a potential gap between opportunity recognition and perceived readiness for independent implementation. Although career awareness was not directly measured, the findings highlight the relevance of technology-supported agricultural learning to future-oriented educational experiences. The study concludes that smart aquaculture offers a promising educational approach for connecting rural agricultural education with digital competencies, practical learning, and entrepreneurial opportunities, while underscoring the importance of continued guidance and institutional support.

Keywords: Smart Aquaculture; Rural Education; Future-Ready Skills; Career Awareness; Entrepreneurial Mindsets

INTRODUCTION

Education plays a fundamental role in preparing young people to participate in an increasingly technology-driven and competitive economy. Beyond academic achievement, contemporary education is expected to equip students with practical competencies, digital literacy, problem-solving abilities, adaptability, and entrepreneurial awareness. These competencies are particularly important for students in rural communities, where access to emerging technologies, industry exposure, and diverse career development opportunities may be more limited than in urban settings. Despite improvements in educational access, disparities in learning opportunities and skills development remain important challenges to achieving inclusive and equitable education (OECD, 2023c; UNESCO, 2023a). Addressing these disparities requires innovative educational approaches that connect classroom knowledge with practical experiences, technological applications, and opportunities for future economic participation.

The increasing digitalization of agriculture presents opportunities to transform agricultural education, particularly in rural high schools. Modern agricultural practices increasingly incorporate digital monitoring, automated systems, data-driven decision-making, and resource management technologies. These developments have expanded the skills required in agriculture beyond conventional farming knowledge to include technological competence, analytical thinking, innovation, and entrepreneurial capabilities. Xu et al. (2023) highlighted the growing importance of educational technology in agricultural education, while Hassim et al. (2024) emphasized the need for equitable access to digital agricultural technologies in Malaysia. For rural students, exposure to technology-enhanced agricultural activities may broaden their understanding of agriculture as a modern, knowledge-intensive sector offering diverse career and business opportunities.

School-based smart aquaculture provides a practical setting in which agricultural education can be integrated with digital technology and real-world problem-solving. Unlike conventional classroom instruction, technology-enhanced aquaculture allows students to participate directly in production activities while observing the application of technological systems in agricultural management. Through activities such as monitoring water conditions, managing fish production, interpreting digital information, and addressing operational challenges, students encounter situations that require practical judgment, responsibility, collaboration, and adaptive thinking. These experiences are consistent with the growing emphasis on analytical thinking, technological literacy, resilience, and adaptability as essential workforce competencies (World Economic Forum, 2025). Such learning opportunities may strengthen students' confidence in applying classroom knowledge while encouraging them to recognize the relevance of technological competencies to future employment and entrepreneurial activities.

Importantly, the educational value of smart aquaculture extends beyond acquiring technical farming skills. Participation in technology-supported agricultural projects may provide students with opportunities to reconsider traditional perceptions of agricultural occupations and explore alternative pathways for career development. Agriculture is frequently associated with physically demanding and conventional production activities; however, technological innovation has introduced opportunities in digital farm management, agricultural entrepreneurship, environmental monitoring, and technology-supported production systems. The Food and Agriculture Organization of the United Nations (FAO, 2025) highlighted the importance of youth participation, innovation, and entrepreneurship in transforming agrifood systems. Similarly, OECD (2025) emphasized the importance of providing adolescents with meaningful career exploration opportunities to support informed educational and occupational decisions. Exposure to modern agricultural technologies during high school education may therefore help students recognize connections between technological competence, career opportunities, and potential economic participation.

Entrepreneurial learning represents another important dimension of technology-enhanced agricultural education. Beyond developing technical competencies, participation in agricultural projects may expose students to production planning, resource management, operational costs, and potential income-generating activities. Such experiences can encourage opportunity recognition and strengthen students' understanding of the relationship between innovation and economic value. Udekwe and Iwu (2024) highlighted the relevance of digital technology and innovation in entrepreneurship education, while Boye et al. (2024) identified skills training, perceptions of agriculture, and access to opportunities as important factors influencing youth engagement in agribusiness. These findings suggest that technology-supported agricultural activities may provide a meaningful context for introducing entrepreneurial concepts to rural high school students.

Social Cognitive Career Theory (SCCT) offers a relevant perspective for understanding how educational experiences may relate to students' confidence, career interests, and perceptions of future opportunities. The theory emphasizes the role of learning experiences, self-efficacy beliefs, outcome expectations, and contextual influences in career development (Lent et al., 1994). Within technology-enhanced agricultural education, participation in practical activities may provide opportunities for students to develop confidence in applying knowledge and to recognize potential occupational pathways. However, exposure to career-related learning experiences does not necessarily demonstrate changes in career awareness. Distinguishing between perceived competencies, career awareness, and actual occupational intentions is therefore essential when evaluating educational interventions.

Despite increasing attention to digital agriculture, entrepreneurship education, and future workforce competencies, further context-specific evidence is needed to understand how school-based smart aquaculture relates to rural high school students' perceived preparedness for future educational and economic opportunities. Existing research on agricultural technology frequently emphasizes technological adoption, production efficiency, and operational outcomes, while studies of entrepreneurship education often focus on entrepreneurial intentions in broader educational settings. Comparatively less attention has been directed toward understanding how technology-enhanced agricultural activities at the high school level may contribute to students' perceived digital competencies, practical confidence, and awareness of entrepreneurial opportunities. Addressing this gap is important because the educational value of smart aquaculture should not be assessed solely through agricultural productivity but also through its potential contribution to students' preparation for changing occupational demands.

