# IoT to Monitor Native Potato Crops in the Apurímac Region, Peru

Anabel Aranibar-Molina[1], Wilfredo Soto-Palomino[1], Carmen Palomino-Peralta[1] and Edward Flores[2]

[1] *Universidad Tecnológica de los Andes, Perú*
[2] *Universidad Nacional Federico Villarreal, Lima, Perú*

**Abstract**

In recent years, there has been a concern to bring research closer to university academic activities with the purpose of creating spaces for the teaching of science and the development of new capacities that allow research to be discovered in university students. The use of development and application of technologies allows students to experiment with research capabilities through experimentation. The objective of this research was to build a device using the Internet of Things (IoT) to control humidity in native potato fields in the Apurímac-Peru region. The study carried out has a quantitative, pre-experimental approach and is oriented towards the application of scientific knowledge for science teaching. The results demonstrate that a pre-experimental approach can be carried out by developing the proposed proposal by building an IoT device using Arduino UNO and sensors to measure the pH of the soil, the turbidity of the water and the humidity, also allowing the data to be sent to the cloud to have information at all times in real time from an application. It is concluded that through an IoT project to monitor humidity where native potato crops are grown in the Apurímac region, science can be taught through the scientific method, developing the activities of problem identification, problem statement, objectives, justification, theoretical framework, methodology, experimental application, results, discussion and conclusions of the work carried out.

**Keywords**
Formative research, mobile applications, IoT, Arduino.

## 1. Introduction

The escalating global demand for food is exerting detrimental effects on the environment and placing significant strain on agricultural productivity [1]. The agricultural sector encounters numerous obstacles. In contemporary public discourse and scientific literature, discussions on the future are progressively characterized by the dichotomy between "alternative" and "conventional" agriculture [2]. The utilization of traditional high-input agricultural techniques, encompassing the application of hazardous pesticides, herbicides, chemical fertilizers, genetically modified microorganisms, growth regulators, and other chemical substances, has had adverse effects on both soil fertility and has posed significant threats to human health and the environment [3]. The preference for organic foods among consumers is mostly driven by their perceived health benefits compared to foods produced through conventional agriculture, as well as their perceived environmental sustainability [4]. Agriculture offers enormous potential to achieve sustainable agriculture from societal, economic and environmental perspectives. However, the transformation towards Agriculture 4.0 is still slow [5]. A considerable portion of the agricultural information already accessible is underutilized. The implementation of digital technology in the agricultural sector has been shown to enhance both productivity and efficiency

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dra.anabel.aranibar.molina@gmail.com (A. Molina); dr.wilfredo.soto.palomino@hotmail.com (W. Soto); dra.carmen.palomino.peralta@hotmail.com (C. Palomino); eflores@unfv.edu.pe (E. Flores);
0000-0003-1819-2314 (A. Molina); 0000-0001-5926-8077 (W. Soto); 0000-0002-0567-4907 (C. Palomino); 0000-0001-8972-5494 (E. Flores)

within the industry. The application of the Internet of Things (IoT) in the agricultural sector represents a promising trajectory of technical progress for a logical and reasoned approach, resource-saving Agriculture 4.0 [6]. Investing in technology research is of utmost importance in order to facilitate the development of sustainable solutions for Agriculture 4.0. The shift towards the agricultural era is propelled by advancements in various technologies such as the Internet of Things, sensor networks, robotics, artificial intelligence, cloud computing, and big data, among other notable factors [7]. In recent years, there have been notable advancements in the field of information technology (IT), leading to the emergence of intelligent gadgets as well as advancements in computer and sensor technologies. The utilization of intelligent technologies has promise in facilitating the agriculture sector in addressing its productivity and sustainability concerns [8]. The direct influence of information technology (IT) on agricultural output is an unquestionable fact [9].

