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Interdisciplinary Rationality Islands and Teaching of Natural Sciences: A Study on Evaluation of Learning and Problem-solving Skills

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A R T I C L E I N F O

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A B S T R A C T

The present study investigated the utility of the Interdisciplinary rationality islands methodology as an alternative for teaching students how to creatively solve everyday problems. The data were collected before, during, and after the didactic intervention. Collections involved the application of questionnaires to identify the (1) profile of students and (2) evaluation of learning and problem-solving skills. Qualitative and quantitative approaches were used in the analysis. The results showed significant gains in terms of learning and problem-solving skills and demonstrated that this innovation initiative through islands has moved towards promoting the scientific and technological literacy of students. Thus, this proposal allowed leaving teaching based on memorization and reproduction of information and still fragmented and disciplinary, i.e., teaching that does not value life experiences of students.

1. Introduction

Significant advances marked the knowledge society in the second half of the twentieth century. It highlights the explosion of scientific knowledge and introduction of new technologies as responsible for such changes of global scale. Consequently, these changes have brought new challenges to the educational system because trained human resources are needed to deal with technological innovations and transform the information hitherto known to new knowledge. In this context, the teaching of natural sciences plays an essential role in promoting critical and logical thinking of students in order to enable them to solve problems and make informed decisions. Moreover, the teaching of science is fundamental to inspire the choice for the activity of researcher in the scientific and technological area and new teachers (Roitman 2009).

Nevertheless, purely expositive classes predominate in the teaching of natural sciences, contributing little or nothing for the effective participation of the student in the construction of knowledge. As an alternative, the current literature presents student-centered teaching methodologies (or active learning methodologies) to provide an active and critical formation of students in an attempt to meet the demands present in the current panorama.

The focus of instruction in student-centered teaching methodologies is transferred from teacher to student. Students maintain an active and critical posture about knowledge in this approach, being co-responsible for their learning. These methodologies allow them to use the sensory/motor, affective/emotional, and mental/cognitive dimensions as they learn. For this, they collaborate with their peers and consult the teacher when they cannot solve doubts alone (Jones 2007; Monteiro and Smole 2010; Sesen and Tarhan 2011; Wilke 2003; Prince 2004).

The teacher, in turn, has the role of proposing relevant challenges to the students. In addition, the teacher assumes the role of facilitator of learning, ceasing to be the holder of knowledge. The teacher guides the student to deal with the enormous amount of information available, allowing academics to assess, interpret, and reflect from the information available. In this sense, the role of the teacher is much broader and more complex than in teaching in which purely expositive classes predominate (Moran 2017).

From this description, it is evident the importance of the teacher giving voice to students and abandoning the narrative. According to Moreira (2011, p. 7), "letting the students speak means to use strategies in which they can discuss, negotiate meanings among themselves, present orally to the large group the product of their collaborative activities, receive and criticize." This approach presupposes that the student speaks, argues, and participates actively in the construction of knowledge (Moreira 2011).

Student-centered teaching, in addition to this change in the focus of instruction, presupposes that the teacher considers real and relevant situations to students. It requires that knowledge is not fragmented, seeks an interdisciplinary pedagogical practice since a single discipline cannot cover the contents needed to deal with such complexity. This conception of teaching allows students to understand and analyze their reality in a critical way, besides making it possible to propose actions in the social context in which they are inserted. These arguments highlight the interdisciplinary potential of

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student-centered teaching (Sivan et al., 2000; Sesen and Tarhan 2011; Wilke 2003).

In summary, the use of student-centered teaching methodologies through stimuli to critical and logical thinking and exploring creativity contributes to overcoming educational challenges present in the current panorama, as previously mentioned. Transmission of information-based teaching is a methodology of past centuries and no longer meets the needs and desires of students. In this sense, centering the teaching in the student represents a possibility to rethink scientific education considering an interdisciplinary and contextualized approach (Moreira 2011). However, how to implement a practice with these characteristics? This questioning is essential if we are not to remain in a theoretical discussion.

2. Interdisciplinary rationality island

In an attempt to answer the previous question, in this research an Interdisciplinary rationality island was developed as a strategy to rethink science education through a student-centered approach. The interdisciplinary rationality island, proposed by Fourez, is a methodology directed to scientific and technological literacy, which enables students to participate in the construction of knowledge autonomously and collaboratively (Fourez 1997).