In response to this gap, the present study examines a technology-enhanced school-based aquaculture initiative implemented at Pulau Nyior High School, a rural high school in Kedah, Malaysia. The initiative involved students enrolled in Agricultural Science who participated in catfish farming activities supported by Internet of Things (IoT) monitoring technology, including the Blynk application. Under teacher supervision, students engaged in practical aquaculture management and related agricultural activities, including the reuse of aquaculture wastewater for vegetable cultivation. The school also implemented hydroponic vegetable cultivation as a separate agricultural learning activity. These experiences provided opportunities for students to connect agricultural knowledge with technological applications, resource management, and practical decision-making.

Drawing on questionnaire responses from 30 participating students, this study aims to: (1) examine students' perceptions of digital and practical competencies developed through technology-enhanced aquaculture activities; (2) explore students' perceived confidence and interest in applying acquired knowledge to future career-related and economic opportunities associated with modern agricultural practices; and (3) assess students' perceptions of entrepreneurial learning and potential income-generating opportunities arising from participation in the initiative. By positioning smart aquaculture as an educational intervention rather than primarily an agricultural production initiative, the study seeks to contribute to discussions on rural educational transformation, future-ready skills development, and the potential role of technology-supported agricultural education in preparing young people for future occupational and entrepreneurial participation.

LITERATURE REVIEW

Smart Aquaculture and Rural Educational Transformation

Rural educational transformation requires learning opportunities that enable students to connect academic knowledge with emerging technological, occupational, and economic developments. Although digital technologies have created opportunities to improve educational access and instructional practices, disparities in technological infrastructure, learning resources, and digital competencies continue to influence educational experiences. UNESCO (2023a) highlighted the importance of ensuring that educational technology addresses learners' needs and promotes equitable participation rather than merely increasing access to digital devices. Similarly, OECD (2023a) emphasized that meaningful digital transformation requires the integration of technological resources, pedagogical practices, and institutional support.

These considerations are particularly relevant to rural high schools, where students may have fewer opportunities to encounter emerging technologies in authentic occupational settings. The OECD (2023c) identified persistent inequalities in educational outcomes associated with socioeconomic circumstances, while UNESCO (2023b) documented the opportunities and challenges associated with technology integration across Southeast Asian education systems. Together, these findings suggest that educational innovation should address not only academic achievement but also the development of competencies that support students' future social and economic participation.

The increasing digitalization of agriculture provides opportunities to introduce technology-oriented learning into rural education. Modern agricultural practices incorporate digital monitoring, automated systems, information management, and technology-supported decision-making. Xu et al. (2023), in a scoping review of educational

technology in agricultural education, highlighted the growing use of technology-supported instructional approaches to prepare learners for contemporary agricultural practices. Similarly, Hassim et al. (2024) examined the challenges and opportunities associated with equitable digital agricultural transformation in Malaysia, emphasizing the importance of accessibility and institutional support.

Smart aquaculture offers a practical educational context for introducing students to these technological developments. Through the use of Internet of Things (IoT) monitoring systems, students can observe how digital information supports agricultural management. Rather than learning technology as an isolated subject, students encounter its application in activities involving water monitoring, fish management, and operational decision-making. Such exposure may broaden their understanding of agriculture as a technologically evolving sector.

Chan et al. (2025) examined youth readiness for smart farming and highlighted the influence of structural and institutional conditions on participation in technology-oriented agriculture. Their findings suggest that young people's engagement with smart agriculture cannot be understood solely through individual interest, as opportunities for technological exposure and institutional support also matter. Consequently, school-based smart aquaculture may provide an accessible introduction to agricultural modernization for students who would otherwise have limited exposure to these technologies.

The educational significance of such initiatives extends beyond agricultural production. By integrating technology into existing Agricultural Science activities, schools may create learning environments in which students connect scientific knowledge, digital applications, and practical responsibilities. This approach is consistent with UNESCO's (2023a) emphasis on learner-centered and contextually appropriate educational technology. Accordingly, smart aquaculture can be examined as a potential mechanism for broadening rural students' educational experiences and their awareness of technology-related opportunities.

Technology-Enhanced Learning and Future-Ready Skills

Future-ready skills encompass competencies that enable individuals to adapt to technological change, solve unfamiliar problems, collaborate effectively, and participate in evolving economic environments. These competencies are increasingly important as technological innovation changes occupational requirements and creates new expectations for workforce preparedness. The World Economic Forum (2025) identified analytical thinking, technological literacy, resilience, flexibility, and creative thinking among the competencies relevant to changing labor-market demands.

Digital competence represents an important component of future readiness. Vuorikari et al. (2022) described digital competence as encompassing the knowledge, skills, and attitudes required to engage confidently, critically, and responsibly with digital technologies. Their DigComp 2.2 framework provides a broader understanding of digital competence beyond basic familiarity with digital devices. Within agricultural education, this distinction is important because operating a digital monitoring application does not necessarily demonstrate comprehensive digital literacy.

Technology-enhanced agricultural activities may nevertheless create opportunities for students to develop applied technological competencies. In smart aquaculture, students can observe digital measurements, interpret information, recognize operational problems, and understand how technological systems support production management. Such experiences may contribute to students' perceived technological confidence and their understanding of the practical relevance of digital information.

