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# Robotic ecology from the coast: results of a science skills strengthening program

Ecología robótica desde el litoral: resultados de un programa fortalecedor de las habilidades para la ciencia

来自海岸的机器人生态学：科学技能强化计划的结果

Роботизированная экология с побережья: результаты программы развития научных навыков

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## Abstract

Introduction: Coastal waste increases up to four times each year, although many of them can generate sustainability if they are used as renewable resources; in this sense, the research is based on Garofalo's STEAM proposal, adapting its urban robotic version to the educational exploration of beaches. An experiment of social responsibility was developed through a robotic ecology program based on three pedagogical phases: (a) Social ecological intelligence, (b) Social scientific task, (c) Scientific reflection; whose effects try to contribute to the sustainable care of a polluted beach.

Method: Through the positivist paradigm, experimental design study, two groups of students were formed out of a total of 80 subjects residing in a coastal district of Lima. A contaminated beach context was approached, from which basic school students recycled waste to elaborate robot prototypes.

Results: The data compared in the experiment reported significant indices that support the increase in scientific skills and awareness of the environment, as well as the indicators that care for natural elements and their resources. The robotic ecology program improved the skills of scientific knowledge, observation and reflection.

Conclusions: The improvement of scientific skills increased significantly in the experimental group ($t_{(74)} = -3.831$; $p < .005$), as well as in environmental awareness ($t_{(72)} = -2.720$; $p < .005$). Although the dimensions improved, the differences obtained in knowledge capacity were not significant in the group comparison.

*Keywords:* environmental awareness, scientific skills, school robotics, sustainability.

## Resumen

Introducción: Los desechos del litoral se incrementan hasta cuatro veces cada año, aunque muchos de ellos pueden generar sostenibilidad si se les aprovecha como recursos renovables; en este sentido, la investigación se basa en la propuesta STEAM de Garofalo adaptando su versión robótica citadina a la exploración educativa de playas. Se desarrolló un experimento de responsabilidad social mediante un programa de ecología robótica basado en tres fases pedagógicas: (a) Inteligencia ecológica social; (b) Tarea científica social y; (c) Reflexión científica; cuyos efectos intentan aportar en el cuidado sostenible de una playa contaminada.

Método: A través del paradigma positivista, estudio de diseño experimental, se conformaron dos grupos de estudiantes de un total de 80 sujetos residentes en el distrito costero de Lima. Se abordó un contexto playero contaminado, desde el cual, estudiantes de escolaridad básica realizaron el reciclaje de desechos para elaborar prototipos de robot.

Resultados: Los datos comparados en el experimento reportaron índices significativos que sustentan el incremento de las habilidades científicas y de la conciencia sobre el medio ambiente, así como los indicadores de cuidado de los elementos naturales y sus recursos. El programa de ecología robótica mejoró las habilidades de conocimiento, observación y reflexión científica.

Conclusiones: La mejora de las habilidades científicas se incrementaron de forma significativa en el grupo experimental ($t_{(74)} = -3.831$; $p < .005$), así como en la conciencia ambiental ($t_{(72)} = -2.720$; $p < .005$). Aunque las dimensiones mejoraron, las diferencias obtenidas en la capacidad de conocimiento no fueron significativas en la comparación de grupos.

*Palabras clave:* conciencia ambiental, habilidades científicas, robótica escolar, sostenibilidad.

## Аннотация

Введение: Прибрежный мусор увеличивается в четыре раза каждый год, хотя большая его часть может обеспечить устойчивость, если будет использоваться в качестве возобновляемых ресурсов; в этом смысле исследование основано на предложении Гарофало по STEAM, адаптирующем его городскую роботизированную версию для образовательного исследования пляжей. Эксперимент по социальной ответственности был разработан с помощью роботизированной экологической программы, основанной на трех педагогических этапах: (a) Социальный экологический интеллект; (b) Социальная научная задача и (c) Научное осмысление; последствия которого должны способствовать устойчивому уходу за загрязненным пляжем.