The growing necessity for enhanced quality and quantity of food has resulted in a heightened requirement for industrialization and intensification within the agriculture sector. The Internet of Things (IoT) is a highly promising technological advancement that presents numerous novel ideas for the modernization of the agricultural industry [10]. The Internet of Things (IoT) refers to the integration of computing devices, mechanical and digital machinery, items, or humans into a unified system that enables the transmission of data through both human-to-human and computer-to-human interactions [11]. The Internet of Things (IoT) refers to an extensive network of interconnected systems that rely on internet infrastructure. Its primary objective is to facilitate instantaneous communication and interaction among diverse entities, including objects, machines, and individuals, through the utilization of modern technological methods [12]. The Internet of Things (IoT) is presently revolutionizing various aspects of society, including the development of intelligent urban areas, advanced agricultural practices, efficient energy distribution networks, innovative transportation systems, automated residential environments, and sophisticated healthcare systems [13]. The primary purpose of the Internet of Things (IoT) is to establish a global network that interconnects various items, enabling anyone to remotely manage and manipulate them through the Internet. Furthermore, these items also offer consistent and timely notifications regarding their present condition to their intended recipient [14]. Within the market for electronic components and devices, a diverse range of devices exists that are specifically designed to offer solutions based on the Internet of Things (IoT). These devices possess distinct functionalities and configurations, enabling the resolution of numerous problems [15]. The progression of scientific knowledge since the inception of the scientific discipline has been primarily facilitated by the development of technology, which has significantly broadened the scope of observation, experimentation, data acquisition, data processing, data communication, and information utilization [16].

The Andean region is widely recognized as a significant geographical location that exhibits early indications of food production systems and boasts unparalleled agrobiodiversity on a global scale. This remarkable diversity is a direct outcome of thousands of years of deliberate cultivation within an environment characterized by a remarkable heterogeneity of ecosystems and a diverse array of human civilizations that place a high value on diversity as a means of managing risks [17]. Peru serves as the focal point for the birth and proliferation of over 3,000 distinct local potato cultivars, however with only a limited number of these kinds being commonly consumed outside of the Andean vicinity [18]. Within this variety are native potatoes that have a unique shape, smell, texture and flavor, and are a crop that adapts to different types of climate and has resistance to adverse climatic factors such as frost and drought. For this reason, the Incas cultivated them throughout the Andean region and improved them [19]. Native potatoes (Solanum tuberosum spp. andigena) The pigments found in these plants are diverse and are cultivated in the elevated Andean areas of Peru. These plants are distinguished by their composition of bioactive chemicals, which exhibit preventive properties against a range of degenerative disorders [20]. In the Apurímac region, producers are using increased returns to scale (1.27), that is, an increase of 27% according to the elasticity of production in a single year, which means that if production factors production such as seeds, wages and tractors would double, native potato production would more than double [21]. Figure 1 shows the traditional way of harvesting native potatoes by hand in the Apurímac region.

**Figure 1:** Hand harvesting of native potatoes, Apurímac- Perú.

In the Apurímac region, potato cultivation is one of the main agricultural resources that supplies other regions in Peru, including the capital of Lima, however, it is necessary to maintain adequate standards that allow better control over the crops. of potatoes, this is because the weather can vary from one moment to the next and can cause losses in the harvest. Currently, this concern is greater in the face of the coastal Niño phenomenon, where the climate has become unstable throughout the agricultural sector, causing greater concern in potato crops, because only one potato crop can be harvested per year, (it cannot be compared with other products such as blueberries, which can produce up to eight harvests per year). The objective of this research is to build a low-cost technological solution based on IoT to teach science through applied research, developing a prototype that allows evaluating humidity and temperature control to improve agricultural productivity in the Abancay region, Perú.

## 2. Methodology

Because it represents a set of procedures organized sequentially to verify certain assumptions, the study carried out has a quantitative approach. The order is rigorous, but we can redefine some stages; each phase precedes the next [22], pre-experimental type, since they have the lowest control of variables and do not assign subjects to the experiment randomly. In this type of experiment, the researcher has no control over the extraneous or intervening variables, there is no random assignment nor is there a control group [23].