OECD (2024) emphasized the importance of creative thinking and the ability to generate and evaluate ideas in educational contexts. These competencies are relevant to agricultural learning environments where students encounter changing conditions and operational challenges. Activities involving fish management, resource utilization, and technological monitoring may provide opportunities for students to consider alternative solutions and apply knowledge to practical situations.

The OECD (2023b) further highlighted the importance of coherent digital education systems that connect technological infrastructure with teaching and learning practices. Similarly, OECD (2026) examined the

opportunities and limitations of emerging technologies in education, reinforcing the importance of purposeful educational integration rather than assuming that technological availability automatically improves learning outcomes.

For rural Agricultural Science students, technology-enhanced aquaculture may provide a context in which digital learning is connected to practical agricultural responsibilities. UNESCO (2024c) emphasized that technology-enhanced education should prioritize learners' needs and experiences while ensuring that digital learning opportunities are appropriate, equitable, and relevant to local educational contexts. Students can encounter technological applications while developing familiarity with operational procedures, resource management, and collaborative activities. However, the extent of competency development depends on students' actual participation, teacher guidance, and opportunities to apply acquired knowledge.

Therefore, the educational contribution of smart aquaculture should be examined through clearly defined learning outcomes. In the present study, emphasis is placed on students' perceived technological and practical competencies rather than assuming that participation has produced objectively measurable improvements in all dimensions of future readiness.

Career Awareness and Rural Youth Development

Career development during adolescence is influenced by educational experiences, perceived abilities, social expectations, and access to information about occupational opportunities. High school represents an important period during which students begin exploring possible career pathways and evaluating the relevance of their educational experiences to future employment. However, access to meaningful career exploration opportunities is not equally distributed across socioeconomic and geographical contexts.

OECD (2025) reported substantial gaps between teenagers' occupational expectations and actual labor-market demands. The report also highlighted the influence of socioeconomic background on educational ambition and the importance of providing students with opportunities to encounter different occupations and working environments. These findings are particularly relevant to rural education, where access to diverse occupational experiences may be constrained by geographical and institutional factors.

The agricultural sector provides an important context for examining changing career opportunities. UNESCO (2024a) further highlighted persistent gender disparities in access to digital technologies and STEM-related career opportunities, emphasizing the importance of inclusive educational experiences that enable students to explore emerging technological fields. Technological developments have expanded agricultural activities beyond conventional production to include digital monitoring, agricultural data management, precision farming, technology-supported resource management, and agribusiness services. Nevertheless, young people may continue to associate agriculture primarily with traditional farming activities, potentially limiting their awareness of emerging occupational pathways.

Boye et al. (2024), in a systematic review of youth engagement in agribusiness, identified perceptions of agriculture, access to training, and structural constraints as important factors influencing youth participation. Their review also highlighted the relevance of skills training interventions in supporting young people's engagement with agricultural opportunities. Although the reviewed studies focused on African contexts, the findings provide a useful comparative perspective for understanding the relationship between agricultural exposure, youth perceptions, and occupational possibilities.

The Food and Agriculture Organization of the United Nations (FAO, 2025) similarly emphasized the importance of youth participation in transforming agrifood systems. The report identified opportunities for innovation, entrepreneurship, and economic participation while recognizing persistent barriers involving skills, resources, and access to opportunities. These considerations suggest that educational initiatives introducing modern agricultural practices may contribute to career-related learning by expanding students' understanding of the sector.

Within rural high school education, smart aquaculture may expose students to occupations and economic activities that combine agricultural knowledge with technological competencies. Students who participate in digital monitoring and practical production activities may begin to recognize that agricultural careers can involve innovation, technological applications, and business management.

However, career awareness and career aspirations represent distinct concepts. Career awareness refers to students' understanding of occupational possibilities, whereas career aspirations reflect their preferences and ambitions regarding future occupations. Exposure to smart aquaculture may broaden students' understanding of career-related opportunities without necessarily influencing their preferred career pathways. Therefore, interpretations of career-related outcomes must remain consistent with the constructs measured by the research instrument.

Entrepreneurial Mindsets and Future Economic Opportunities

Entrepreneurial education contributes to preparing young people for economic participation by encouraging opportunity recognition, initiative, resource management, problem-solving, and confidence in applying knowledge. Entrepreneurial competencies are not limited to business creation; they are also relevant to employment, innovation, and the ability to respond to changing economic circumstances.

Udekwe and Iwu (2024), in a systematic literature review, examined the relationship between digital technology, innovation, entrepreneurship education, entrepreneurial intention, and motivation. Their findings highlighted the importance of integrating technological applications into entrepreneurial learning to support students' development of relevant knowledge and capabilities.

Similarly, Branca et al. (2025) reviewed the contribution of entrepreneurship education to entrepreneurial competencies, including self-efficacy, creativity, innovativeness, and risk-taking. Their findings indicate that educational strategies and learning tools play important roles in shaping entrepreneurial competencies. These insights suggest that practical agricultural activities may offer opportunities for students to encounter entrepreneurial concepts in meaningful contexts.

Technology-enhanced aquaculture provides opportunities to introduce students to the economic dimensions of agricultural production. Activities involving resource management, production costs, operational planning, and product marketing can demonstrate how agricultural knowledge is connected to business decisions. Through such experiences, students may develop greater awareness of the relationship between technical skills and potential income-generating activities.

