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Promoting Application of IoT and DigComp 2.2 to Competence-Based Learning in Precision Agriculture*

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The digital transformation of the agri-food sector demands new competencies from professionals in agronomic and environmental fields. This study presents the implementation and evaluation of an educational framework designed to develop digital competences among postgraduate students, using IoT technologies in a course on Precision Agriculture. The course was structured around the DigComp 2.2 framework, targeting specific competences such as information management, technical problem-solving, and identification of technological solutions. 21 students participated in a project-based learning experience involving Arduino and ESP32 microcontrollers, sensors, actuators, and cloud platforms for data monitoring and control. A 16-item DigComp 2.2-based questionnaire was used to assess competence acquisition. Results showed significant improvements in students' confidence and abilities, particularly in hardware integration and applied problem-solving. However, lower confidence levels in cloud platform usage revealed a need for more sustained training in digital environments. The findings highlight the effectiveness of hands-on, interdisciplinary methodologies in fostering relevant digital skills in agricultural education. The pro-posed framework aligns academic training with sectoral demands, enhancing students' employability, innovation capacity, and readiness for smart farming systems.

Keywords: precision agriculture; digital competences; DigComp 2.2; Internet of Things; Arduino; ESP32; Higher education

1. Introduction

The ongoing digital transformation of the agri-food sector is reshaping the skillsets required of professionals in agronomic and environmental engineering [1, 2] and is increasingly driven by sustainability, automation, and data-informed practices [3]. In this context, the integration of technologies such as the Internet of Things (IoT) into university education has become essential to prepare students for emerging technological, productive, and societal challenges. Despite notable advancements, the adoption of IoT within agronomic education remains limited [4]. This gap presents a major challenge in training future professionals equipped with the digital competencies required for precision agriculture. The ability to analyse and act upon real-time data collected through IoT systems is becoming essential in modern agriculture, especially as the sector increasingly relies on data-driven decision-making supported by artificial intelligence and big data analytics [5], this is particularly evident in advanced irrigation systems and environmental monitoring applications [6]. Some existing research highlights the benefits of IoT in education, from introducing students to basic programming skills to fostering environmental awareness [7, 8]. However, there is a clear lack of structured educational frameworks specifically designed to support the teaching of IoT and related technologies within the context of precision agriculture.

To structure this educational proposal, the European Digital Competence Framework for Citizens (DigComp 2.2) [9] has been adopted as a reference for identifying and assessing key digital skills. Five specific competencies from the framework were prioritized: information search and filtering (1.1), data and information evaluation (1.2), digital information management (1.3), technical problem-solving (5.1), and the identification of technological needs and innovative solutions (5.2).

This work presents a novel pedagogical approach to Precision Agriculture, a discipline that has traditionally relied on more conventional teaching methods. By implementing a multidisciplinary university course centered on IoT and grounded in a project-based, hands-on methodology, the study addresses a significant gap in the literature and lays the foundation for future research in educational technology applied to sustainable agriculture. Through direct interaction with sensors, microcontrollers, and digital platforms, students develop and apply digital skills in realistic agri-environmental contexts. Similar initiatives using IoT in higher education have shown benefits in student autonomy and collaborative learning [10]. The outcomes of the course are analyzed to evaluate the effectiveness of this innovative training model in

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enhancing students' digital readiness and environmental awareness. Accordingly, this study is guided by the following research questions:

1. To what extent does an IoT-based, project-driven educational framework improve postgraduate students' digital competences as defined by DigComp 2.2?
2. How does the integration of low-cost microcontrollers, sensors, and cloud platforms influence students' technical problem-solving skills and confidence in applying IoT to Precision Agriculture?
3. What gaps and limitations remain in students' digital readiness, particularly in relation to advanced cloud platforms and data management, after completing the course?