Scientific and technological literacy consists of disseminating to society the knowledge necessary to understand technical decisions. It allows such decisions to be supervised by population, giving responsibility to all (Fourez 1997). In this sense, Fourez (1997) suggests the scientific and technological literacy within the scope of the teaching of natural sciences, with a proposal to stimulate the construction of critical thinking and the exercise of citizenship.

According to Fourez (1997), scientific and technological literacy allows approximating science teaching of the science nature itself. This approach allows students to understand scientific theories and models, considering why, in what form, and for whom they were proposed, in addition to understanding the limitations and justifications for the development of new theories and models (Fourez, 1997).

In this sense, Fourez (1997) presents interdisciplinary rationality islands as methodological paths. Through islands, it is possible to propose a project, relevant to students, considering the knowledge of everyday life and coming from different disciplines. For this, the author proposes a procedure to open black boxes, which allows them to open initially with the help of specialists, but also gives them the autonomy to do so without help (Fourez 1997; Fourez, Maingain, and Dufour 2008).

The application of the Islands methodology aims to contribute to the Scientific and Technological Literacy of the students, enabling them to seek solutions to real problems encountered in the school or social context. According to Fourez (1997a, p.81), “Scientific and Technological Literacy develops through contextualized Science Teaching and not as a truth that is a mere end in itself”." Thus science education must be approached with an interdisciplinary perspective, encouraging teamwork and stimulating students to solve real and relevant problems in the context into which they are inserted.

Moreover, according to Fourez (1997), in order to develop problem-solving skills, it is necessary to promote Scientific and Technological Literacy employing a global approach in the teaching of concepts that allow the students to orient and understand themselves in the universe, not in a fragmented and decontextualized way that only exposes them specific knowledge. The author also argues that the construction of knowledge must have meaning and usefulness for the student and that it is necessary he has autonomy with regard to obtaining knowledge during this process so that he is able to make problem-solving decisions without being totally dependent on expert knowledge or ready recipes.

In short, according to Fourez, Scientific and Technological Literacy presupposes that the compression of scientific knowledge contributes to the formation of autonomous subjects, capable of negotiating their decisions, communicating with some mastery and taking responsibility for their actions in the face of concrete situations. Thus, by developing the Interdisciplinary Rationality Islands, students are not only able to understand scientific concepts, but also to develop meaningful problem-solving skills, which can be utilized for addressing specific socio- economic issues, and thus presupposing the development of higher order cognitive skills (Zoller 2000). Next, in more detail, the eight steps for the construction and implementation of an interdisciplinary rationality island.

2.1 Steps of an interdisciplinary rationality island

The sequence of steps and procedures for the elaboration of an interdisciplinary rationality island that guide the development of interdisciplinary practice in the teaching of natural sciences. These steps for the construction of islands can be adapted according to the teacher needs and application context. They are guidelines that encourage curiosity and autonomy of students to open black boxes for the promotion of scientific and technological literacy. Next, the eight steps of the island considering the book Alfabetización Científica y Tecnológica of Fourez (1997):

Step 1 – Elaboration of a cliché of the studied situation:

Cliché can be defined as a set of representations, which may be correct or not, of students about the study situation. For this, a brainstorming session is held at this stage. This activity allows revealing what the group of students thinks on the subject, besides allowing the identification of alternative conceptions and/or misconceptions (Fourez, 1997).

Step 2 – Spontaneous panorama:

The spontaneous panorama complements the cliché. This step is still quite spontaneous because it depends only on the students themselves and not on specialists. The following actions can be produced by students as a result of this step (Fourez 1997):

a. List of involved actors: teachers, students, and others.

b. Search of standards and conditions imposed by the technique: survey of rules of use considering technical, commercial, and cultural aspects.

c. List of postures and tensions: advantages and disadvantages of addressing certain subjects.

d. List of black boxes: list of questions that will be studied further with the progress of the interdisciplinary rationality island.

e. List of bifurcations: corresponds to the selection of strategies to be followed.

f. List of involved specialists and specialties: selection of specialists or fundamental specialties for the opening of black boxes (Fourez 1997).

Thus, by listing the six items above, students will have a complete view of the elements needed to open the black boxes.

Step 3 – Consultation with specialists and specialties:

Specialists and specialties to be consulted are selected from the list elaborated in the spontaneous panorama. This step enables the questions raised by students in the cliché to be answered. In addition, it allows confronting the view of students with that of the specialist on the situation of study. It is a long step because students open the black boxes at this stage (Fourez 1997).