Boye et al. (2024) highlighted the importance of addressing negative perceptions and practical constraints that influence young people's engagement in agribusiness. Similarly, FAO (2025) identified the potential of youth-led innovation and entrepreneurship to contribute to economic development within agrifood systems. These findings support the relevance of educational interventions that expose rural students to the economic possibilities associated with modern agriculture.

The integration of digital technologies may further broaden students' understanding of entrepreneurial opportunities. Chotisarn and Phuthong (2026) examined innovative approaches to digital entrepreneurship education and the institutional conditions influencing their implementation. Their review reinforces the importance of connecting technological learning with entrepreneurial competencies rather than treating digital skills and business education as separate domains.

For Agricultural Science students, smart aquaculture can demonstrate how technology supports production management while introducing the economic considerations associated with agricultural enterprises. Nevertheless, entrepreneurial awareness, entrepreneurial intention, and actual entrepreneurial behavior should be distinguished. Students may recognize the potential for income generation without intending to establish a business or possessing the resources required to do so.

Accordingly, the present study considers entrepreneurial learning in terms of students' perceptions of relevant competencies, confidence, and potential economic opportunities. This approach allows the educational significance of smart aquaculture to be examined without assuming that participation directly produces business creation or measurable economic outcomes.

Social Cognitive Career Theory and the Research Gap

Social Cognitive Career Theory (SCCT), developed by Lent et al. (1994), provides a useful theoretical perspective for understanding how learning experiences, personal beliefs, and environmental influences may shape career-related interests and choices. Its central concepts include self-efficacy, outcome expectations, and career interests. These concepts are relevant to educational initiatives that introduce students to unfamiliar technologies, occupational activities, and economic opportunities.

Self-efficacy concerns individuals' beliefs about their ability to perform particular activities, while outcome expectations relate to their perceptions of the potential consequences of those activities. Within school-based smart aquaculture, students' participation in technology-supported agricultural tasks may provide experiences relevant to their confidence in using technology, managing practical responsibilities, and recognizing the possible value of acquired competencies.

The relevance of career-related learning is reinforced by OECD (2025), which highlighted the importance of meaningful career exploration and exposure to occupational environments. Similarly, Chan et al. (2025) demonstrated the importance of contextual and structural conditions in shaping youth readiness for smart farming. Together, these perspectives suggest that students' career-related perceptions may be influenced by both personal learning experiences and the opportunities available within their educational environments.

The wider educational environment also influences the effectiveness of technology-supported learning. UNESCO (2024b) emphasized the importance of educational leadership and institutional capacity in supporting meaningful educational improvement. For school-based agricultural initiatives, teacher supervision, institutional commitment, and access to technological resources may therefore be important conditions for providing relevant learning opportunities.

Despite growing attention to digital agriculture, entrepreneurship education, and youth career development, the relationship between school-based smart aquaculture and rural high school students' perceived future readiness remains insufficiently examined. Existing agricultural technology research frequently concentrates on technological adoption and production-related outcomes, while entrepreneurship education research often focuses on entrepreneurial intentions and competencies in broader educational settings.

The present study addresses this intersection by examining the experiences of 30 Agricultural Science students participating in a technology-enhanced aquaculture initiative in rural Malaysia. Specifically, the study focuses on perceived digital and practical competencies, confidence, and entrepreneurial awareness as potential dimensions of future economic preparedness.

SCCT is employed as an interpretive perspective rather than as a fully tested structural model. This distinction is necessary because the study does not presume that all SCCT constructs have been measured or that changes in career awareness have been demonstrated. By focusing on students' reported learning experiences and perceived competencies, the study seeks to contribute context-specific evidence to discussions of rural educational transformation and the potential role of smart aquaculture in preparing young people for future occupational and entrepreneurial opportunities.

METHODOLOGY

Research Design

This study adopted a quantitative exploratory case study design to examine students' perceptions of future-ready competencies, career-related opportunities, and entrepreneurial learning associated with participation in a

technology-enhanced school-based aquaculture initiative. The approach was selected to investigate students' reported experiences within a specific rural educational setting, with emphasis on the perceived educational and economic relevance of practical agricultural activities supported by digital technology.

A cross-sectional survey approach was employed to collect students' perceptions of their participation in the initiative. The study focused on perceived learning outcomes rather than establishing causal relationships between program participation and subsequent educational or occupational achievements. Social Cognitive Career Theory (SCCT) provided an interpretive perspective for discussing the relevance of learning experiences, perceived confidence, and career-related opportunities, rather than a structural model subjected to hypothesis testing.

Study Setting and Educational Intervention

The study was conducted at Pulau Nyior High School, a rural high school in Kedah, Malaysia. The school implemented a technology-enhanced aquaculture initiative that integrated catfish farming with practical agricultural education and digital monitoring applications.

The initiative involved the use of fish culture tanks supported by an Internet of Things (IoT)-based monitoring system. Students participated in practical aquaculture activities under teacher supervision, including fish management, observation of water conditions, routine maintenance, and monitoring through the Blynk application. These activities provided opportunities to observe how digital technology could support agricultural management and practical decision-making.

The initiative also incorporated related agricultural activities, including the reuse of aquaculture wastewater for vegetable cultivation. Hydroponic cultivation was undertaken as a separate school-based agricultural activity and was not directly connected to the fish-tank wastewater system.