2. Materials and Methods

2.1 Educational Context and Participant Profile

This study was conducted within the framework of a postgraduate course in Precision Agriculture at the Universidad Politécnica de Madrid. The course aimed to develop digital and technological competencies related to IoT, particularly in agri-environmental applications. A total of 21 master's students participated in the course. Their academic backgrounds included Agricultural Engineering, Agro-environmental Engineering, and related disciplines. A diagnostic questionnaire administered prior to the intervention revealed that most students had little to no prior experience with programming, microcontrollers, or IoT systems, highlighting the need for a structured educational approach to introduce these concepts.

2.2 Pedagogical Approach and Framework Alignment

The course was designed to address specific digital competence areas defined by DigComp 2.2. This framework was not only used for evaluating learning outcomes, but also as a reference for the instructional design, ensuring alignment between teaching activities and digital skill development. Recent research has confirmed the relevance of DigComp 2.2 for structuring digital education across levels and domains, highlighting its adaptability and comprehensive coverage of knowledge, skills, and attitudes [9]. Comparative studies of digital competence frameworks also position DigComp as one of the most robust and actionable models for educational settings [11]. Furthermore, systematic reviews emphasize the value of using DigComp to guide both curriculum design and digital competence assessment in higher education, underscoring their practical utility in diverse learning environments [12]. These findings are consistent with studies that emphasize the value of DigComp in promoting autonomy and digital fluency through active methodologies such as problem-based learning [13].

Five key DigComp 2.2 competencies were targeted throughout the course:

1.1 Information and data literacy: Browsing, searching and filtering data, information, and digital content.
1.2 Evaluating data, information and digital content.
1.3 Managing digital content and structured data.
5.1 Solving technical problems.
5.2 Identifying technological responses to needs.

These competencies guided the course structure, learning outcomes, and student as-signments. The course adopted an active learning methodology, combining theoretical input with collaborative project-based learning (PBL). This approach is consistent with best practices in engineering education, where PBL fosters real-world skills and deeper engagement [14]. Instruction was delivered through three consecutive sessions of three hours each, following a gradual increase in complexity and autonomy.

2.3 Course Design and Teaching Methodology

The chosen approach was multidisciplinary, involving professors from ETSIAAB (School of Agricultural, Food and Biosystems Engineering) and ETSISI (School of Computer Systems Engineering) of the Universidad Politécnica de Madrid. It was structured into five progressive modules, combining theoretical and practical sessions. Each session typically began with a brief theoretical part, followed by group work, allowing students to apply concepts in a collaborative setting. Each group of students received an Arduino/ESP32 kit, which they used during class activities and could also take home to continue practicing individually or collaboratively within the school facilities. The course modules were:

1. Introduction to electronics and microcontrollers – Explanation of basic concepts of Arduino and ESP32.
2. Use of sensors in agriculture – Installation and calibration of agronomic sensors.
3. Automation with IoT actuators – Implementation of controllers for irrigation and ventilation systems in greenhouse conditions.
4. Connectivity and cloud monitoring – Use of Thingsboard or Arduino IDE for remote data visualization.
5. Data transformation and decision-making –

Application of models to interpret agronomic variables.

Although the full course extended over a longer period, the analysis presented here focuses exclusively on these three sessions, as they offered the most direct alignment with the assessment of students' digital competencies based on the DigComp framework. The sessions were the following:

- Session 1: Introduced foundational IoT concepts, including sensor and actuator types, circuit logic, and basic Arduino programming. The session followed a traditional lecture format to build essential background knowledge.
- Session 2 and 3: Implemented a hands-on, project-based methodology. Students were divided into teams and tasked with designing a functional prototype using Arduino boards, environmental sensors (light, temperature, humidity), and actuators such as valves and LEDs. Each team developed a simulation of an automated irrigation system, applying their understanding of digital data collection and response logic.