Step 4 – Going to practice:

Going to practice makes it possible to consider aspects of science and technology concretely. It means leaving the abstract forms actually to delve into the study situation. Some strategies can be used at this step of the interdisciplinary rationality island: interviews, field trips, readings, and researches on the subject (Fourez 1997).

Step 5 – In-depth opening of one or another black box and discovery of “disciplinary principles” that support a technology:

This step aims to understand more rigorously some aspects of the study situation. For this, it is necessary to deepen elements peculiar to each one of the disciplines necessary to solve the problem. It may require the help of experts from other areas of knowledge, such as the collaboration of a specialist in the field of human sciences to open black boxes on cultural and political aspects present in the subject of the interdisciplinary rationality island (Fourez 1997).

Step 6 – Global outlining of technology:

This step presupposes the elaboration of a partial and objective synthesis of the interdisciplinary rationality island. Students can summarize or use graphical representation to systematize the study situation (Fourez 1997).

Step 7 – Opening black boxes without the help of specialists:

In everyday life, it is not always possible to count on the help of specialists or the resources needed to solve problems are not all available. Thus, this step aims to allow students to construct explanations for the study situation. For this, they are encouraged to have greater autonomy in trying to solve the black boxes that they still have doubts. At this step, students can check the Internet and other sources to obtain answers not answered by specialists (Fourez 1997).

Step 8 – Synthesis of an interdisciplinary rationality island:

At this step, students develop a product that synthesizes the interdisciplinary rationality island. It can be an oral or written production from project development. This product synthesizes the main learning of students along the island and also allows them to reflect on the scientific-technical world. To do so, Fourez presents some questions to be answered:

a. "How does what we have studied helps us to negotiate with the highlighted technological world?"

b. "How does it give us some autonomy in the scientific-technical world in society in general?"

c. "How do the obtained knowledge help us to discuss with higher precision the decisions to be made?"

d. "How does it give us a representation of our world and our history that allows us to situate ourselves better and communicate with others?" (Fourez 1997, p. 121).

This sequence of eight steps carried out in the present research for elaborating an interdisciplinary rationality island was conducted to explore the thematic of dairy activity in the southwestern region of Rio Grande do Sul. Details on the selection of the subject and questions from students were described in the methodology section.

Some notes of the literature on the selected subject for the study situation were presented in the following section.

3. Objective

The present study investigated the utility of the Interdisciplinary Rationality Islands methodology as an alternative for teaching students how to creatively solve everyday problems using their scientific knowledge, and without being totally dependent on expert knowledge or ready-made recipes, which are essential attributes for Scientific and Technological Literacy.

3.1 Research questions

Following are the research questions that guide data collection and analysis: 1. What is the relationship between students and dairy activity? 2. Have the problems proposed in the study situation contributed to the promotion of scientific and technological literacy? 3. Have students mastered scientific concepts and developed higher-order cognitive skills?.

4. Methodology and methods

4.1 Research subjects

This work is part of a master's research developed in Brazil (Santos 2019). The subjects of this research (n=20) were students from the third grade of high school of a state school of the Rio Grande do Sul, Brazil. A consent form was signed by parents or guardians of each adolescent participating in this investigation, ensuring the anonymity of the research data and the possibility of withdrawal at any time. Following is a description of how this action was carried out, based on the objects corresponding to each step of the adopted methodology.

4.2 Didactic intervention

As described in section 2.1, the development of an interdisciplinary rationality island contemplates the following steps: cliché, spontaneous panorama, consultation with specialists and specialties, going to practice, in-depth opening of one or another black box, global outlining of a technology, opening black boxes without the help of specialists, and synthesis of the island. This procedure was carried out within the school context to explore the thematic of dairy activity in the southwestern region of Rio Grande do Sul, Brazil. However, why tackle this theme?

The interest of students, school location, and the experience that many had with milk production were considered to select the study situation. Several students indicated this subject as central to the community in which they are inserted. The thematic was chosen at the end of the year that preceded the data collection, i.e., when the students were still in the second grade of high school. The main doubts about the dairy activity presented by them were systematized below:

a. What are the factors that lead to low profit from milk production?

b. What is the cost of milk production considering the different types of animal feeding and form of commercialization?

c. What are the milk quality parameters and analysis techniques?

