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Teaching scientific inquiry to develop critical thinking skills

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***Abstract* – This study proposes a scientific inquiry activity as a teaching strategy to develop critical thinking skills among 24 biology students from the Faculty of Chemical Engineering at a university in Cartagena, Colombia. The activity begins with a problem-based scenario designed to encourage investigation and is guided by a driving question. During the scientific inquiry activity, students formulate explanations and design experiments to test their hypotheses. The results are then discussed and debated within working groups. To further enhance the development of critical thinking skills, students complete a project, the findings of which are presented in a document following the criteria of a scientific article.**

***Keywords*-- Scientific inquiry, critical thinking skills, teaching strategy**

I. INTRODUCTION

In 21st century education the emphasis has shifted from simply learning content to the comprehensive development of advanced cognitive skills, with critical thinking being one of the most important[1, 2]. This underscores the importance of integrating educational experiences from preschool through higher education that promote scientific inquiry as a foundation for the development of critical thinking. Critical thinking is considered an essential cognitive competence and plays a central role in academic and professional training. Its development allows not only to address complex problems with well-founded solutions but also to adapt to changing and multidisciplinary contexts. The ability to critically evaluate and relate information is essential in a world where massive access to information does not ensure an adequate understanding of reality. Therefore, the inclusion of educational strategies that integrate scientific inquiry as a tool for developing these skills represents a fundamental part of contemporary pedagogical processes. Such an approach not only optimizes the quality of learning but also prepares students to play active roles in a society that requires informed and ethically responsible decisions[3, 4].

Critical thinking is the ability to logically and thoughtfully analyze, evaluate, and synthesize information to make informed decisions and solve problems effectively. This process involves several important intellectual skills, such as interpretation, analysis, evaluation, inference, explanation and self-regulation, which enable the individual to not only process information in a structured manner but also to apply reasoned judgment to reach valid conclusions. It is a cornerstone of intellectual growth. In today's rapidly evolving world, where individuals are faced with a wealth of information and complex problems, critical thinking is not only a desirable skill but a necessity. It enables individuals to make informed decisions, solve complex challenges, and navigate uncertainty with confidence and precision[5].

The development of critical thinking skills in an educational context means to promote the ability of the students, to think critically, analytically and creatively and at the same time approach the content[6-8]. In the event of learning a natural science such as biology, physics or chemistry, this means that the students not only learn facts by heart but are also able to 1. identify patterns, make precise observations and analyze information. 2. Be curious and ask relevant questions that lead your investigation and understanding. 3. Use available information to create well - founded assumptions, build up causal relationships and derive possible solutions for problems. 4. Apply concepts and methods to find solutions in new or complex situations, not only in typical classroom situations, but also in real scenarios. 5. Be able to assess the quality of information, evidence and arguments, think about your own thinking processes and improve based on feedback[9, 10]. In the natural sciences, these skills are developed when the students carry out experiments, analyze data, make predictions and compare scientific theories. This not only helps you to understand the topics but also enables you to develop a stricter and more structured way of thinking. A strategy to promote the development of critical thinking skills in scientific learning is to teach through scientific studies[11, 12].

The active participation of students in their own learning process is essential for the development of critical thinking, and teaching scientific inquiry is presented in this context as a key strategy. This approach promotes the development of a thinking system for students, encourages them to ask questions, to discuss and argue ideas, to formulate hypotheses, to propose experimental designs and to search for certain problems. In this way, learning becomes an intellectual exercise that not only prefers the acquisition of knowledge, but also the critical and reflective ability of the students.

In this sense, teaching scientific inquiry was consolidated as a promising framework for the promotion of critical thinking skills in educational contexts. Based on principles such as questioning, evaluation of evidence and systematic research, this strategy includes the students in active learning processes that go beyond the simple passive absorption of information. By formulating hypotheses, the implementation of research and draw conclusions based on empirical data, the scientific inquiry not only develops critical thinking, but also offers the students cognitive tools to apply their learning in real situations[13-15].

Inquiry-based science learning should be based on activities that represent the characteristics of scientific practice. This method requires following clear and systematic procedures that enable the acquisition of rational and verifiable knowledge about nature. In this context, inquiry-based science teaching is essential for understanding scientific concepts and developing critical thinking skill[16, 17].