Based on the preliminary investigation, the scope was defined and the guidelines of the proposed project were determined, a detailed plan was prepared and the theoretical framework was developed, identifying the necessary components, and then in the experimental part, measuring the quality of the soil and the water, the prototype for implementing the solution was designed, then the physical construction of the system was carried out with the use of Arduino and the sensors selected for the proposal (measuring pH, humidity and turbidity), the appropriate interconnection was made. between components, ensuring that sensors accurately and reliably capture the required data. Likewise, the code necessary for the operation of the system was developed. Subsequently, a database was established in a cloud service to store the collected data and monitor it from anywhere and at any time. The resulting data were validated with the average data and the theoretical optimal data for proper cultivation. of the native potato plantation. In the end, the results obtained were compared with other investigations and subsequently concluded based on their experience and results.

## 3. Result.

Table 1 describes the activities developed in the formative research process during an academic semester for science teaching.

**Table 1.**
**Training activities in science teaching**

| Activity | Description | Weeks |
|---|---|---|
| Study topic and problem Identification | Review of the literature on a topic of your preference and identification of a real problem. | 2 |
| Problem Statement | Elaboration of the context of the problem, statement of the general and specific research problem | 1 |
| Project objectives | Determination of research objectives. | 1 |
| Justification and scope | Social, technological, and economic justification, others if applicable depending on the study. Scoping | 1 |
| Theoretical framework | Development of the theoretical framework necessary to identify the components and the technology necessary to use to develop the solution proposal, development of the necessary construct. | 2 |
| Methodology | Identification of the type and design of the research, as well as the population and sample of the study. | 1 |
| Experimental application | Development of the solution and application of instruments (registration sheet). | 4 |
| Results | Analysis of the data obtained and validation with the proposed objectives. | 2 |
| Conclusions | Preparation of conclusions that respond to the proposed objectives. | 1 |
| Final report | Preparation and delivery of the final report. | 1 |

The activities developed according to what is indicated in the previous table are described below.

### 3.1. Study topic and Problem identification

The first element developed consists of the research topic that the students know or can develop in it, the participants identified their strengths and weaknesses to develop in a field of application, they adequately identified the topic, as well as the theoretical or technical knowledge of the tools. with which they could develop within this field of the topic of study, so for example, in the present proposed work, the group of students opted for a topic related to IoT, to develop and deepen research and knowledge, this was viable because the participants They confirmed that they know or identify some concepts and tools that may be required within this field.

### 3.2. Problem Statement

Regarding the problem statement, the participants identified a real problem that can be treated and investigated to make a proposal or possible solution viable. Within this point to be discussed, the participants searched for studies related to the problem to be proposed (state of the art), the which allowed them to know more precisely about the identified problem and, in the same way, the possible alternative solutions. They supported the problem to be studied and formulated the main objective of the study, as well as a minimum of two secondary problems that derived from this main problem. The teacher was a knowledgeable and effective manager of the proposal presented by the students, who received support and feedback from the teacher during this activity.

### 3.3. Project objectives

Once the main problem and the specific problems were defined, the students proposed the objectives that could be answered with the work carried out. They were aware at all times that the activity developed should have responded to their approach, so that in this way, by answering the objectives they could Identify if these influence the solution of the proposed problem. Regarding this activity, they were guided regarding its formulation, identifying some main aspects such as the use at the beginning of the verb in the infinitive and the application of common taxonomies of verbs for the development of research, such as Bloom's revised taxonomy, levels and verbs, or Bloom's Digital taxonomy that seeks to address new actions or objectives of current practices where ICTs are used [24], Figure 2 shows Bloom's digital taxonomy. Depending on the problem posed, the objectives to be developed and the orientation they may have will depend on the digital context, if applicable.

| **Higher Order Thinking Skills** | **Digital environment verbs** | **Activities** |
|---|---|---|
| Create | Film, program, blog, animate, video, mix, blog, participate in a wiki, publish, direct, videocast, broadcast. | Collaborate<br>Moderate<br>Negotiate<br>Debate<br>Comment<br>Meet online Hold video conferences via Skype<br>Review<br>Ask<br>Answer<br>Publish and blog<br>Participate in networks<br>Contribute<br>Chat<br>Communicate by email<br>Communicate by Twitter/Microblogs<br>Instant messaging |
| Assess | Review, comment on a blog, publish, collaborate, moderate, rework, participate in networks (networking), test. | |
| Analyze | Link, recombine, reverse engineer, validate, crack, media information, collect. | |
| Apply | Load, run, play, hack, operate, share, upload files to a server, edit. | |
| Grasp | Do Boolean searches, do advanced searches, use Twitter, do journalism in blog format, categorize, tag, annotate, comment, subscribe. | |
| Remember | Highlight, use bullets, bookmark, bookmark sites, search, participate in the social network, do Google searches. | |
| **Lower Level Thinking Skills** | | |