A problem situation was elaborated from these doubts, being presented to the students through a fictitious letter supposedly written by the community. As a product of the island, they were expected to be able to answer to this letter by considering the items above. This objective was achieved with the help of professionals from different knowledge areas, such as natural sciences and their technologies to understand the importance, properties, and composition of milk, as well as professionals from the agrarian sciences for the discussion of techniques of product quality analysis, different techniques of feeding management, and different forms of commercialization. Professionals from mathematics and their technologies were also consulted to assist in the economics of milk production, from the area of languages, codes, and their technologies for guidance in elaborating a response letter to members of the community, as well as from Geography and History. This integration of different professionals and areas of knowledge was conducted according to Table 1. For this, the steps with the respective activities and time used in each of them were described.

Table 1 Steps of the interdisciplinary rationality island for the problem situation of dairy activity in the southwestern region of Rio Grande do Sul, Brazil.

Step	Activity
Cliché	- Reading the fictional letter by the students.

	- Brainstorming to identify alternative conceptions and doubts of students.
Spontaneous panorama	- List of involved actors. - List of standards and conditions imposed by the technique. - List of postures and tensions. - List of black boxes. - List of bifurcations. - List of specialists and specialties involved.
Consultation with specialists and specialties	- Participation of specialists from the area of Agrarian Sciences.
Going to practice	- Elaboration of an interview script to be carried out with family and/or people of the community who work with milk production. - Conducting the interviews.
In-depth opening of one or another black box	- Deepening of specific aspects of each discipline through the resolution of a script with challenges to be answered with the help of teachers from natural sciences, mathematics, and other areas, according to the need of the specialty.
Global outlining of a technology	- Scheme with each of the investigated subjects.
Opening black boxes without the help of specialists	- Search on the Internet, books, videos, and other materials. - Seminars.
Synthesis	- Elaboration of products.

4.3 Research design

A study of a mixed nature was chosen given the inherently subjective nature of the evaluation of the teaching-learning process. This approach presupposes the integration of quantitative and qualitative methods as a strategy to obtain greater robustness and reliability in the results of this research (Johnson and Onwuegbuzie 2004).

4.4 Data collection

Data collection included (1) the analysis of student profile and (2) assessment of learning and problem-solving skills. Questionnaires and student activity records through their portfolios were used as data collection tools.

4.4.1 Profile of students

The student profile was verified through a questionnaire containing the student identification data (including name, age, sex, school, and place of residence). In addition, the students were invited to produce a text to tell briefly about them. For this, they answered the following questions: Who am I? What is my experience with dairy activity?

4.4.2 Evaluation of learning and problem-solving skills

The evaluation of learning and problem-solving skills was performed through different indicators: questionnaires (initial and final) and portfolio. For this, a questionnaire was used at the beginning of the didactic intervention and two questionnaires at the end (with open questions). The questionnaire applied at the beginning included questions at the level established by Zoller as low-order cognitive skills (LOCS) (Zoller 1993). On the other hand, a questionnaire similar to that applied at the beginning and another with high-order cognitive skills (HOCS), according to the Zoller classification, was applied as a final instrument. In addition, the records made by students in their portfolios were also considered. Questionnaires were elaborated and later validated by two specialists, one of them of the area of natural sciences with a doctorate in the teaching area and other of the agrarian sciences with a doctorate in animal science.

4.5 Data analysis

4.5.1 Qualitative analysis

Qualitative data were treated through content analysis (Bardin 1977), as well as evaluative rubrics (Andrade 2005). Content analysis known as thematic or categorial analysis consists of the dismemberment of the text into units of meaning. In this analysis, units are grouped into categories according to the meaning of the message (Bardin 1977). All categories were defined a priori in this research.

Student answers in the profile questionnaire were classified according to the relationship of the student with dairy activity. For this, three categories were used: present, partially present, and absent. The present category was used for answers of students who indicated to present direct bond (familiar) with dairy activity in the present moment. The partially present category was attributed to answers of students indicating they know people who work in the activity, but do not have a direct bond, or even when their parents worked in the activity when they were still children. The absent category was used with students who do not have a bond to the dairy activity.