Метод: С помощью экспериментального исследования были сформированы две группы студентов из 80 человек, проживающих в прибрежном районе Лимы. Был использован загрязненный пляж, на котором учащиеся начальной школы перерабатывали отходы для создания прототипов роботов.

Результаты: данные, сопоставленные в ходе эксперимента, показали значительные индикаторы, подтверждающие рост научных навыков и осведомленности об окружающей среде, а также показатели бережного отношения к природным элементам и их ресурсам. Программа роботизированной экологии улучшила научные знания, навыки наблюдения и размышления.

Выводы: Улучшение научных навыков значительно возросло в экспериментальной группе ($t\ (74) = -3.831$; $p < .005$), также как и экологическая осведомленность ($t\ (72) = -2.720$; $p < .005$). Хотя показатели улучшились, различия, полученные в способности к знаниям, не были значительными при сравнении групп.



*Ключевые слова:* экологическая сознательность, научные навыки, школьная робототехника, устойчивое развитие.



## 摘要

引言：沿海废物每年以四倍速度增长，但如果将它们用作可再生资源，其中一大部分可以达到可持续性发展；从这个意义上说，这项研究基于 Garofalo 的 STEAM 提案，将其城市机器人版本应用于海滩的教育探索。通过基于三个教学阶段的机器人生态学计划开发了一项社会责任实验：(a) 社会生态智能；(b) 社会科学任务；(c) 科学反思；其影响力图为污染海滩的可持续保护做出贡献。

研究方法：我们使用实验设计研究，将居住在利马沿海地区的80名学生组成两组受试者。学生从受污染的海滩环境中回收废物用以制作机器人原型。

研究结果：实验中比较的数据提供了支持提高科学技能和环境意识的重要指标，以及对自然元素及其资源的关注指标。机器人生态学计划提高了科学知识、观察和反思的技能。

结论：在实验组科学技能 ($t_{(74)} = -3.831$; $p < .005$) 以及环境意识($t_{(72)} = -2.720$; $p < .005$). 中表现出显着提高。虽然维度有所提高，但在知识容量方面获得的差异在组间比较中并不显着。



**关键词：**环境意识、科学技能、学校机器人、可持续性。

# Introduction

According to Garofalo (2019), evidence of ecological transformation from active recycling in an urban context is reported. In this experience we seek to follow other works that inquire into STEAM work forms, with the production of teaching elements based on educational robotics (Chalmers, 2018; Garofalo & Bacich, 2020; Gentil et al., 2019). This work reports the results of the scientific skills development based on a Robotic Ecology program in the school-society interrelationship. It contributes to the study of the basic skills of observation, inquiry and reflection through the use of creativity, together with the care for the environment. This evidence shows the first results in science and technology learning from an experience-based teaching applied in a Latin American coastal context, which reflect the increase of science skills, the development of social responsibility and ecological care attitudes.

## Robotic ecology for education

The robotic ecology proposal supports the work of educational robotics based on overcoming difficulties in learning science and technology. In the proposal of Garofalo and Bacich (2020), the needs of scientific learning from the development of social-emotional skills through STEAM are found. This is evidenced in other studies that have reflected the development of interrelationships that schematize I-C-R [individual-computer-robot] behavior (Oliveira et al., 2021), as well as work in groups with learning difficulties (Pivetti et al., 2020).

Social learning has been established in educational management to develop various emotional components in students. This has begun to be achieved from gamification, developing from the individual's commitment to master their own ways of learning through autonomous and participatory learning (Donnermann et al., 2021; Lin et al., 2021; Liu et al., 2021). In this regard, robotics has also been intermediary; however, evidence is still unclear regarding human engagement and interaction when teaching processes are exchanged between man and machine based on the structure of robotic models (Donnermann et al., 2021); this is how robotics, as a scientific practice, allows to provide new ways to be still explored in STEM practice (Chalmers, 2018).