Throughout the sessions, instructors assumed the role of facilitators, providing minimal guidance to encourage self-directed learning. Students were encouraged to identify problems, formulate solutions, and explore relevant documentation – thus fostering the technical problem-solving and information management competencies defined in DigComp 2.2. Peer learning was also integrated: when a team solved a specific challenge, they were invited to explain their approach to the rest of the class, promoting collaborative learning and metacognitive reflection. Fig. 1 summarizes the pedagogical progression adopted throughout the course, illustrating how the sequential structure supported competence development in alignment with DigComp 2.2.

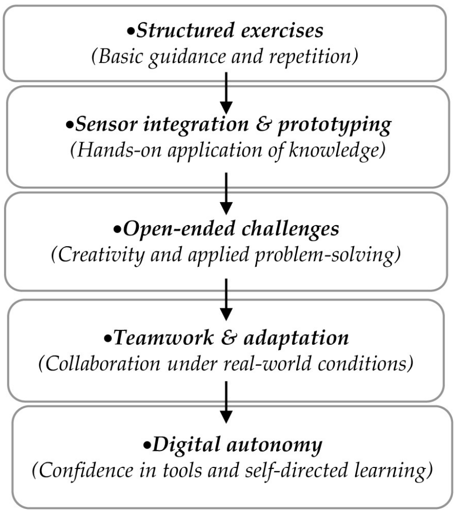

Fig. 1. Pedagogical progression of the course aligned with the DigComp 2.2 framework.

2.4 Materials and Technical Resources

- Microcontrollers: Arduino Uno and ESP32, used for data collection and processing. These devices are widely used in IoT projects due to their flexibility, low cost, and ease of use [15].
- Proximal sensors: soil moisture sensors, temperature, ambient humidity, solar radiation, etc. These sensors are essential in precision agriculture to monitor environmental conditions and optimize crop performance [16, 17].
- Actuators: relays, servomotors, and fans for automating agronomic needs. Automation helps improve resource efficiency and reduce operational costs [18].
- Development and visualization environments:
  (a) Arduino IDE: a development environment for programming microcontrollers. Known for its ease of use and wide developer community [19].
  (b) Thingsboard: a cloud platform used for remotely monitoring agricultural data. It allows real-time data visualization and analysis to support informed decision-making [20].
  (c) Moodle: a widely used educational tool for managing online courses. Used for content management, documentation, and course activity tracking [21].
- Network infrastructure: WiFi connectivity to integrate the devices with the cloud.

These elements are summarized in Fig. 2 and Table 1.

2.5 Student Deliverables

As part of the learning process, students completed a sequence of structured assignments aligned with the course modules and DigComp 2.2 competencies. These deliverables corresponded to the full duration of the course, reflecting the progressive development of digital competencies across all modules. The students completed five deliverables related to the material covered in class; all five are explained below, with the second one described in greater detail:

- Deliverable I Sensor research and data sheet analysis (1.1, 1.2).

Find a low-cost sensor that can measure a variable of interest (e.g., temperature, humidity, air/water quality, light, etc.) and identify it by name. Students must review and comment on its characteristics, such as voltage and current requirements, communication protocols, acquisition range, sensi-