**Figure 2:** Bloom's Digital Taxonomy [24].

### 3.4. Justification and scope

The justification of the proposal to be developed was always supported by the group that carried out the research. They had to indicate why they wanted to carry out the research and under what contexts it could be identified. The most common justifications by which they can be guided are related to the social context (where they obtained the problem), the technological (on the need for the technology with which the possible evaluation or solution to the problem presented is carried out), and the economic (where they will allow the savings value to be identified with the study to be carried out). The scope of the research was made up of the delimitation of the study, where the limitations of attention to the problem presented, as well as the proposal or solution developed, were identified.

### 3.5. Theoretical framework of the activity to be developed.

Regarding the theoretical framework within the present proposal, this allowed us to mainly identify the necessary elements to be used in the experimental part, as well as schemes or constructs that were needed to understand the proposed research. The following is a basic example of the elements that can be identify for a better understanding of the activity carried out.

Arduino UNO: A board to start with programming and electronics is the Arduino UNO. The Arduino UNO is the most reliable, widely used version with the greatest amount of documentation that the Arduino family can provide [25]. Figure 3 shows the Arduino board to use.

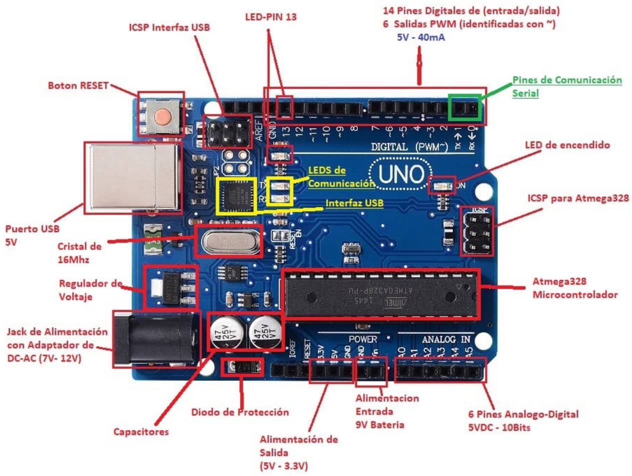


**Figure 3:** Arduino UNO board with its inputs and outputs.

pH Sensor (PH-7BNC): This probe sensor easily measures the pH of a liquid through its controller board, which provides an analog value proportional to the measurement. The controller has a potentiometer that helps the probe calibrate correctly.

Humidity Sensor (fc28): The sensor monitors the humidity level of plants and remembers when to water them, or even to create a fully automated irrigation system by adding a valve or water pump.

Turbidity Sensor (ST100): The sensor is optimized to measure air temperature. Reflective thermal shrinkage reduces solar loading on the cable behind the thermistor. Wire transition is used to minimize thermal conduction to the sensor tip. It can be installed outdoors and can withstand various climates.

NodeMCU V3: is a Wifi board that is compatible with Arduino for use in various IoT projects. It is mounted on the ESP8266, and offers an integrated voltage regulator, and has USB programming.

In Figure 4 you can see the components described above.


**Figure 4:** pH, humidity, turbidity, and Wi-Fi sensor.

As could be seen, the theoretical framework is not necessarily extensive for this formative stage of the students, it can be completed with more information, but the objective is to focus the theoretical framework on the essential components for the application of the experimental part.