Some studies based on the use of simulation algorithms already demonstrate attempts to improve the quality of learning and human-robot interactions (Liu et al., 2021). In the area of language, improvements in orality and vocabulary are already evident with this type of interaction (Lin et al., 2021), and this is also corroborated in collaborative communicative interaction in research-based online education (Schouten et al., 2022).

In the educational area, other proposals have been found with innovative and ludic methodological structures such as Design Thinking, which help to mediate previous knowledge, new knowledge and cognitive feedback (Da Costa et al., 2020; Gentil et al., 2019). Among other proposals, the use of technology-derived inorganic materials has also been used as an opportunity to create more advanced and autonomous robots with more practice hours than theory ones (Bula et al., 2019; Fortunati et al., 2020); although the use of previously presented designs generates better preventive knowledge in the development of robotic models (Fortunati et al., 2020), instead of being developed with neutral or very basic knowledge. Another approach is implemented from R-H [robot-human] pedagogical structures, whereby the conditions of scientific and attitudinal development are mediated by the use of robots beforehand without building them using waste (Arnett et al., 2020; Castellano et al., 2021; De Albuquerque et al., 2021; Madyal et al., 2020). These approaches are much more instructional than constructionist approaches based on social responsibility, although they apply increasingly gamified teaching in the classroom.

Works based on waste recycling to create robotic models by students have developed new approaches to sustainability when learning starts at school (Pearce et al., 2020), mediated by curricula oriented towards social responsibility. In Belgium, energy savings have already been sought in the school-family-society trinomial. Therefore, these types of experiences are developed for a more participatory educational programming in society, not limited to the use of theory manuals. This research supports the development and use of school robotics as a practice of sustainability in the care for water.

In this sense, we based this experience on an educational robotics program based on solid waste recycling in a specific context. The proposed teaching processes were divided into three pedagogical cornerstones: Social Ecological Intelligence (IES), Social Scientific Task (TCS), and Social Scientific Reflection (RCS). Each one is based on the theory proposals for the development of ecological and social intelligence (Aghajani, 2018; Gardner et al., 1996; Nuri et al., 2014).

The implementation of the IES phase sought to generate cultural knowledge and the recognition of the diversity of a polluting environment in students, in order to achieve a capacity for inquiry and generate new knowledge through social self-reflection. Then, the TCS phase allowed the student to use the objects, prevent damages to his person, and succeed in proposing robotic designs in the classroom with the replica of other pre-existing ones. Regarding the RCS process, pedagogical questions were posed to raise two types of reflection, one is cognitive about the robotic models, and the other is social about the conservation of the environment and its sustainability. The processes proposed herein try to follow the steps of the multiple teaching methods by Irianto et al. (2018), based on the search for cultural and social recognition for the development of technological models.

## Scientific skills: cognitive approach

Scientific skills from the cognitive approach are conceived as the set of abilities that allow developing knowledge from empirical experience (Zimmerman, 2005). This position includes the set of skills stimulated for the search of new knowledge as a precedent of the previous knowledge acquired by the student (Fisher, 2014; Valdés, 2016), by contrasting it with the results obtained, by observing, analyzing, comparing, arguing, refuting and reflecting on certain phenomena that allow him or her to arrive at knowledge. In certain students, better knowledge has been found in the use of technologies when they perform reflective tasks by interpreting knowledge (Chang et al., 2016); likewise, combinatorial thinking generates better skills when some type of cooperation is achieved among the members of a student group (Yuksel, 2019). Other evidence has reported results describing the use of technology as a motivation generator, the development of critical thinking and better opportunities to learn science (Pramono et al., 2019), and the reflective ability to pose solutions to certain scientific problems.

In some countries such as China and Russia, science education policies implement the development of inquiry skills, considering the reflective ability from the use of technology. In this sense, if the student applies the design and transformation of digital products to their recycling activities, managing solid waste such as metals and plastic, could create reflective attitudes towards science (Maiurova et al., 2022; Yang et al., 2021). This is how methodologies that seek to solve problems from the use of these reusable objects need to be introduced in all schools to obtain potential indicators in the care for the environment (Lizana et al., 2021). This encourages independent, conscious and investigative training for professional life.