The educational intervention was intended to expose students to contemporary agricultural practices while providing opportunities to develop practical competencies, technological familiarity, responsibility, and awareness of potential agricultural entrepreneurship.

Participants and Sampling

The study involved 30 high school students enrolled in Agricultural Science at Pulau Nyior High School, Kedah, Malaysia. All participants were directly involved in the school-based smart aquaculture initiative. Purposive sampling was employed to select students based on their participation in the project and their ability to provide relevant insights into their learning experiences. All 30 completed questionnaires were included in the final analysis.

As the study was conducted in a single rural high school with a relatively small sample, the findings provide context-specific insights into students' perceptions and experiences rather than statistically representative conclusions about rural high school students across Malaysia.

Research Instrument

Data were collected using a structured questionnaire comprising 30 items adapted from previously developed research instruments. The questionnaire was used to examine students' perceptions of the educational and practical value of the school-based aquaculture initiative. The items addressed four broad areas: entrepreneurial learning, STEM and technology-related learning, perceived financial benefits to the school, and confidence in applying acquired skills to future activities.

All items were measured using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire items were examined according to their conceptual relevance to the research objectives. Items concerning technological applications and STEM learning were used to explore perceived digital and practical

competencies. Items addressing business opportunities, entrepreneurial confidence, and future applications of acquired knowledge were used to examine entrepreneurial learning and future-oriented perceptions.

The questionnaire was not subjected to a formal expert review or content validity assessment before data collection. Therefore, the four areas were treated as descriptive content categories rather than independently validated measurement constructs. Selected items were analyzed individually using descriptive statistics to ensure that the findings remained consistent with the specific statements measured.

Internal consistency was assessed using Cronbach's alpha. However, the coefficient was interpreted as an indicator of overall internal consistency rather than evidence of content validity or construct validity. Furthermore, the questionnaire did not directly measure students' knowledge of specific occupations, career preferences, or changes in career awareness. Accordingly, career-related interpretations were limited to the potential educational implications of the learning experiences.

Data Collection Procedure

Students participated in the school-based aquaculture initiative as part of their Agricultural Science learning activities under the supervision of teachers. Following their involvement in the project, questionnaire responses were obtained to capture their perceptions of the educational experiences associated with technology-enhanced aquaculture.

A total of 30 Agricultural Science students participated in the study and completed the questionnaire. All 30 responses were included in the final dataset for analysis.

Data Analysis

The quantitative data were analyzed using descriptive statistical procedures appropriate for an exploratory study with a relatively small sample. Frequencies and percentages were used to summarize response distributions, while means and standard deviations were considered for describing students' responses to relevant questionnaire statements.

Questionnaire items were organized according to their conceptual relevance to the study objectives, particularly technology-related learning, practical competencies, confidence, and entrepreneurial opportunities. These groupings served as an analytical framework and were not assumed to represent independently validated measurement scales.

Where composite scores were considered, their construction required assessment of item compatibility and internal consistency. Given the sample size of 30 students, the analysis prioritized transparent item-level reporting and cautious interpretation rather than complex multivariate modeling.

The findings were interpreted in relation to the educational objectives of the initiative and the broader perspective of SCCT. However, no causal effects or direct changes in career awareness, entrepreneurial intentions, or economic outcomes were inferred solely from students' self-reported perceptions.

RESULTS

Data Completeness and Internal Consistency

The analysis included responses from 30 high school students who participated in the technology-enhanced aquaculture initiative. All respondents completed the 30 questionnaire items, resulting in 900 valid item responses with no missing values. Responses were measured using a five-point Likert scale.

The overall questionnaire demonstrated high internal consistency, with a Cronbach's alpha coefficient of 0.976 across the 30 items. This result indicates a high degree of consistency among questionnaire responses. However, because the instrument covered several educational and economic dimensions, the coefficient was interpreted as an overall reliability indicator rather than evidence of a single underlying construct.

Perceived Digital and Practical Competencies

Students generally reported positive perceptions of technology-supported agricultural learning. Understanding how technology could improve agricultural efficiency recorded a mean score of 4.10 (SD = 0.96). The practical application of STEM concepts in aquaculture activities received a similar mean score of 4.10 (SD = 0.89).

Students also expressed positive perceptions of their ability to use IoT technology to improve project productivity (M = 4.00, SD = 0.87) and apply STEM knowledge to calculate project costs and profits (M = 4.00, SD = 0.79). These findings suggest that participants recognized the relevance of digital technologies and scientific knowledge to practical agricultural management.

However, the findings reflect students' self-reported perceptions rather than independently assessed technological proficiency or demonstrated improvements in STEM competencies.

Table 1 presents the descriptive statistics for selected questionnaire items relating to students' perceived technological competencies, practical learning, entrepreneurial opportunities, and confidence in applying acquired skills beyond the school-based initiative.

Table 1. Students' Perceptions of Future-Ready Skills and Entrepreneurial Opportunities (n = 30)

No	Questionnaire Item	Mean	SD
1	Understanding how technology improves agricultural efficiency	4.10	0.96
2	Applying STEM concepts in practical aquaculture activities	4.10	0.89
3	Using IoT technology to improve project productivity	4.00	0.87
4	Applying STEM knowledge to calculate project costs and profits	4.00	0.79
5	Identifying business opportunities in agriculture	4.20	0.85
6	Confidence in starting a small business	4.07	0.87
7	Interest in using acquired skills to establish a business	4.17	0.79
8	Motivation to explore opportunities related to acquired learning	4.17	0.83
9	Interest in using IoT technology for future home or business projects	3.90	0.84
10	Confidence in establishing a catfish farming project at home	3.80	0.89

Note. M = mean; SD = standard deviation. Responses were measured on a five-point Likert scale (1 = strongly disagree; 5 = strongly agree). Results represent students' self-reported perceptions rather than objectively assessed competencies.