*Methodology of the activity to be developed.*

The methodology proposed in this basic stage consisted of identifying the type, level and design of research, taking as a source referential information or standardized bibliography of the best-known authors. Within the identification at this stage, students understood the meaning of basic research or applied, in the same way they identified which were the levels associated with their research (exploratory, descriptive, correlational or explanatory), finally they understood if the research design in this initial stage corresponds to transversal (a photograph of reality to carry out the study , without modifying the existing reality), quasi-experimental (where two identical study groups participate, one of control without experiment and another group to which the experiment is applied), and finally if it is of pre-experimental type, differentiating it from the type experimental because the intervening or environmental variables were not considered in the study.

### 3.6. Experimental application of the activity to be developed.

Once the necessary components were identified, it was always ideal to develop a previous and simulated prototype in software that allows checking the operation of the real development to be implemented. There are various applications that facilitate the previous installation work before proceeding with the physical devices, one of them ideal for Arduino. was TinkerCad, an online website that allows you to simulate the prototype to be developed, another could be Proteus, among others, the good thing about using the Arduino UNO board is that because it is the most basic or common board, you could find various applications to use. Figure 5 shows the development of the computer prototype with the elements described above.

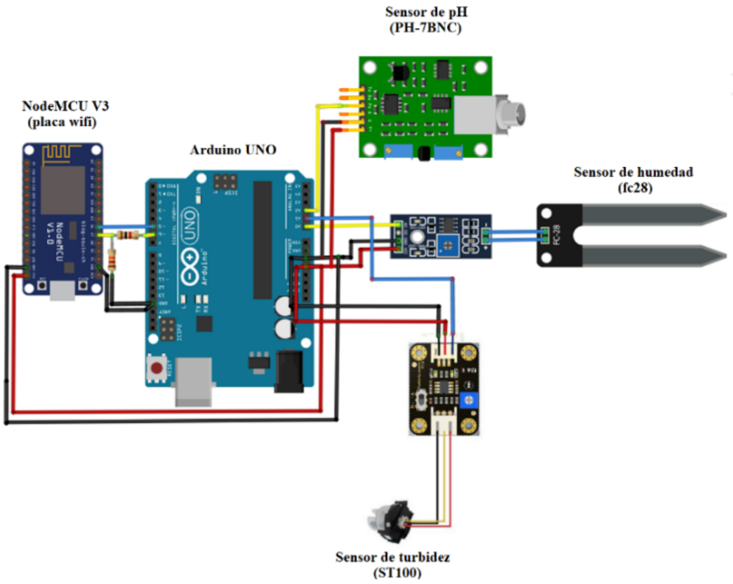


**Figure 5:** Circuit prototype

Subsequently, once it was verified that the pins are connected correctly and that all the components have been validated in a simulation process for their operation, the circuit was implemented with the acquired components. Figure 6 shows the implementation with real components for the experimental application.

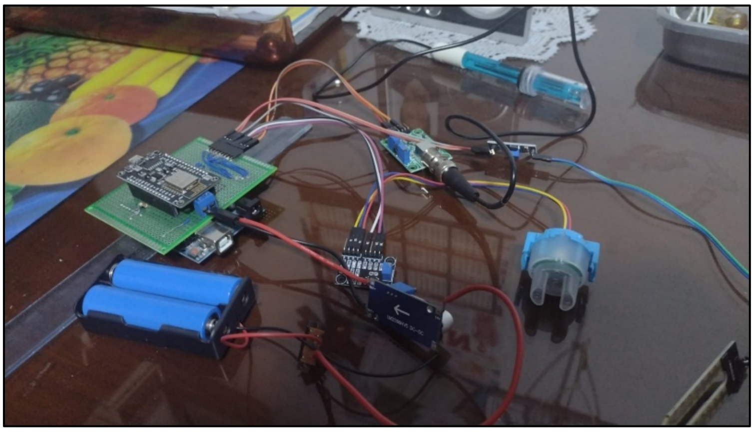

**Figure 6:** Circuit implementation.

Once the circuit has been implemented and the Arduino board has been programmed, it must be tested to check its operation. Then, once the physical circuit has been implemented, the connectivity between the circuit's Wi-Fi and the free cloud server that was obtained for this prototype was also configured. During the investigation, the circuit must measure humidity, pH and turbidity in short time intervals to send the information to cloud services so that it can be read through an application.