In the study of Hiğde and Aktamış (2022) and Luo et al. (2020) it is shown that involving the development of inquiry and analysis in disciplines related to engineering enhances the results in students' academic performance, in the scientific and computational domains. These types of proposals contribute to the curriculum prepared in South America, in contexts without the implementation of science education based on the development of projects. In other countries, the curriculum has already been developed based on the contributions of science, mathematics and engineering (Aranzabal et al., 2022). However, the main problem in the curriculum and school teaching methods in South America focuses on the lack of understanding of strategies and the use of resources, or on the contrary, on the coherence between the use of strategies and the biological, social and personal characteristics of the students to participate in classes that create a better awareness of sustainability.

In this case, the IES-TCS-RCS educational scheme is proposed through a scientific skills development program with environmental ecology. However, there is special interest in the use of other methodologies such as: Inquiry [I]-Problem-Based Learning [ABP]-Reflection and Feedback [RR], which are based on other studies whose purpose is to develop informational, communicative and scientific skills in students with low cognitive level (Ormanci & Çepni, 2020; Palupi et al., 2020). Therefore, we adapted these processes to the methodological phases of the Robotic Ecology program: phase I to the social ecology intelligence process, which is more recognized as a motivational process; ABP adapted to the activities: scientific and social tasks, and autonomous reflection adapted to the RR process. This made it possible to bring the scientific research process closer to the studies and proposals focused on recycling and the search for social ecological awareness (Garofalo, 2019; Garofalo & Bacich, 2020).

# Method

The research is based on the positivist paradigm, an applied study in which an independent variable is manipulated and its effects on another dependent variable are verified; this is how we carried out measurements in the quantitative approach. The design was experimental with pretest and posttest. This study sought to modify science skills (dependent variable) from the effects of the robotic ecology program (dependent variable) in the school year of a group of coastal schoolchildren. The measurement of scientific skills involved both science abilities and environmental awareness competencies. We carried out this measurement with the instruments that allowed us to evaluate these conditions on each component.

## Subjects

We made a methodological comparison between two groups of students ($n_{(Exp.)} = 45$; $n_{(Cont.)} = 35$). Eighty subjects from fifth and sixth grade of elementary education were selected and included in the overall experimental sample. The number of subjects was mostly female (male = 39%; female = 61%), all of them attended schools in vulnerable contexts in the capital districts. The average age of the participants was 10 years and 8 months (fifth grade = 10.43; sixth grade = 11.2). Variables controlled for were: (a) daily classroom attendance; (b) profound cognitive deficits; (c) age above the educational range; (d) pre- and post-pandemic reinforcement stages, and (d) health status.

All participants gave their consent by signing the informed parental consent form. This document was prepared in accordance with the acceptance of the parents and signed by them to include their children in the experiment. This was given as part of a cognitive reinforcement cycle in the area of science and technology in their respective educational institutions. The aforementioned process made it possible to avoid biases such as the institutional management obligation or the teacher's demands. After contacting the parents, the school administrators and the respective classroom teachers who intervened in the research in general were contacted. This administrative procedure followed the research ethics model based on the model established by the Declaration of Helsinki and avoided generating exogenous factors that would invalidate the study.

## Instruments and procedure

We developed a theory and practice performance test on scientific skills, in which the following dimensions were measured: (a) knowledge, (b) observation and (c) reflection. The tasks performed allowed measuring the content of these dimensions through tasks called "Scientific Situations" (Table 1). The tasks were based on the research proposed by Pramono et al. (2019) and Ong et al. (2015), choosing and diversifying the most appropriate dimensions to assess students in the context. An Environmental Awareness Scale was also used with the intention of supporting the grade in scientific reflection, in this case, the instrument allowed measuring the constructs: (a) awareness of the environment and (b) beliefs about care.