Answers of learning evaluation questionnaires were categorized from the conceptual correction. Four categories of analysis were used to classify the answers according to their messages: adequate, partially adequate, inadequate, and do not know/absent. The adequate category was attributed to the conceptually correct answers. The partially adequate category was attributed to answers in which there was some conceptual misconception, but with the indication that the student understood concepts inherent to milk theme, or incomplete answers. The inadequate category was attributed to answers that did not mention any relevant idea. Finally, the do not know/absent category was assigned when the student did not know the answer or left it blank.

Records of students in the portfolios were evaluated through rubrics that included a scale with four levels, considering the following extremes: fully developed and undeveloped.

4.5.2 Quantitative analysis

Descriptive statistics were used to obtain a general appreciation of the data in a univariate form. This analysis allowed calculating the means, standard deviations, frequencies, and percentages (Cohen and Lea 2004).

Multivariate statistical methods (Pereira 2004) were used to recognize natural patterns as a function of similarities in the answers of students. The hierarchical cluster analysis (HCA) was used with the software Pirouette. This analysis was generated from categories obtained from the qualitative analysis. For this, the performance (P) of students in the questionnaires (Equation 1) and portfolio (Equation 2) was calculated according to the following equations:

$$D_{questionnaire} = [(A \times 4) + (P \times 3) + (I \times 2) + (N \times 1)]/(A + P + I + N) \quad \text{(Equation 1)}$$

where A, P, I, and N are the number of answers categorized as adequate (A), partially adequate (P), inadequate (I), and do not know/absent (N), respectively.

D portfolio = [(F × 4) + (P × 3) + (I × 2) + (U × 1)]/(F + P + I + U) (Equation 2)

where F, P, I, and U are the number of activities classified as fully developed (F), partly developed (P), incorrectly developed (I), and undeveloped (U), respectively.

5. Results and discussion

5.1 Profile of students

The subjects of this research had ages between 16 and 19 years, being mostly female (65%, n=13) and 95.0% of them live in rural areas and only one student (5%) lives in the urban area. The brief report showed that 60% (n=12) of them presented a direct bond with dairy activity. The following excerpts show the presence of this economic activity in the daily life of students:

[...] My experience with dairy activity has come since I was a baby, as my parents are farmers and work in the dairy activity, serving a dairy barn with an average of 30 cows [...].

My father has worked with dairy cattle since he was a child, and to this day, he is daily involved with it as a means of survival [...]. I get involved with it only on vacation, when my father ends up taking on other dairy barns for people who want to take a vacation, in order to get some more money [...].

[...] My experience with dairy activity began when I was nine years old, helping my parents in the barn and putting the cows on the pasture [...].

Only 15% (n=3) of the students who participated in the didactic intervention had no bond with dairy activity, and 25% (n=5) of them knew people who worked in the activity but did not have a direct bond or were children when their parents worked in this economic activity. These cases were exemplified in the following excerpts:

[...] My parents worked a long time in the dairy activity [...]. Currently, they do not work on it anymore. They stopped working when I was very little. Partially present

[...] even living in the rural area [...] I have no involvement [...], no experience and no knowledge on the subject. Absent

These profile data highlight the potential of the selected theme, under the context in question, to arouse the curiosity of students as transforming agents of their realities. The proposition of study situations that are part of their daily lives contributes not only to the learning of school contents but also allows them to broaden their knowledge, aiming at acting on problems of their communities. According to the Brazilian Curricular Common Base, the social, historical, and cultural contextualization of science and technology does not consist merely in a simple exemplification of everyday situations. In this approach, learning must value the knowledge necessary for individual life, life projects, and the world of work. Therefore, natural sciences in high school have an important task of allowing students to develop skills to interpret the phenomena and social problems present in their daily life so that they can act as transforming agents of reality (Brazil, 2018).

5.2 Evaluation of learning concepts and problem-solving skills

Results obtained from the questionnaire, with questions classified at the level established by Zoller as low-order cognitive skills (LOCS) (Zoller 1993), applied at the beginning of the intervention, were shown in Table 2, and those at the end were shown in Table 3.

Table 2. Frequencies, in percentage, of the categories of analysis obtained from the answers of students in the initial questionnaire (LOCS questions).