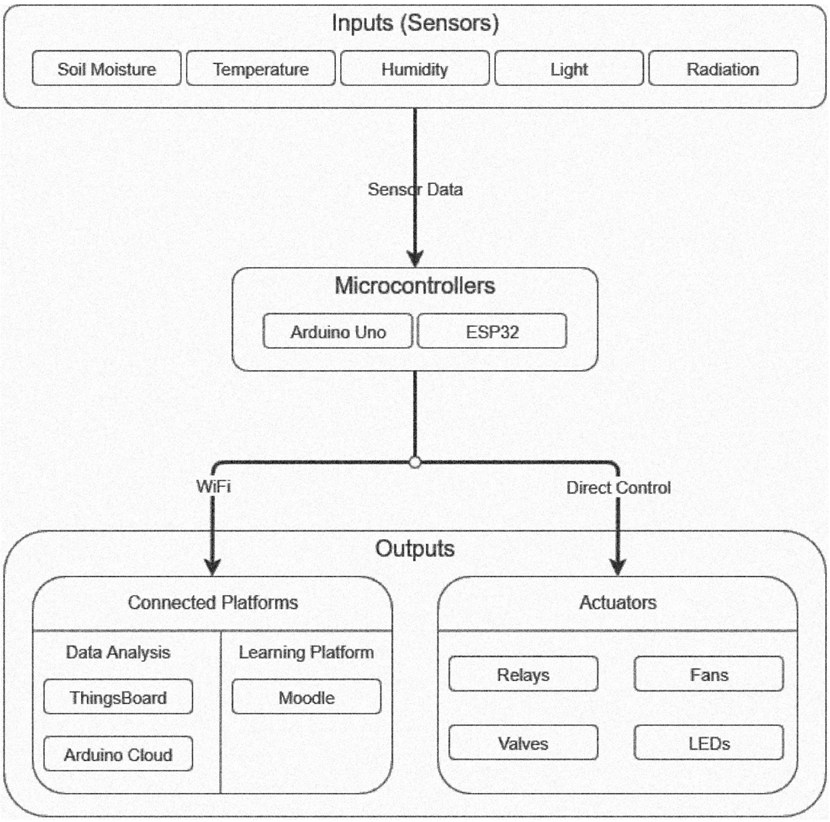

Fig. 2. system-level diagram illustrating the architecture of the IoT-based Precision Agriculture framework implemented in the course (microcontrollers, sensors, actuators, connectivity, and cloud monitoring).

Table 1. structured overview of the technologies and components used (microcontrollers, sensors, actuators, software platforms, and network infrastructure)

Category	Technology / Tools use	Purpose in course
Microcontrollers	Arduino Uno, ESP32	Data collection and processing
Sensors	Soil moisture, DHT22, temperature, humidity, solar radiation	Monitoring environmental variables
Actuators	Relay, servomotors, fans, LEDs	Automations of irrigation, ventilation, etc.
Platforms	Arduino IDE, Thingsboard, Moodle	Programming, cloud visualization, course management
Connectivity	WiFi	Cloud integration

tivity, IP protection, accuracy, resolution, tolerance, sampling period, etc.

- Deliverable II Wiring and programming a basic circuit with LED and button (5.1).

In this assignment, students are required to design the wiring diagram for a circuit that allows a LED to be turned on and off using an Arduino board, a push button, and a breadboard, according to the code discussed in class. The circuit layout must be modelled using the Fritzing tool. The full and detailed instructions for its preparation and submission are provided in Appendix A.

- Deliverable III Relay activation based on sensor thresholds (5.2).

Activate buzzer and electric motor using breadboard, Arduino, threshold temperature/humidity, and relay. Fritzing diagram required.

- Deliverable IV Cloud integration and dashboard visualization (1.3, 5.2).

Practice with DHT22 sensor and relay on ESP32 with Arduino Cloud Dashboard. Students must replicate the setup from Arduino UNO to ESP32 and visualize humidity/temperature on the Dashboard, as well as control a LED via a switch.

- Deliverable V Sensor calibration and data modelling using regression techniques (1.2, 5.1).

Install and calibrate SEN0308 soil moisture sensor on Arduino UNO or ESP32. Convert raw data to soil moisture percentage using a linear regression function. Understand and explain the regression curve based on known moisture levels.

Each assignment was designed to develop specific technical and digital abilities through real-world problem-solving.

2.6 Student Deliverables

To assess the acquisition of digital competences, a 16-item questionnaire based on DigComp 2.2 descriptors was administered at the end of the course. The survey was designed to assess perceived competence in key areas including information management, digital problem-solving, and technological adaptation. A total of 16 students completed the survey. The survey used a 5-point Likert scale (1 = not competent at all, 5 = fully competent). Approximately 25% of the items were negatively worded to reduce response bias and detect inconsistencies. In addition to the survey, instructors con-ducted non-intrusive direct observation during sessions, focusing on student interaction, technical problem-solving strategies, and engagement. The combination of quantitative and qualitative data enabled a comprehensive evaluation of the impact of the course on students' digital competence development.