Table 1

*Test-subtest correlations in the Test and Scale constructs*

| Variables | Dimensions | r* |
|---|---|---|
| Scientific skills | Knowledge | .891 |
| | Observation | .901 |
| | Reflection | .789 |
| Environmental awareness | Awareness of the environment | .871 |
| | Beliefs about care | .883 |

*Note*. The R-values are the respective values of bivariate Pearson correlation coefficient, correlations between variables and dimensions are performed. *p < .001.

The level of reliability achieved in both instruments was acceptable (Ins. $_{(\alpha\text{-}1)}$ = .921; Ins. $_{(\alpha\text{-}2)}$ = .890). Table 1 reflects the results of correspondence between variables and dimensions through a component-variable correlation analysis. From the relationships obtained to establish test-subtest correspondences, a higher index was found between observation ability and scientific skills, and beliefs about environmental care and awareness. It should be noted that all the indices found exceeded the index of .70, so it was accepted as a standard correspondence between the factors and their respective variables.

The ecological problem of a coastal beach was addressed with a social responsibility program, conducted through an agreement between a private university and three schools in vulnerable contexts. The program consisted of three pedagogical phases [IES-TCS-RCS], implemented in six months of the school term. The implementation is shown in Figure 1. These allowed the subjects in the experimental group to come into contact with the recycled waste to develop basic robot prototypes, following their creativity criteria and the teaching pathways applied by the teachers. Students in the control group performed common recycling activities.

Subjects in the experimental group participated in the IES-TCS-RCS phases for six months. In the first phase [social ecological intelligence], students visited a coastal beach in Callao up to five times in the two-month period; the visits were combined with evaluative work in class on the information gathered from the context. Working groups were organized for the questioning to analyze: (a) context and characteristics of the site, (b) atmospheric and aquatic conditions, and (c) recycling actions. The information was collected during the five visits; each working group was able to preventively organize the use of the necessary resources for the collection, selection and revision of the useful renewable objects.

In the second phase [social scientific task], we applied the scientific inquiry activity as a means of searching for information on the robotic models to be implemented by each group. In a second stage, we designed mockups of robot prototypes, for which we used usable resources, which are shown in Figure 1, and were submitted for evaluation by teachers specialized in science and educational robotics. The purpose was to encourage the inclusion of these prototypes in the schools' innovation projects, in order to generate their own economic income. The non-usable resources were disposed of in an organized manner from the waste request by the municipality involved. These were collected in compactor trucks for distribution to the respective Recycling-Waste Collection Centers. Waste collection and compaction took place during the three months following the execution of the first phase.

Finally, with the third phase: social scientific reflection, we were able to organize advertising events on environmental care, these were intended to discuss knowledge-environment, environment-user and context-awareness topics. The first topic was used to generate self-questioning about the elements that prevent achieving sustainability in the care of the environment and what the inhabitants and visitors of the beach in question would need to take care of it. The products were banners and posters aimed at promoting care for the physical environment (the coastline). For the second and third topics we were able to prepare banners, posters and others that could be pasted in each street of entry to the beach, in other environments near the disposal centers. Therefore, we were able to make a social criticism of the care of the environment near the visitors. In this sense, the products were intangible, due to the fact that awareness-raising activities were planned and carried out. These were carried out in the last month of the program implementation.

Figure 1

*Pedagogical phases of the robotic ecology program*

(a)

(b)

(c)

*Note*. The figure represents different phases of the ecological approach program: (a) social ecological intelligence [IES], (b) social scientific task [TCS], (c) social scientific reflection [RCS].