### 3.7. Results of the activity to be developed.

The activity developed was carried out by checking the operation of the circuit, validating specific points through pots that contained the plants and in the same way, with other similar plants for comparison and confirmation, allowing the values proposed for the application to be measured in this way. . Figure 7 shows the packaging of the prototype and the execution of the project through pots with plants for this purpose.

**Figure 7:** System packaging and implementation for measurement.

Similarly, Figure 8 shows data collected from the measurement of humidity, turbidity, and the associated soil pH.

| id | valor_hume | valor_turbid | valor_ph | fecha_actual |
|---|---|---|---|---|
| 219 | 621 | 15 | 6 | 04/06/2023 23:14 |
| 220 | 621 | 15 | 6 | 04/06/2023 23:15 |
| 221 | 633 | 19 | 6 | 04/06/2023 23:16 |
| 222 | 633 | 19 | 6 | 04/06/2023 23:17 |
| 223 | 633 | 19 | 6 | 04/06/2023 23:18 |
| 224 | 592 | 18 | 6 | 04/06/2023 23:19 |
| 225 | 551 | 16 | 6 | 04/06/2023 23:21 |
| 226 | 551 | 16 | 6 | 04/06/2023 23:22 |
| 227 | 531 | 18 | 6 | 04/06/2023 23:23 |
| 228 | 531 | 18 | 6 | 04/06/2023 23:24 |
| 229 | 531 | 18 | 6 | 04/06/2023 23:25 |
| 230 | 531 | 18 | 6 | 04/06/2023 23:26 |
| 231 | 531 | 18 | 6 | 04/06/2023 23:28 |
| 232 | 531 | 18 | 6 | 04/06/2023 23:29 |
| 233 | 531 | 18 | 6 | 04/06/2023 23:30 |
| 234 | 531 | 18 | 6 | 04/06/2023 23:31 |
| 235 | 531 | 18 | 6 | 04/06/2023 23:32 |
| 236 | 479 | 18 | 6 | 04/06/2023 23:33 |
| 237 | 479 | 18 | 6 | 04/06/2023 23:34 |

| id | valor_hume | valor_turbid | valor_ph | fecha_actual |
|---|---|---|---|---|
| 238 | 479 | 18 | 6 | 04/06/2023 23:35 |
| 239 | 472 | 19 | 6 | 04/06/2023 23:36 |
| 240 | 472 | 19 | 6 | 04/06/2023 23:37 |
| 241 | 467 | 15 | 6 | 04/06/2023 23:38 |
| 242 | 467 | 15 | 6 | 04/06/2023 23:39 |
| 243 | 467 | 15 | 6 | 04/06/2023 23:40 |
| 244 | 460 | 16 | 6 | 04/06/2023 23:41 |
| 245 | 460 | 16 | 6 | 04/06/2023 23:42 |
| 246 | 456 | 16 | 6 | 04/06/2023 23:43 |
| 247 | 456 | 16 | 6 | 04/06/2023 23:44 |
| 248 | 453 | 15 | 6 | 04/06/2023 23:45 |
| 249 | 453 | 15 | 6 | 04/06/2023 23:46 |
| 250 | 451 | 16 | 6 | 04/06/2023 23:47 |
| 251 | 451 | 16 | 6 | 04/06/2023 23:50 |
| 252 | 451 | 16 | 6 | 04/06/2023 23:51 |
| 253 | 444 | 14 | 6 | 04/06/2023 23:52 |
| 254 | 444 | 14 | 6 | 04/06/2023 23:53 |
| 255 | 441 | 14 | 6 | 04/06/2023 23:54 |
| 256 | 441 | 14 | 6 | 04/06/2023 23:55 |

**Figure 8:** Reading data in real time.

The data was stored in the cloud so that it could be viewed and downloaded through a csv file. In this way, it was possible to monitor in real time how the potato crops are in order to later carry out better control over the harvest and production. Likewise, they could be compared with the average or ideal values of native potato cultivation in the region.

The conclusions of the work were drawn from the experience carried out in comparison with the objectives set in the initial stage.