	Category			
	Adequate	Partially adequate	Inadequate	not know/absent
Question 1	0	30 (n=6)	50 (n=10)	20 (n=4)
Question 2	0	0	65 (n=13)	35 (n=7)
Question 3	0	30 (n=6)	35 (n=7)	35 (n=7)
Question 4	0	40 (n=8)	25 (n=5)	35 (n=7)
Question 5	20,0 (n=4)	10 (n=2)	20 (n=4)	50 (n=10)
Question 6	0	20 (n=4)	30 (n=6)	50 (n=10)

The first item of the initial questionnaire focused on factors leading to low profit from milk production. In this case, 50% of the students had their answers categorized as inadequate, and 20% answered that they did not know or simply did not want to answer the question. Despite this, 30% of them presented in their answers evidence that they knew some of the factors that result in the low profit of milk producers, being categorized as partially adequate. Question 2, which dealt with the different types of feeding management of dairy cattle, had 65% of the answers categorized as inadequate and 35% of the students did not know or did not want to answer this item. Question 3 had as objective to verify the previous knowledge of students on production costs for different feeding management of dairy cattle. This item presented 35% of the answers categorized as inadequate, and the same frequency was verified for students who did not know or did not want to answer. A frequency of 30% was observed in the partially adequate category. The fourth question was used to ascertain the knowledge of students on the ways to add value to the milk product, and 40% of the answers were categorized as partially adequate, 25% as inadequate, and 35% of the students did not answer it. Question 5, which included variables that compose the amount paid to the producer per liter of milk, had 20% of the answers categorized as inadequate and 50% as do not know/absent. Despite this, 10% of the answers were categorized as partially adequate and 20% as adequate. Finally, question 6, which dealt with tests used in rural properties to verify milk quality, presented 30% of the answers classified as inadequate, 20% as partially adequate, and 50% of the students did not know or did not answer it.

The systemic appreciation of the initial questionnaire, with elementary questions on dairy activity, allows concluding that the students had little previous knowledge regarding technical and scientific aspects. Item 5 presented answers only in the adequate category. The other items presented answers classified only as partially adequate, inadequate, or do not know/absent. Thus, most students have insipid knowledge on the subject, even with a direct bond with dairy activity. It may be due to the lack of involvement of students in the activity developed by parents and family members, or they do not use milk quality control techniques, do not perform production cost calculations, do not use other ways to add value to milk, and hence children do not have this experience.

The results obtained for the questionnaire applied at the end of the didactic intervention, which required the same cognitive level of the initial questionnaire, are shown in Table 3.

Table 3 Frequencies, in percentage, of the categories of analysis obtained from the answers of students in the final questionnaire (LOCS questions).

	Category			
	Adequate	**Partially adequate**	**Inadequate**	**not know/absent**
Question 1	0	30 (n=6)	50 (n=10)	20 (n=4)
Question 2	0	0	65 (n=13)	35 (n=7)
Question 3	0	30 (n=6)	35 (n=7)	35 (n=7)
Question 4	0	40 (n=8)	25 (n=5)	35 (n=7)
Question 5	20,0 (n=4)	10 (n=2)	20 (n=4)	50 (n=10)
Question 6	0	20 (n=4)	30 (n=6)	50 (n=10)

All the answers of students to question 1 were categorized as partially adequate. It means that they indicated up to three factors that lead to low profitability in dairy activity, but some of the factors discussed during the instruction were not listed in the answers. Question 2 had 85% of the answers categorized as adequate, and only 15% as partially adequate. It means that most students understand the different types of feeding management of dairy cattle, which is different from the results obtained in the initial questionnaire. Question 3 showed a higher distribution among categories when compared to the others because of the four possible classifications three were filled. This item investigated the knowledge of students on the production costs for different feeding management of dairy cattle. Despite this, most of the answers are in the adequate (40%) and partially adequate (35%) categories. The fourth item also presented all responses categorized as partially adequate. It indicates that they included aspects of milk processing in the property (milk sweet, cheese, butter, among others) as a way of adding value, but students did not mention the organization of producers into groups, use of milk collection stations, and creation of trademarks (quality and origin seals) as strategies to achieve this goal. Question 5 presented expressive data in relation to the adequate category (85%). It indicates that most students understood the variables that compose the amount paid to the producer per liter of milk. The last item of this instrument of data collection showed the same pattern of the previous one, with 85% of the answers categorized as adequate. In this item, students could list some of the tests used in rural properties to verify milk quality.

The comparison of results obtained in the final and initial questionnaires for LOCS questions evidences the significant gain in learning on dairy activity. It can be verified by a significant increase in the final questionnaire of answers categorized as adequate and absence of answers in the do not know/absent category. In addition, the results showed that the students were able to solve problems on the subject (HOCS problems), as shown in Table 4.