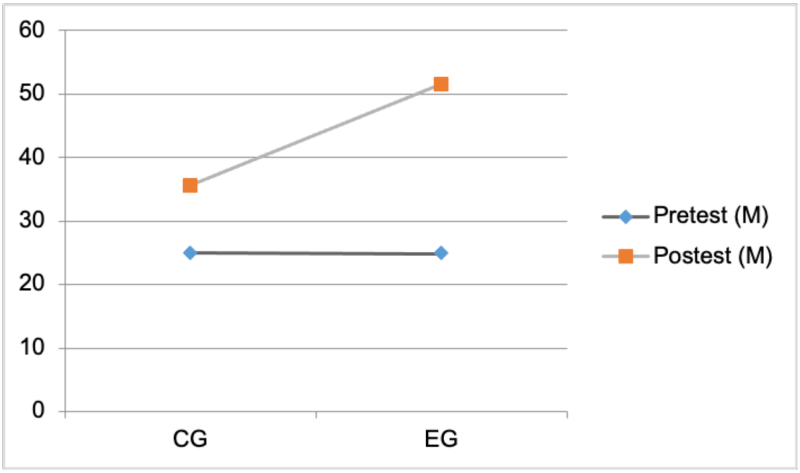
# Results

## Scientific skills and environmental awareness

The initial scores for scientific skills ($t_{(53)} = -1.073$; $p > .005$) and environmental awareness ($t_{(41)} = -1.110$; $p > .005$) were statistically equal (no significance). The overall results (Figure 2) allowed finding notable differences that support the improvement of scientific skills ($t\text{-}SS_{(74)} = -3.831$; $p < .005$) after implementing the robotic ecology program.

Figure 2

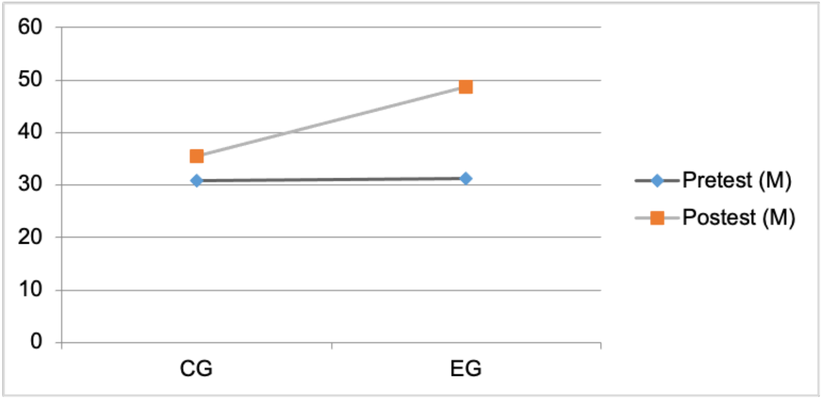
*Pretest and posttest measurements in scientific skills*




The scores obtained in environmental awareness are shown in Figure 3. The comparison of medians allowed establishing significant increases in the experimental group ($t\text{-CA}_{(72)} = -2.720$; $p < .005$) and evidenced the parallel development of scientific skills.

Figure 3

*Pretest and posttest measurements of environmental awareness*



## Comparison of average measures in dimensions

The initial scores did not show significant differences before starting the experimental approach in the components of scientific skills and environmental awareness. On the other hand, as shown in Table 2, there were favorable scores for the experimental group after applying the pedagogical phases [IES-TCS-RCS] of the robotic ecology program, which represented significant differences in the dimensions of scientific skills: observation ($t_{(70)} = -2.45$), reflection ($t_{(77)} = -2.31$).

Table 2

*Average in dimensions of scientific skills and environmental awareness*

| | Pretest | | Posttest | |
|---|---|---|---|---|
| Dimension | CG | EG | CG | EG |
| Knowledge | 10.11 | 10.19 | 15.16 | 16.01 |
| Observation | 9.21 | 9.16 | 15.21 | 18.32 |
| Reflection | 5.71 | 5.8 | 6.34 | 10.81 |
| Awareness of the environment | 15.20 | 15.01 | 20.41 | 21.30 |
| Beliefs about care | 12.30 | 12.35 | 18.83 | 20.01 |

Regarding the dimensions of environmental awareness, differences were also reported in awareness of the environment ($t_{(75)} = -2.21$), beliefs about care (t (78) = -2.10). However, Table 2 also shows non-significant differences in the scientific knowledge dimension ($t_{(61)} = -1.02$).