### 3.8. Final report of the activity to be developed.

For the preparation of the final report, which was developed in the last week of the academic semester, the activities previously developed were collected, as well as the preparation of the metadata among others, according to the structure described in table 2, the information could be identified. necessary between what has already been developed in the previous activities and the new information required to be built in this final stage.

**Table 2.**
**Outline of the final report.**

| Report structure | Content |
|---|---|
| Qualification | Describe the final title of the work in less than **20 words.** |
| Summary | They prepare a structured summary of no more than 250 words and must include the **objectives**, the **methodology** developed, the **results** found and the **conclusions**. |
| Keywords | Determine the words that represent the work done, maximum **5 words or expressions.** |
| Introduction | It will include the activities previously developed:<br>- **Study topic and Problem identification.**<br>- **Problem Statement.** |
| Goals | It will include the activities previously developed:<br>- **Project objectives.** |
| Justification and scope | It will include the activities previously developed:<br>- **Justification and scope.** |
| Theoretical framework | It will include the activities previously developed:<br>- **Theoretical framework.** |
| Results | It will include the activities previously developed:<br>- **Experimental application.**<br>- **Results.** |
| Conclusions | It will include the activities previously developed: |

| | |
|---|---|
| | - **Conclusions.** |
| References | They add all **references** used in the project. |
| Annexes | They add relevant information, tables, images, procedures, development or others, that are part of the project carried out and that complement the report presented. |

With this, the students were able to understand science teaching through formative research by seeing how an investigation was developed by developing all the processes indicated in the outline of the final report.

## 4. Discussion

Murugan [26], In his work carried out, the author suggests the implementation of a smart measurement system, referred to as TMHG, for the purpose of quantifying diverse agricultural characteristics including soil moisture, temperature, humidity, and gas levels. The measured values are presented on a liquid crystal display (LCD). Upon the detection of soil moisture and humidity levels, the pump will activate or deactivate in accordance with the observed values. The motor pump is controlled by the Arduino module through the utilization of an integrated C application. Under typical circumstances, the pumps are deactivated. However, when the soil moisture levels fall below specific threshold values, the pump is activated. This functionality has been programmed within the Arduino module. The Arduino interface is responsible for regulating the functioning of the pumps, which are utilized for ongoing irrigation of the fields until the humidity levels above the predetermined upper threshold value, which is a work consistent with the developed proposal that focuses on providing a monitoring solution for optimal cultivation while maintaining controlling soil moisture and working with low-cost solutions.

Devira [27], in their work indicates that the sensors installed in the system can function optimally and can send data values of sensor readings in real time to the Thingspeak cloud server, so that users can monitor remotely through the application/web. To obtain more accurate and precise measurement results, he recommended using a better-quality soil moisture sensor than the YL-69, namely the VH400 sensor. However, for general use, such as implementing a smart agriculture system in a residential garden, it is recommended to use the YL-69 soil moisture sensor as it is more than sufficient, which is a relevant activity to evaluate the necessary capabilities of the sensors installed to improve data collection in real time, similarly, in this work the most suitable sensor for field data collection was evaluated.

Finally, Cui [28] presents an agricultural greenhouse intelligence control system, The system, which is capable of monitoring, presenting, and regulating the greenhouse environment in real-time, utilizes the Arduino UNO R3 microcontroller as its foundation. It incorporates many components such the DHT11 temperature and humidity sensor, GY-30 light sensor, relay, and LCD screen. The system is capable of gathering, presenting, and regulating the current measurements of temperature, humidity, and light intensity within the greenhouse environment, which is a similar application for the control of agricultural factors, in a similar way to the present proposal developed.

## 5. Conclusions

For all the above, it is concluded that through a project developed in IoT to monitor the pH of the soil, the humidity, and the turbidity of the water, where native potato crops are grown in the Apurímac region, it is possible to teach science through the scientific method, developing the activities of identifying the topic of study, problem statement, objectives, justification, theoretical framework, methodology, experimental application, results and conclusions.

It is also concluded that it is necessary to adequately identify each stage of the process so that the student can learn science by constructing knowledge, evaluating at all times the described stages of the scientific method process and respecting the times assigned by week for the activities to be developed.

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