Entrepreneurial Awareness and Confidence

Students reported positive perceptions of the entrepreneurial opportunities associated with agricultural activities. Their ability to identify business opportunities in agriculture recorded a mean score of 4.20 (SD = 0.85). Interest in using the skills acquired through the project to establish a business also received a positive rating (M = 4.17, SD = 0.79).

Confidence in starting a small business recorded a mean score of 4.07 (SD = 0.87). These results indicate that students perceived the initiative as relevant to understanding entrepreneurial possibilities and developing confidence in business-related activities.

Nevertheless, the findings should be interpreted as perceived entrepreneurial readiness rather than evidence of actual business establishment or subsequent economic participation.

Future-Oriented Learning and Economic Opportunities

Students expressed interest in applying their acquired knowledge beyond the immediate school project. Motivation to explore opportunities associated with their learning experiences recorded a mean score of 4.17 (SD = 0.83).

Interest in using IoT technology for future home or business projects received a mean score of 3.90 (SD = 0.84), while confidence in establishing a catfish farming project at home recorded a mean score of 3.80 (SD = 0.89).

These findings suggest that students recognized potential applications of their learning beyond the classroom. However, their comparatively lower confidence in independently establishing a home-based aquaculture project indicates that awareness of future opportunities may not necessarily translate into readiness to undertake entrepreneurial activities.

Overall, the results provide preliminary evidence that participation in school-based smart aquaculture was associated with positive student perceptions of technology-related learning, practical competencies, and entrepreneurial opportunities. The questionnaire did not directly assess specific occupational preferences or changes in career awareness; therefore, conclusions regarding career development are limited to the broader relevance of these learning experiences to future opportunities.

DISCUSSION

Smart Aquaculture as a Platform for Developing Future-Ready Skills

The findings indicate that technology-enhanced school-based aquaculture provides a promising educational context for developing competencies relevant to future learning and employment. Students reported positive perceptions of their understanding of how technology improves agricultural efficiency (M = 4.10, SD = 0.96) and the practical application of STEM concepts in aquaculture activities (M = 4.10, SD = 0.89). These findings suggest that participation in the initiative enabled students to recognize the relationship between classroom knowledge, digital technology, and practical agricultural management.

The findings are consistent with Xu et al. (2023), who highlighted the potential of educational technology to strengthen agricultural learning through practical applications and innovative instructional approaches. Similarly, Vuorikari et al. (2022) emphasized that digital competence involves the ability to use technological resources meaningfully and responsibly rather than merely possessing basic operational knowledge. Within the present study, exposure to IoT monitoring technology introduced students to the application of digital information in agricultural production, providing a practical context for understanding how technology supports decision-making.

The relevance of these experiences extends beyond aquaculture. The World Economic Forum (2025) identified analytical thinking, technological literacy, adaptability, and problem-solving among the competencies increasingly valued in changing labor markets. Although the present study did not objectively assess these competencies, students' positive perceptions suggest that technology-supported agricultural activities may provide opportunities to recognize and practice skills relevant to future occupational environments.

Importantly, the educational contribution of smart aquaculture should not be interpreted solely through technological exposure. The integration of digital monitoring with practical agricultural responsibilities allowed students to observe how scientific knowledge and technology are applied in real-world situations. This supports UNESCO's (2023a) argument that educational technology should serve meaningful learning objectives rather than function merely as an additional instructional resource.

For rural high schools, such initiatives may offer a practical approach to introducing technological applications within existing Agricultural Science activities. By connecting familiar agricultural practices with emerging digital technologies, schools can provide students with learning experiences that demonstrate the relevance of scientific knowledge and technological innovation to contemporary economic activities.

Technology-Related Confidence and the Application of Learning

Students also reported positive perceptions of using IoT technology to improve project productivity (M = 4.00, SD = 0.87) and applying STEM knowledge to calculate project costs and profits (M = 4.00, SD = 0.79). These

results indicate that participants recognized the usefulness of technological and scientific knowledge in managing practical agricultural activities.

From the perspective of Social Cognitive Career Theory, participation in task-related learning experiences may contribute to students' beliefs about their capabilities and the potential value of acquired competencies. Practical exposure to technology-supported activities can provide opportunities for students to develop familiarity with unfamiliar tasks and consider how such skills might be applied in future settings.

However, the findings should be interpreted cautiously. The questionnaire measured students' perceptions of their learning experiences rather than changes in self-efficacy using a validated SCCT instrument. Consequently, the results cannot establish that participation directly increased students' technological self-efficacy or produced measurable improvements in their technical abilities.

The findings are nevertheless relevant to broader discussions of educational digitalization. OECD (2023b) emphasized that effective digital education requires meaningful integration between technological resources and learning practices. Similarly, Hassim et al. (2024) highlighted the importance of accessibility and institutional support in enabling participation in digital agriculture in Malaysia.