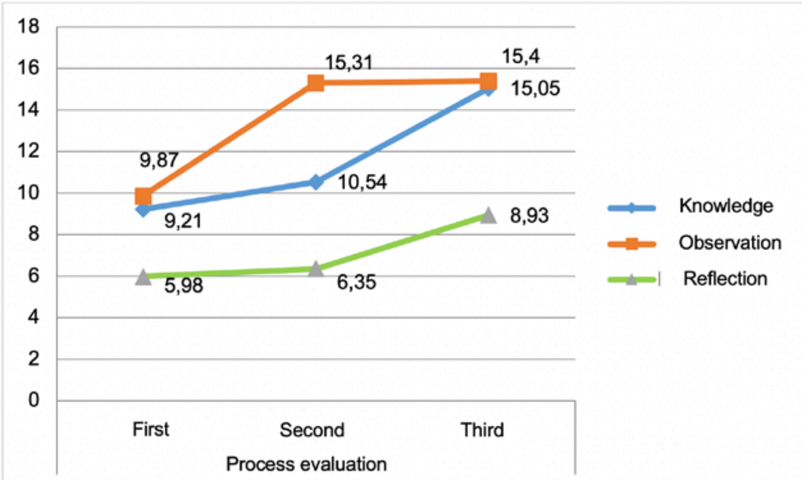
## Measures of progression in scientific skills

In order to measure the progress of scientific skills over a six-month period, additional tests were developed, applying the evaluations on three occasions to monitor the quality of progress in each of the dimensions or skills considered (knowledge, observation, reflection). The first test was conducted a few weeks after the application of the pretest, and the last, two weeks before the posttest evaluation.

In Figure 4 we note better progress in the knowledge skill, with a better difference between the first and second evaluation (diff. = -5.44), and between the second and third evaluation (diff. = -4.51). On the other hand, the progression in the observation dimension was slightly less smooth and the increase was smaller between the first and second report (diff. = -1.33). Nevertheless, from the second evaluation there is evidence that the property to perform basic observation was complex to develop for the test subjects (diff. = - .09). Finally, there was less evident progress in reflective ability between the first and second evaluation. The increase was more evident in the last evaluation (diff. = -2.58), although it was a low-level progress up to that last evaluation (M = 8.93) with respect to the beginning of the program (M = 5.98).

Figure 4

*Pretest and posttest measurements in components of scientific skills*




## Descriptors by levels in the variables

For a more descriptive report of the variables, we classified the results by levels. It was found that less than 20% of the individuals in the experimental group reached the high level of scientific skills, more than 30% presented a moderate level and more than 40% presented a low level. In the control group, less than 30% represented a high level of these abilities for science; 40% showed a moderate level and more than 25% at a low level. Once the program was applied in the experimental group, more than 40% reached a high level, decreasing the number of subjects in the low level, since less than 20% reached that level. In the control group, the level of progress was static, with only 45% of the total showing growth at the moderate level.

In the levels of environmental awareness evaluated before the robotic ecology program was implemented, 22% of the subjects in the control group and 24% in the experimental group showed a high level. 30% of the participants of the experimental group and 35% of the control group showed a low level. At the end of the coastal beach intervention program, the levels were similar in the control group. More than 45% of participants in the experimental group achieved a high level.

# Discussion

The findings allow affirming that the phases of the responsibility-based method [IES-TCS-RCS] contributed in the strengthening of scientific skills with the awakening of prior knowledge as already evidenced in other studies (Da Costa et al., 2020; Garofalo, 2019), which has been evident in the robotic prototypes developed in the students. This has been evidence of the constructive period of scientific learning. In this sense, the program was able to integrate creativity towards scientific inquiry processes through STEAM in the experimental group as scientific feedback processes (Garofalo & Bacich, 2020; Gentil et al., 2019).