3. Results

3.1 Acquisition of Digital Competences Aligned with DigComp 2.2

The results of this study provide strong evidence of the positive impact of the proposed educational framework on the development of digital competences among postgraduate students in agronomic disciplines.

At the outset of the course, students reported low confidence in their digital abilities, particularly in relation to programming, data acquisition, and IoT systems, with average self-assessment scores of 2.00 for IoT and 1.69 for programming. Following the intervention, confidence in IoT-related tasks rose significantly to 3.25 (Wilcoxon $p < 0.001$; Student's t-test $p < 0.001$), confirming the effectiveness of the hands-on, project-based approach in promoting digital literacy and technical skills.

Factor analysis revealed that the first component extracted from student responses explained 34% of the total variance and grouped items related to practical competence, prototype development, and digital autonomy. This suggests that the acquisition of DigComp 2.2 competences in this setting does not occur in isolation but rather emerges from an integrated process involving applied knowledge, teamwork, and iterative problem-solving.

3.2 Correlations Between Technical Foundations and Digital Fluency

The analysis of correlations between self-reported competences highlighted meaningful relationships aligned with DigComp 2.2 domains. A strong positive correlation ($\rho = 0.73$, $p < 0.01$) was found between students' perceived competence in using Arduino/ESP32 boards and their confidence in designing functional prototypes – both falling under Area 5 (Problem Solving) (Fig. 3). This finding reinforces the need to integrate hardware prototyping into digital competence training within agronomy curricula.

Additionally, a moderate correlation ($\rho = 0.37$) was observed between advanced problem-solving skills and students' confidence in using IoT cloud platforms such as ThingsBoard. While this correlation is not as strong, it points to a gradual progression: once students master physical-level interactions and basic automation, they are better positioned to tackle competence 5.2 (identifying technological responses to needs) in the context of remote monitoring and data-driven agriculture (Fig. 4).

3.3 Training Gaps and Recommendations for Curricular Improvement

Despite the overall positive outcomes, the results also revealed a significant gap between basic technical competence and advanced digital tool usage. For example, students reported high confidence in troubleshooting simple circuits, but notably lower confidence in configuring and interpreting cloud-

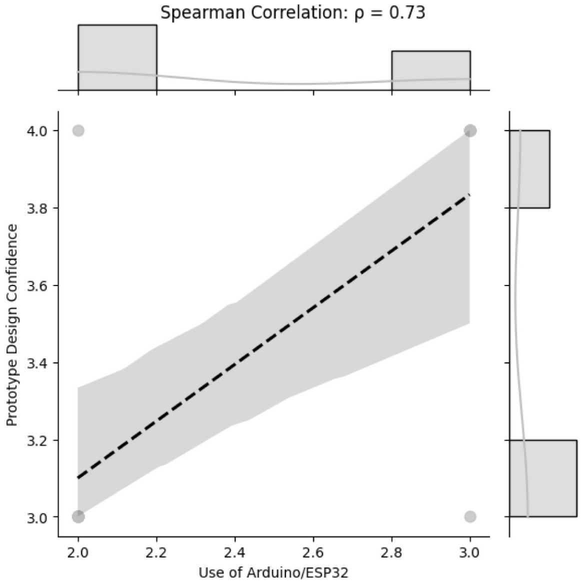

Fig. 3. Scatter plot with regression line and marginal histograms showing the relationship between students' perceived competence in using Arduino/ESP32 boards and their ability to design functional prototypes.