One of the most effective strategies for teaching through inquiry is the presentation of a meaningful and motivating problem situation[18, 19]. This situation is supported by a driving question that leads the students through different phases of the examination process, such as observation, information collection, hypothesis formulation, prediction and experiment[20]. The students then analyze the results obtained, draw conclusions and communicate their results. This approach not only makes it easier for active learning but also promotes a deep and critical understanding of the scientific concepts. The driving question plays a crucial role in this process because it must be important for the students, which is suitable and solvable for learning scientific concepts. This implies that students must critically identify and utilize pertinent information or relevant data to facilitate problem-solving effectively. In this context, the driving question serves not only as a catalyst for the analytical process but also as a mechanism to ensure that students engage in meaningful learning aligned with authentic scientific practices.

This article analyzes how scientific inquiry can become an effective approach to promoting the development of critical thinking skills in higher education. Its main objective is to propose a teaching strategy based on scientific inquiry and intended to promote the analysis, synthesis and critical evaluation of information. This strategy aims to introduce students to scientific thinking by encouraging them to ask questions, form hypotheses, conduct experiments, and draw conclusions based on evidence. This strengthens their ability to approach problems in a reflective and methodical way.

II. Materials And Methods

This study adopts a qualitative approach with the aim of examining the interaction dynamics of 24 biology students from the Faculty of Chemical Engineering at a university in Cartagena, Colombia, with the teaching strategy focused on scientific inquiry. It also analyzed how this strategy promotes the development of critical thinking skills in students. The research is based on the theoretical contextualization of scientific research as well as on the results obtained through the implementation of specific activities designed for this purpose.

A. Scientific inquiry activities

Scientific inquiry activities are practices or processes employed in the scientific field to investigate phenomena, conduct experiments, and acquire knowledge through systematic observation, questioning, data collection, hypothesis development, experimentation, and result interpretation[21]. These activities play a crucial role in fostering critical thinking skills among students while enhancing their understanding of the scientific method. Common activities within the scientific inquiry process include observation, question formulation, hypothesis development, experimentation, data analysis, result interpretation, and evaluating whether the hypothesis is supported or requires revision. The following scientific inquiry activities were designed in this work:

Activity I. Problem statement. Students are presented with a problem based on a driving question, designed to assess their prior knowledge and the way they conceptualize the phenomenon under investigation. This approach encourages students to draw on their existing understanding while also challenging them to engage in critical thinking and problem-solving. By addressing the driving question, students are guided to develop a deeper understanding of the topic, formulate hypotheses, and design experiments or investigations to explore the phenomenon in greater detail. Additionally, this process fosters an inquiry-based learning environment, where students actively participate in their own learning and refine their scientific reasoning skills through hands-on experiences. Driving question: Where do the worms that occur in ripe fruits come from?

Activity II. Hypothesis formulation. The students propose in writing a possible hypothesis to answer the question. Students explain their answers, which may be correct or incorrect. This process promotes critical thinking by allowing students to reflect on their thought processes and consider alternative explanations

Activity III. Experimental design. Students with similar hypotheses are grouped together to design an experiment to test their hypothesis. The group identifies the variables, describes and documents the process for measuring, managing and controlling these variables. In addition, they present and defend their hypotheses orally to the group, suggesting possible outcomes and drawing tentative conclusions.

Activity IV. Experimentation. The experiences previously planned in the experimental design are carried out, collected data and the observations made are carefully recorded. These observations could include any unexpected occurrences, patterns in the data, or anomalies that arise during the experiments. The importance of accurately recording data and observations cannot be overstated, as this information serves as the foundation for later analysis and interpretation.

Activity V. Analysis of results. The data or experimental observations are analyzed and processed to evaluate the validity of the proposed hypotheses. Through scientific inquiry, the goal is to determine whether the results or observations confirm or refute the hypothesis.

Conclusion. The conclusions are derived from the interpretation of the results in accordance with the theoretical model that supports the answer to the driving question and requires a critical examination of both expected and unexpected outcomes, encouraging students to reflect on the implications of their findings

Publication of results. To share the findings of the research, the students presented the following outputs: a written document adhering to the criteria of a scientific article and a poster presenting the experience, that was exhibited during the institution's Science Fair Week This exercise not only reinforced their understanding of the scientific process but also helped them develop essential academic writing skills, including how to effectively communicate complex ideas in a clear, concise, and logical manner.