The present study extends these discussions to a rural high school context by illustrating how a technology-enhanced agricultural initiative can expose students to digital applications through practical activities. Rather than treating digital technology as an abstract subject, the initiative provided opportunities for students to observe its relevance to agricultural management and resource utilization.

These findings suggest that future educational initiatives should emphasize sustained opportunities for students to operate technological systems, interpret digital information, and apply knowledge independently. Such opportunities may help students progress from recognizing the usefulness of technology toward developing greater confidence in its practical application.

Career-Related Learning Opportunities Through Technology-Enhanced Agriculture

An important contribution of the study concerns the potential role of smart aquaculture in exposing students to career-related learning experiences and future economic opportunities. Traditional perceptions of agriculture may emphasize physically demanding production activities, while technological developments have introduced opportunities involving digital monitoring, resource management, agricultural innovation, and agribusiness.

The findings suggest that students recognized the potential value of technology-enhanced agricultural learning beyond the immediate school project. Motivation to explore opportunities associated with acquired learning recorded a mean score of 4.17 (SD = 0.83), while interest in using IoT technology for future home or business projects recorded a mean score of 3.90 (SD = 0.84).

These results are relevant to OECD (2025), which highlighted the importance of providing adolescents with meaningful opportunities to explore occupational pathways and understand changing labor-market demands. Similarly, FAO (2025) emphasized the importance of youth participation in innovation and economic opportunities within agrifood systems.

From an SCCT perspective, exposure to unfamiliar occupational activities may provide learning experiences relevant to students' beliefs about possible career pathways. By participating in technology-supported agricultural activities, students may encounter applications of technology that challenge conventional perceptions of agricultural work.

However, the questionnaire did not directly measure students' knowledge of specific occupations or their intentions to pursue particular careers. Therefore, the findings should not be interpreted as evidence of measurable improvements in career awareness or changes in occupational preferences. Instead, they indicate positive perceptions of learning experiences that may support future career exploration.

This distinction is particularly important in rural educational settings. Introducing students to modern agricultural technologies may expand the range of activities they associate with agriculture, but additional career guidance, industry engagement, and structured occupational exploration may be required to translate technological exposure into informed career decisions.

Accordingly, smart aquaculture should be viewed as a potential starting point for career-oriented educational development rather than a standalone intervention capable of determining students' future occupational choices.

Entrepreneurial Mindsets and Perceived Economic Opportunities

The entrepreneurial dimension of the findings provides further insight into the perceived value of technology-enhanced agricultural education. Students reported positive perceptions of their ability to identify business opportunities in agriculture (M = 4.20, SD = 0.85), their interest in applying acquired skills to establish a business (M = 4.17, SD = 0.79), and their confidence in starting a small business (M = 4.07, SD = 0.87).

These findings suggest that the initiative was perceived as relevant to entrepreneurial learning and opportunity recognition. The integration of agricultural production with technological applications may have helped students recognize that agricultural activities involve economic decisions, resource management, and potential income-generating opportunities.

This interpretation is consistent with Udekwe and Iwu (2024), who highlighted the relationship between digital technology, innovation, entrepreneurship education, and entrepreneurial motivation. Similarly, Branca et al. (2025) identified entrepreneurial self-efficacy, creativity, and innovation as important competencies associated with entrepreneurship education.

The findings also align with Boye et al. (2024), who emphasized the importance of skills development and perceptions of agricultural opportunities in supporting youth engagement in agribusiness. Although the present study focused on high school students rather than established agricultural entrepreneurs, the results suggest that early exposure to technology-supported agricultural activities may provide a meaningful introduction to entrepreneurial possibilities.

Nevertheless, an important distinction emerged between recognizing entrepreneurial opportunities and feeling confident about undertaking independent agricultural activities. While students reported positive perceptions of business opportunities, confidence in establishing a catfish farming project at home recorded a comparatively lower mean score (M = 3.80, SD = 0.89).

This difference may reflect the practical challenges associated with independently managing an agricultural enterprise, including access to financial resources, technical knowledge, equipment, and ongoing operational support. However, these explanations remain tentative because the questionnaire did not directly investigate the reasons for students' lower confidence.

From an SCCT perspective, the difference between recognizing potential opportunities and feeling prepared to undertake independent activities is relevant to the distinction between outcome expectations and task-specific confidence. Students may perceive agricultural entrepreneurship as beneficial while remaining uncertain about their ability to manage a project without institutional support.

These findings suggest that future school-based initiatives could incorporate additional entrepreneurial activities, including basic business planning, financial management, marketing, and guided opportunities for students to make operational decisions. Such activities may help students develop a more realistic understanding of the resources and competencies required for entrepreneurial participation.

Implications for Rural Educational Transformation

The findings have several implications for rural educational development. First, they suggest that technology-enhanced agricultural projects may provide opportunities to connect classroom learning with contemporary

technological applications. For high schools offering Agricultural Science, smart aquaculture represents a contextually relevant approach to introducing digital technology without separating it from existing subject content.

Second, the findings highlight the potential value of integrating career-related learning into practical agricultural education. Rather than focusing exclusively on production activities, schools could incorporate structured discussions about technology-related occupations, agricultural entrepreneurship, and further educational pathways. Such activities may help students connect acquired competencies with future opportunities.

Third, the comparatively lower confidence associated with independently establishing an aquaculture project suggests the importance of sustained practical guidance. Teacher supervision, access to equipment, and opportunities for progressive responsibility may support students in developing greater familiarity with the demands of agricultural management.