The general approach based on the use of social ecological intelligence (Gardner et al., 1996; Nuri et al., 2014) and processes of cooperative and motivational teaching methods (Pramono et al., 2019; Yuksel, 2019) have contributed in the improvement of knowledge acquisition, in the increase of knowledge production and in its reflection. The cognitive reflection dimension was also supported after developing the contribution in environmental awareness processes through the coastal beach cleanup.

The evidence obtained from the implementation of the program allows us to accept that the knowledge dimension has less complexity for development, since the group of students performed their classes in a receptive way, without traces of being constructivist. Some evidence has demonstrated that, as a basic skill, it tends to be applied in subjects with certain characteristics similar to those of this study (Donnermann et al., 2021; Schouten et al., 2022). Consequently, the extension of individualistic work with robotics has been transformed into this experience due to the collaboration generated by the individuals themselves in their guided learning, as they also do in other contexts through cognitive collaboration (Schouten et al., 2022; Lin et al., 2021; Liu et al., 2021). In any case, the reflective processes assessed in the progress of reflective ability seem to be linked to the observational processes of the subjects in the experiment. Therefore, it is argued that the individual-robotics-learning experience can be crucial due to the stimulation generated in the science processes themselves (Chalmers, 2018).

Regarding the factors of awareness of the environment and beliefs about care, values have been found that supported their change in the subjects of the experimental group, due to the fact that many of them added reflective events based on the analysis of their own environment to their previous knowledge, so the use of contextual information about the public waste and the quality of the environment visited by the students involved is highlighted. If we consider studies that involved student work through knowledge of the immediate environment (Garofalo, 2019; Garofalo & Bacic, 2020), it is assumed that the practice of prior knowledge added to the search for knowledge of the context stimulates the generation of scientific information, as well as in studies in which the development of pedagogical feedback processes in the classroom is reported (Lin et al., 2021; Nuri et al., 2014; Schouten et al., 2022; Yuksel, 2019). In the study we found that the context is used as a means to feed back the students' environmental awareness, as well as critical thinking about the problems that affect their community.

Finally, although no significant differences were found in the knowledge dimension, it is important to note the progress shown by both the subjects in the control group and those of the experimental group, since both discovered the immediate environment, they were facing, which helped them to obtain permanent information on environmental pollution and environmental settings as an academic status.

# Conclusions

The robotic ecology experience premeditated the modification and improvement of scientific skills, developing observation and reflection in the participants of the coastal beach approach program. This was corroborated in the significant differences obtained, which were favorable to the experimental group at the end of the robotic ecology program ($t_{(74)} = -3.831$; $M = 51.62$; $p < .005$). Regarding their ways of reflecting, the scientific task and social scientific reflection phases of the program improved awareness of the environment and care for the environment as part of the students' scientific reflection. The specific results evidenced effects of improvement in scientific knowledge, although the results are promising, their low statistical significance prevents them from being understood as totally determinant evidence.

According to the objective, scientific skills were compared, and it was concluded that they increased in parallel to the environmental awareness of the subjects in the experimental group ($t_{(72)} = -2.720$; M = 48.78; $p < .005$), although this increase can be considered as an implicit moral condition that supports the learning of science from the application of robotic models with recycled waste.

The pedagogy that sought to implement the use of ecological robotics as a means to develop abilities for science allowed demonstrating that the phase based on the use of social ecological intelligence, allowed the subjects to develop their skills to observe and analyze the information that surrounds them, establishing knowledge about the environment and the contamination factors of the environment. On the other hand, the direct tasks with renewable resources have allowed the development of robotic knowledge in each student and analytical thinking as a means to achieve scientific knowledge. Scientific reflection promoted both the development of the actions of other citizens, their competencies to care for the environment, as well as the knowledge of the factors to achieve the sustainability of this care.

The study helped to clarify links between science learning, conservation of the environment and the use of waste as a method of STEM education. It becomes clear that the ability to know is crucial to the skills of observation and reflection, albeit in contexts where the use of the natural environment are issues of social (environmental) necessity. These latter skills generate broader conservative thinking, investigative analysis skills and positive attitudes toward creative robotics at the schooling stage.

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