III. RESULTS

Based on the answers to the driving question: Where do the worms that occur in ripe fruits come from? proposed in the problem statement of activity I, students formulated the following hypotheses in activity II:

a. The worm arises from the decomposition of the fruit

Student: fruits and food decompose over time and then suddenly, at the moment of decomposition, the worm appears.
Student: I know from a hypothesis I read that we are made of matter and when something decays it is obvious that matter is constructed and I think that everything has its origin, that everything has its law... That's why I believe that the worm arises from the decomposition of the fruit.

Student: I don't think the worm comes from outside. My hypothesis is that the fruit already has or is developing the worm, and as the fruit grows, it develops, it ripens, and the worm that was normally present develops.

b. The worm comes from an insect, such as a fly.

Student: It's a fly that lands on the fruit and lays its eggs there. This egg ripens in the fruit and feeds on it.

Student: Some insects such as fruit flies lay their eggs in ripe fruits, from there larvae or worms emerge, which produce flies through metamorphosis.

Student: The worms come from the Drosophila fly, which lays its eggs in the ripe fruit, creating worms that later become flies.

c. The worm comes from microorganisms such as viruses or bacteria.

Student: If the fruit is left outside, an animal will deposit bacteria there. It could be any animal that leaves the bacteria there. It develops and then the worm comes out.

Student: Some fly carries a virus or something, I don't know, and it can deposit it on the fruit

Student: Fruits always tend to decompose... it's like when a person dies, when everything decays, worms always come, this rot is what attracts the worm-producing bacteria in the fruits.

Table 1 shows that the students' hypotheses, based on their previous knowledge, are based on three explanations: a) spontaneous formation b) from the fly c) from microorganisms

TABLE I
STUDENT ANSWERS TO THE DRIVING QUESTION: WHERE DO THE WORMS THAT OCCUR IN RIPE FRUITS COME FROM?

Origin of the worm	Number of answers
Fruit decay (spontaneous generation)	13 (54%)
Fly / insect	7 (29%)
Microorganisms (Viruses / Bacteria)	4 (17%)
Total number of students	24 (100%)

These hypotheses show that a group of students has misconceptions about some scientific concepts that relate to concrete realities of everyday life that the student thinks he knows, but he has internalized a misconception about them. However, interpretation, a structuring element of critical thinking, is already evident in the students' answers, as they can identify the problem and describe their beliefs to give possible explanations for the phenomenon addressed, even if these may be incorrect.

Based on the hypotheses formulated above, the student groups in Activity III proposed the following experimental designs:

Group 1: Two fruits are selected that are neither too ripe nor too green, along with two containers: a closed one that prevents insects from entering and an open one that allows them to enter. The fruits are exposed to the elements for a period of 10 to 15 days, with daily observations made to detect changes in fruit color and possible signs of decay. After this time, the fruits are removed from the open container. If there are a significant number of worms, this indicates that insects have laid their eggs there. However, if the fruit in the closed container has worms, you can assume that they come from the fruit itself. To ensure that the selected fruit does not contain eggs that have already been laid, one that does not have any visible holes or dents is selected.

Group 2: Only a sealed jar with a fruit in it is used, which is left to rest for a period of 15 days. The heat causes the fruits to decompose. After this time, the fruit is removed and cut to determine whether it contains worms. If no worms are found, the decomposition of the fruit is used for a new observation. The decomposed fruits are placed on a plate outside to check whether insects, such as flies, land on them. Before the fruits are placed in the closed jar, they are cut to ensure that they do not contain any worms or residues that may have arisen from their presence.

Group 3: We believe that the experimental designs proposed by Groups 1 and 2 are not the most appropriate. Instead, we propose an alternative approach that begins with selecting a tree that will produce fruit from the beginning of its cycle when it is still flowering. Throughout the entire process, the different phases of fruit development are closely monitored. Then, without removing it from the tree, the fruit is isolated using a plastic bag while another fruit is picked from the same tree and exposed to the elements. This approach allows us to determine whether the presence of maggots is due to the decomposition of the fruit or whether it is the result of a fly that has laid its eggs on the uncovered fruit.