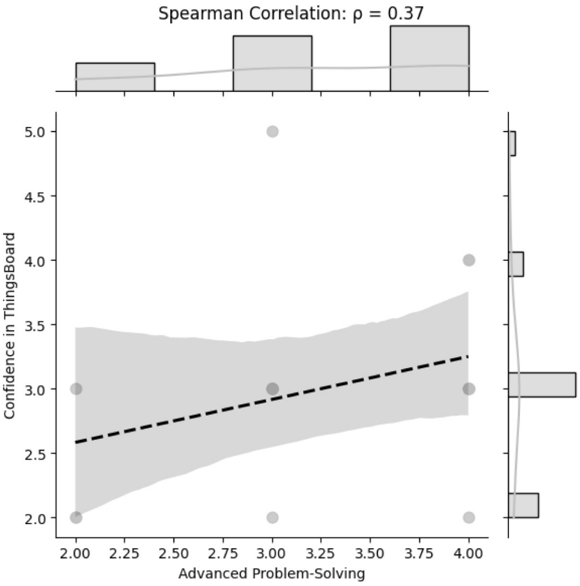

Fig. 4. Scatter plot with regression line and marginal histograms showing the relationship between students' confidence in solving advanced technical problems and their confidence in configuring IoT platforms such as ThingsBoard.

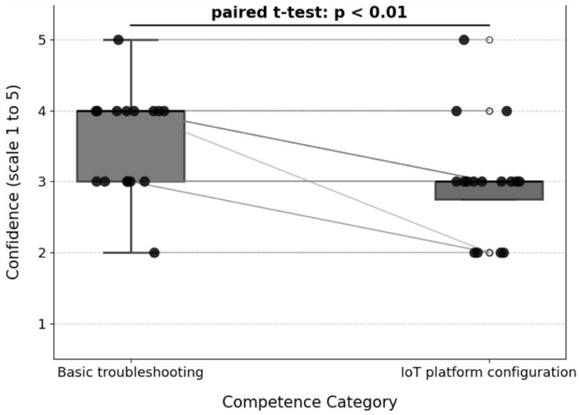

Fig. 5. Paired boxplot comparing students' self-assessed confidence in basic troubleshooting versus IoT platform configuration. Each gray line represents an individual student's scores. Most lines descend, indicating a consistent drop in confidence from basic to advanced digital competences

based IoT platforms (paired t-test, $p < 0.01$) (Fig. 5). This highlights a limitation in current training: although foundational skills are successfully acquired, more explicit and extended engagement with platforms like ThingsBoard and Arduino Cloud is needed to fully develop competences 1.3 (managing digital content) and 5.2..

To address this, it is recommended to allocate more instructional time to the configuration, interpretation, and use of digital platforms, including specific tutorials and case studies grounded in agronomic scenarios. Reinforcing the data transformation and decision-making component would strengthen the transition from hands-on experimentation to intelligent data management, which is critical in the context of digital agriculture.

3.4 Impact on Motivation, Employability and Sectoral Relevance

Students expressed high levels of engagement and satisfaction with the learning methodology, frequently citing the practical relevance of the activities and their alignment with real-world agronomic challenges. The framework promoted competence 5.1 (solving technical problems) not only through structured exercises but also through open-ended challenges that required initiative, adaptation, and team collaboration.

The competence development observed throughout the course is consistent with the broader goals of DigComp 2.2, particularly in fostering autonomy in digital environments, the ability to evaluate and interpret data (1.2), and the capacity to adapt to new technologies (5.2). These competences are increasingly valued in the labor market and directly contribute to improving the employability and innovation potential of graduates in the agri-food sector.

4. Discussion

Although the experience proved largely successful, it is essential to acknowledge the structural and pedagogical challenges inherent in implementing IoT-centered training within university contexts. Commonly cited barriers include inadequate digital infrastructure, disparities in students' prior knowledge, and insufficient teacher preparation [22]. Comparable issues are highlighted in the broader literature on digital agriculture, where training gaps, infrastructural limitations, and low levels of data literacy persist as significant obstacles [23]. In this case, the use of accessible hardware, open-source tools, and a progressive teaching strategy helped overcome many of these limitations.