Table 4 Frequencies, in percentage, of the categories of analysis obtained from the answers of students in the final questionnaire (HOCS problems).

		Categorias			
Problems		Adequate	Partially adequate	Inadequate	not know/absent
Problem 1	Item a	20 (n=4)	80 (n=16)	0	0
	Item b	0	95 (n=19)	5 (n=1)	0
Problem 2		20 (n=4)	0	80 (n=16)	0
Problem 3	Item a	85 (n=17)	15 (n=3)	0	0
	Item b	30 (n=6)	55 (n=11)	15 (n=3)	0
Problem 4		100 (n=20)	0	0	0
Problem 5	Item a	75 (n=15)	25 (n=5)	0	0
	Item b	35 (n=7)	40 (n=8)	25 (n=5)	0

Problem 1 (item a) of the questionnaire applied at the end of the didactic intervention had 80% of the answers categorized as partially adequate and 20% as adequate. This item dealt with the influence of quality and quantity on the amount paid for the liter produced in the properties. Students who had their answers categorized as partially adequate, although correctly answering that these factors influenced the amount paid, did not present consistent arguments to justify this fact. On the other hand, students with answers classified as adequate indicated that milk quality influences the value paid because it presents indicators such as fat content and biological contaminations. In addition to arguing that the amount of milk collected in the property also interferes, as it reduces production costs of the industry since it does not need to collect milk at many points of collection. Problem 1b showed that students should propose actions to assist in improving profitability with dairy activity from producer observations. This item also showed that 95% of the students were restricted in their answers. Most of them presented only one action to assist in improving profitability with dairy activity.

They considered only the quality or quantity of produced milk.

Students presented great difficulty in answering problem 2 about the implementation of milk collection stations as a strategy to add value to the product. Most students (80%) confused the role of milk collection stations with centers for its processing. Thus, several answers showed that the implementation of this station would allow producers to produce milk derivatives, such as cheese, sweets, and others. However, the expected answer was that agroindustries remunerate farmers better when it is possible to collect more product in a single station, thus adding value to the product. Despite this, 20% of the students were able to solve this problem successfully.

Students were challenged in problem 3 with a question on the types of animal feeding. They should have argued in item a about the advantages and disadvantages of moving from a native pasture to winter pasture. In this case, 85% of the answers were categorized as adequate. This result shows that the students understood the involved costs, investments, and results provided by each feeding system. Only 15% of the answers were categorized as partially adequate. In item b, students should indicate modifications that would need to be carried out in the rural property for such a change. For this item, 55% of the answers were categorized as partially adequate, i.e., most students presented incomplete answers. Despite this, 30% of them were categorized as adequate, as they adequately described modifications necessary to change animal feeding management.

In item 4, students should solve a problem about mastitis in the herd. They needed to identify environmental contaminants responsible for causing the disease. All students had their answers categorized as adequate. It means they understood the environmental factors that cause mastitis, such as lack of hygiene in the milking room and equipment, improper litter management in the confinement system, and others.

Problem 5 dealt with an investigation by the federal police in the Rio Grande do Sul on milk adulteration. Police found in this investigation that some companies were adding urine and water into milk. In this context, students should argue on the role of these substances as adulterating agents. In this sense, 75% of the answers stated that water was added to increase milk volume, and urine had the same function as well as masking the density in laboratory tests. It indicates that students understood the activities on milk adulteration carried out during the didactic intervention. In item b, students should argue about ethical issues related to the use of scientific knowledge for food adulteration. In this case, 35% of the answers were categorized as adequate, and 40% as partially adequate. In the latter case, it means that they presented inconsistent arguments on ethical issues related to the use of scientific knowledge to obtain undue profits. On the other hand, students who answered adequately presented consistent arguments on ethical aspects. Additionally, the records of students in their portfolios were analyzed using the evaluative rubrics, according to Table 5.