Group 4: Another option would be to select a fruit in good condition without bruising and store it in the refrigerator to prevent spoilage. This approach could determine whether the appearance of worms is due to the natural decomposition of the fruit or whether it is due to the presence of bacteria that may be present in the refrigerator environment.

Group 5: Our group assumes that the worms found in the fruits come directly from the tree as part of their metamorphosis process. In this sense, it is not necessary to place the fruits in a container since the worms emerge from the tree itself. Therefore, our design is to observe the fruits directly on the tree during a certain period to show how the worms emerge in their natural environment.

Group 6: We assume that fruits do not necessarily need to be stored in a container as microorganisms develop due to moisture and sunlight. The moisture generated in the natural environment contributes to the growth of these microorganisms, which favors the appearance of worms in them. Therefore, our experimental setup is to select a fruit tree exposed to natural environmental conditions, i.e. h. one that receives both rain and sunlight during the day. We select several ripe fruits that are in good condition and without bruises or visible damage to prevent external factors such as bumps or wounds from affecting the decomposition process. Over a period of 10 to 15 days, we carry out daily observations of the fruit and record any changes, such as: Such as the appearance of dampness, wrinkles, changes in texture or color, as well as the presence of worms both inside and on the surface of the fruit.

In the experimental designs proposed by the students, various aspects were identified that revealed difficulties in the learning process and in the development of scientific skills. First, students tend to incorporate misconceptions into their designs due to a limited or incorrect understanding of the scientific concepts involved. Second, they often resort to everyday language to explain scientific phenomena. This practice not only makes conceptual precision difficult but also contributes to the formation of misconceptions and inappropriate stereotypes about the nature of science. Furthermore, there is a lack of knowledge about the management of variables and their control, which affects the validity of the designs proposed to test their hypotheses. Despite these limitations, students strive to organize, communicate, and justify the results of their reasoning to others. This behavior suggests the presence of explanatory elements, an essential critical thinking skill. Although these measures are not sufficient to formulate appropriate scientific designs, they provide a starting point for developing more advanced reasoning and scientific inquiry skills.

The experimental designs formulated by the students were the subject of a joint discussion between the teacher and the groups involved. These discussions particularly focused on aspects related to the control of variables, a key competency to ensure the validity of the experiments and the interpretation of the results. During this process, a critical analysis of the proposed strategies was encouraged, which made it possible to identify limitations in the original designs, such as the proper management of dependent and independent variables and the lack of clear strategies for their control.

The teacher assumed a facilitating role and provided guidance to students in identifying the relevant variables and causal relationships underlying the experimental design. This instructional support was essential in helping students understand the need to minimize the effects of external factors and ensure that the observed results were directly attributable to the proposed hypotheses. This collaborative process not only strengthened students' critical thinking skills but also promoted meaningful learning by bridging theory and practice. In addition, the consensus supported the acquisition of scientific and methodological concepts and demonstrated the positive influence of reflective interaction between teachers and students on the development of scientific skills

Through interaction between teachers and students, a consensus space emerged where common criteria were established to structure a more relevant experimental design to answer the guiding question.

The aim of the experiment (activity IV) in was to investigate the influence of fruit flies on the emergence and development of larvae in ripe fruits. To investigate this connection, two identical glass jars were made, each containing a ripe fruit that had been heat-sterilized to eliminate pre-existing microorganisms. Both containers were covered with gauze to allow air circulation while preventing external contamination.

Ten fruit flies were introduced into the jar called the experimental group, which constituted the independent variable of the study. The second jar, which remained free of fruit flies, served as a control group to establish baseline conditions for comparison. Both jars were placed in a cool, well-ventilated environment to ensure consistency of external factors and minimize variability in the experimental setup.

The experiment lasted about 20 days, during which systematic observations were carried out, including monitoring the presence and development of larvae, changes in fruit appearance and other relevant phenomena

In didactic terms, this dynamic represents a practical example of inquiry-based learning, where students' active participation in knowledge construction promotes both the development of critical thinking skill and a deep understanding of the principles underlying experimentation in academia.

IV. Discussion

The experimental results presented by the students demonstrate the ability to think critically. The observations and conclusions of the students from the experiments carried out are presented and analyzed below:

Student: The results of the project showed that the worms came from fruit flies, as they only appeared in the jar with flies, while they were not observed in the jar without flies.