Finally, the findings suggest that school-based smart aquaculture may offer a useful educational approach for rural communities seeking to strengthen the relevance of Agricultural Science to changing technological and economic environments. However, the study's small sample, single-school setting, and reliance on self-reported perceptions limit the extent to which the findings can be generalized.

Overall, the study contributes context-specific evidence suggesting that technology-enhanced aquaculture is perceived positively by participating rural high school students, particularly in relation to practical learning, technological applications, and entrepreneurial opportunities. Its principal contribution lies in positioning smart aquaculture as a potential platform for future-oriented educational development rather than evaluating it solely through agricultural production outcomes.

CONCLUSION

This study examined the perceived educational benefits of a technology-enhanced school-based aquaculture initiative involving 30 Agricultural Science students at a rural high school in Kedah, Malaysia. The findings indicate that students generally held positive perceptions of the initiative, particularly regarding the application of digital technology, practical STEM learning, entrepreneurial awareness, and potential economic opportunities. The integration of Internet of Things (IoT) monitoring technology with hands-on aquaculture activities provided a practical context for connecting classroom knowledge with contemporary agricultural applications.

The findings further suggest that smart aquaculture may offer opportunities to broaden students' understanding of agriculture beyond conventional farming practices. Exposure to digital monitoring, resource management, and production-related decision-making introduced students to competencies relevant to modern agricultural activities. Positive perceptions of entrepreneurial opportunities also suggest that technology-enhanced agricultural education may encourage students to recognize the potential economic value of acquired knowledge and skills.

Nevertheless, students' comparatively lower confidence in independently establishing a home-based aquaculture project highlights the distinction between recognizing opportunities and feeling prepared to undertake entrepreneurial activities. This finding underscores the importance of sustained guidance, practical training, and opportunities for students to develop greater independence in applying their knowledge.

The study contributes to discussions of rural educational transformation by positioning smart aquaculture as a potential platform for future-oriented learning. Rather than evaluating school-based agricultural initiatives solely through production outcomes, it highlights their perceived relevance to technological learning, practical competencies, and entrepreneurial awareness. However, the findings do not establish causal improvements in skills or career awareness, as these outcomes were not independently measured.

Overall, technology-enhanced aquaculture offers a promising educational approach for rural high schools seeking to connect Agricultural Science with emerging technologies and economic opportunities. With appropriate institutional support, teacher guidance, and opportunities for continued practical engagement, similar

initiatives may contribute to preparing rural students for increasingly technology-oriented educational and occupational environments.

Limitations And Future Research

Several limitations should be considered when interpreting the findings. First, the study involved 30 Agricultural Science students from a single rural high school in Malaysia. The relatively small sample and context-specific setting limit the generalizability of the findings to other schools, educational programs, or student populations.

Second, the study relied on self-reported questionnaire responses, which may be influenced by students' perceptions, expectations, and social desirability. Although the findings indicate positive perceptions of technology-supported learning and entrepreneurial opportunities, they do not provide objective evidence of improvements in digital competence, practical skills, or entrepreneurial performance.

Third, the cross-sectional design did not include baseline measurements or a comparison group. Consequently, the study cannot establish whether students' competencies, confidence, or awareness of economic opportunities changed as a direct result of participating in the initiative.

Fourth, although career awareness forms part of the study's broader educational interpretation, the questionnaire did not directly assess students' knowledge of specific occupations or their intended career pathways. Conclusions concerning career awareness should therefore be regarded as exploratory rather than as evidence of measurable career development outcomes.

An additional limitation concerns the measurement instrument. Although the questionnaire demonstrated high overall internal consistency, its content validity was not formally assessed through expert review before data collection. Furthermore, the original sources of the adapted items could not be fully verified. Consequently, the findings should be interpreted as descriptive evidence of students' perceptions rather than outcomes derived from independently validated measurement constructs. Future studies should establish the content validity of the questionnaire, document the sources of adapted items, and evaluate the reliability and validity of the relevant constructs before applying the instrument to larger student populations.

Future research could address these limitations by involving larger samples across multiple rural high schools and adopting longitudinal or pre-test and post-test research designs. Additional measures could assess students' digital competencies, problem-solving abilities, career awareness, entrepreneurial self-efficacy, and occupational intentions before and after participation.

Qualitative interviews with students and teachers could also provide deeper insights into how technology-enhanced agricultural experiences influence students' perceptions of future opportunities. Furthermore, comparative studies involving schools with and without smart aquaculture initiatives could help determine the educational contribution of technology-supported agricultural learning.

Future investigations may also examine whether sustained participation in such initiatives influences students' subsequent educational choices, engagement in agricultural entrepreneurship, or pursuit of technology-related career pathways.

Ethical Considerations

Permission to conduct the study and collect questionnaire data was obtained from the school administration of Pulau Nyior High School, Kedah, Malaysia. The questionnaire was administered to 30 Agricultural Science students with the assistance of the school's teachers, and student participation was voluntary. The completed questionnaire responses were subsequently shared with the researcher by the teachers for academic analysis. Participants' confidentiality was maintained by reporting the findings in aggregate form without disclosing individual identities. The data were used solely for academic research purposes.

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Conflict of Interest

The author declares no conflict of interest.

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to applicable ethical and confidentiality requirements.

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