Nevertheless, institutional support remains crucial to scaling this type of initiative. Ensuring continuity, allocating sufficient laboratory time, and investing in faculty development are key steps to embed DigComp 2.2 competences more deeply within agronomic education.

The development of educational frameworks for teaching emerging technologies has been explored across various disciplines [24]. Previous models have demonstrated that incorporating PBL and combining simulation platforms with real hardware con-tributes significantly to knowledge retention and student motivation [25, 26]. However, in the context of precision agriculture, literature reveals a noticeable gap in structured pedagogical approaches specifically tailored to teaching IoT.

While some studies have introduced models that employ proximal sensors for crop monitoring, these frameworks tend to focus more on industrial automation than on educational practices within agronomy [27]. This study seeks to address that shortcoming by presenting a theoretical and practical framework for implementing IoT in agronomic education.

Although previous studies have highlighted potential challenges in integrating IoT technologies into agricultural education – particularly concerning technological infra-structure and teacher training [28, 29] – the experience described in this study demonstrates that these barriers can be overcome through well-considered pedagogical planning and the use of accessible, low-cost resources. The effectiveness of this approach hinges on the design of gradual and coherent learning pathways, the reinforcement of teacher readiness, and the promotion of interdisciplinary strategies. These elements are key to achieving an inclusive and sustainable integration of emerging technologies in agronomic education.

Overall, the findings confirm that the implemented educational framework is effective for embedding digital and IoT competences into postgraduate agronomic training. The project-based methodology, supported by accessible hardware and advanced digital platforms, not only strengthens students' confidence and technical skills but also enhances their employability, fosters innovation, and prepares them to meet the evolving challenges of modern agriculture. To amplify its impact, future efforts should focus on deepening training in data management tools and maintaining the progressive and personalized nature of the learning experience, ensuring alignment with European standards and the current demands of the agricultural sector.

5. Conclusions

This study evaluated the implementation of an IoT-based, project-driven educational framework grounded in DigComp 2.2 to foster digital competence among postgraduate students in Precision Agriculture. The results demonstrated that:

- Digital competence development: Students significantly improved their self-perceived skills in technical problem-solving, information management, and the identification of technological solutions.
- Impact of hands-on IoT training: The use of low-cost microcontrollers, sensors, and cloud platforms effectively supported competence acquisition, bridging the gap between theory and practice in agronomic education.
- Training gaps: While students showed confidence in hardware integration and basic automation, lower confidence in using cloud platforms highlighted the need for extended training in advanced digital environments.

Overall, the framework proved effective in aligning academic training with sectoral demands, enhancing student motivation, employability, and readiness for data-driven agricultural systems. Future work should focus on reinforcing training in cloud-based data management and ensuring progressive learning pathways that accommodate diverse student backgrounds.

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Appendix A

Deliverable II instructions in detail:

1. Circuit: You must design the wiring diagram in Fritzing according to the following guidelines:

- Push button connected to digital pin 2 of the Arduino board.
- LED connected to digital pin 3.
- Make sure to include the appropriate resistor to protect the LED.
- The circuit must be built on a breadboard.

2. Code

The base code used is as follows:

```
int BUTTON = 2;
int LED = 3;
int STATE = LOW;
void setup() {
pinMode(PULSADOR, INPUT);
pinMode(LED, OUTPUT);
}
void loop() {
while(digitalRead(PULSADOR) == LOW) {
//Wait for the push button to be pressed
}
ESTADO = digitalRead(LED); // Read the current state of the LED
digitalWrite(LED, !ESTADO); // Toggle the state of the LED
while(digitalRead(PULSADOR) == HIGH) {
// Debounce: wait for the push button to be released
}
}
```

3. Tool: Use Fritzing to model the connection. If not installed, download it from https://fritzing.org/download.

4. Submission: Each team must submit their schematic in. fzz and .pdf formats with explanation on the Moodle platform. Deadline: October 21, 2024 (23:00). Late submissions will not be accepted.

5. Evaluation: Based on correctness, clarity, and appropriate use of components.

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