Student: Flies act as precursors to worms (larvae), as worms were only observed in the jar with the flies. Despite the decomposition of the fruit, no worms formed in the glass without flies. This shows that our original hypothesis was wrong.

Student: We performed the experiment in triplicate and worms were observed in all jars containing flies. In contrast, no worms were produced in the three jars without flies. This confirms that our original hypothesis that worms arose from fruit decomposition was incorrect.

Student: This experiment shows once again that there is no such thing as spontaneous generation. Worms are larvae that correspond to a stage in the metamorphosis cycle of insects such as fruit flies. In our experiments, worms only formed in the jars that had flies in them. In the jars without flies, the fruit was also decomposed, but no worms formed. These results support our original hypothesis.

Student. Our results confirm that the origin of the worms observed in the fruits are flies that lay their eggs in them. These worms transform into new flies after going through several stages. In the experiment, worms only appeared in the jars with flies (experimental group), while they were not observed in the jars without flies (control group).

Student: Although the research results did not support our original hypothesis that worms arise from the development of microbes through fruit decomposition, we found that worms formed only in the jars in which flies were present and not in those in which only the fruit contained flies. This project enabled us to understand and apply scientific inquiry activities as we conducted similar work to scientists and learned through practice.

In the scientific inquiry activities designed to answer the driving question: Where do the worms that occur in ripe fruits come from? students demonstrated various critical thinking skills. In terms of *interpretation*, they were able to understand and express the significance of the results by recognizing that worms do not arise spontaneously but are larvae produced from eggs laid by flies. Through the *analysis*, they clearly identified a cause-and-effect relationship in their experience and concluded that the presence of worms was directly related to the presence of flies in the jars. Through *evaluation*, they compared the results obtained with their original hypothesis, determined that it was incorrect, and justified the validity of their new conclusion based on experimental evidence. As for their *conclusions*, they made solid statements from the data, such as that flies are essential to the process of worm formation in ripe fruit. Finally, they exercised *self-regulation* by reflecting on how their previous conceptions, influenced by false beliefs about spontaneous conception, were changed by more informed knowledge, allowing them to make more rational and informed judgments.

To promote learning through scientific inquiry activities and promote the development of critical thinking skills, the above activities can be strengthened by implementing a more complex project that expands and integrates the knowledge acquired in the original project. This new project is based on a driving question that emerged during discussions about the learning outcomes and was formulated independently by the students: What environmental factors can influence fruit fly reproduction?

This driving question is being investigated in working groups in which students propose the inclusion of independent variables such as the amount of light, temperature, air pressure or type of fruit as food for flies. Based on the teaching guidelines discussed and agreed with the teacher, each group creates a first draft, which goes through a joint review process with the teacher to adjust methodological details. Based on the approved drafts, students develop the final project, integrating theoretical and practical knowledge to reinforce the learning of scientific concepts. This teaching approach promotes meaningful and collaborative learning while promoting the development of critical thinking and the ability to conduct structured scientific inquiry.

V. CONCLUSIONS

Critical thinking skills cannot be taught in the abstract but require activities that involve students in the practical exercise of this thinking. In this context, scientific inquiry activities are effective educational tools for promoting the development of critical thinking skills because they involve solving complex problems that challenge students to evaluate information, formulate hypotheses, analyze data, and formulate solid arguments. In addition to explaining evidence and conceptual and methodological considerations, these activities also integrate processes such as interpretation, analysis, evaluation and inference, thereby promoting a deeper and more structured understanding of scientific phenomena.

The use of scientific inquiry in science education not only develops critical skills but also contributes to students' self-regulation and awareness of their own cognitive processes[22]. This strategy promotes intellectual independence and encourages students to take an active role in learning. In addition, the collaborative nature of many research activities strengthens teamwork skills and helps students develop social skills that are essential for academic and professional life. This process makes learning a dynamic and motivating experience in which students actively participate in building their knowledge.

In a university context, the use of scientific inquiry not only strengthens critical thinking but also promotes a comprehensive education aimed at solving real and complex problems. This approach makes the student the protagonist of their learning and prepares them to overcome intellectual and professional challenges using scientific strategies and critical thinking. In this way, scientific research is established as a teaching strategy to improve the learning of scientific concepts. Additionally, this process encourages students to engage with contemporary issues, fostering their ability to apply theoretical knowledge to practical situations

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