Table 5 Frequencies, in percentage, of the categories of analysis obtained from the answers of students in the final questionnaire (HOCS problems).

	rubric analysis			
Portfolio Evaluation	Fully developed	Partly developed	Incorrectly developed	Undeveloped
Step 1 – Cliché	100 (n=20)	0	0	0
Step 2 - Spontaneous panorama	100 (n=20)	0	0	0
Step 3 – Invitation letter to experts	85 (n=17)	15 (n=3)	0	0
Step 3 - Consultation with Specialists and Specialties	95 (n=19)	5 (n=1)	0	0
Step 4 - Going to practice	100 (n=20)	0	0	0
Step 5 - In-depth opening of one or another black box	95 (n=19)	5 (n=1)	0	0
Step 6 - Global outlining of a technology	75 (n=15)	25 (n=5)	0	0
Step 7 - Opening black boxes without the help of specialists	95 (n=19)	5 (n=1)	0	0
Etapa 8 – Synthesis	40 (n=8)	40 (n=8)	20 (n=4)	0

Table 5 shows that the activities proposed in steps 1, 2, and 4 of the interdisciplinary rationality island were fully developed by students. In steps 3, 5, 6, and 7 only a low percentage (the highest percentage was 25% in step 6) of the students developed the activities partially, and the others fully developed them. Incorrect development was observed only in step 8. It happened because some students (20%) answered letters to community members but did not present alternatives to overcome the challenges found in dairy activity.

The combined analysis of results shown in Tables 2 to 5 presents the gains in terms of learning and problem-solving skills on dairy activity. It can be confirmed by the difference between the previous knowledge of students and their performance at the final questionnaire, with LOCS questions, and also by the results obtained when solving HOCS problems. This latter tool showed that they were able to reach higher cognitive levels, which, according to Zoller (1993), result in cognitive skills for oriented decision-making, development of critical thinking, as well as essential skills to deal with present problems in the context in which they live.

In this perspective, the application of the interdisciplinary rationality island contributed towards breaking with the teaching of natural science marked mainly by the disciplinarity oriented to decontextualized and low-order cognitive skills (LOCS). In other words, with a teaching model attached to neutral, linear, Cartesian, and positivist thinking, which emphasizes memorization, fragmentation, and simple reproduction of contents. The results clearly illustrated that the didactic intervention allowed moving to an interdisciplinary teaching approach centered on the students, leading to the development of higher-order cognitive abilities (HOCS) (Salvadó, Casanoves, and Novo 2013; Wilke 2003; Jones 2007; Monteiro and Smole 2010).

Another aspect of being considered is the promotion of scientific and technological literacy (Fourez 1997; Auler and Delizoicov 2001; Cajas 2001). In order to achieve this purpose, it is necessary to provide the knowledge and skills to enable students to creatively deal with the scientific knowledge present in daily life, solve personally challenging and significant problems, make responsible socio-scientific decisions (Holbrook and Rannikmae 2009) and, consequently, develop higher-order cognitive skills (Zoller 2000).

All these elements were respected for the development of the didactic intervention. During the course of the island, students were challenged to perceive their daily lives with the eyes of science in an integrated way with other areas of knowledge. It was possible through the selection of a thematic of great relevance that emerged from the dialogue with them. In addition, they were encouraged to develop the following skills foreseen by Fourez (1997): decision-making, identification of black boxes, search for strategies to solve the study situation, selection of specialists and specialties, articulation between ethical, political, and economic aspects, implications for science and technology, among others. In this sense, the present research also promoted the scientific and technological literacy of students.

In addition to these results, the hierarchical cluster analysis (Figure 1) was performed to obtain a systemic appreciation of student learning (before, during, and after didactic intervention). This analysis allowed identifying patterns of student answers.

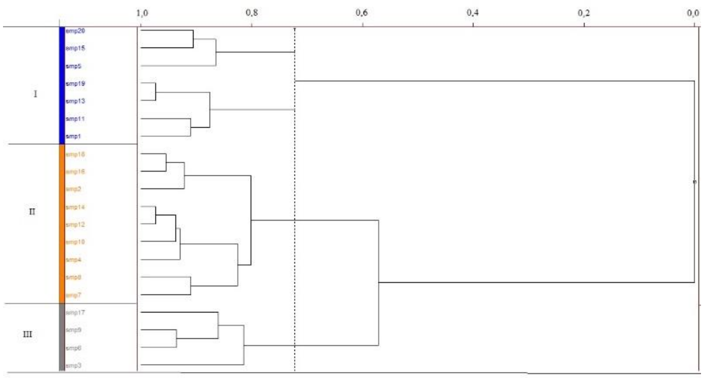

Fig. 1 Dendrogram obtained from HCA using the Ward/Incremental method and the Euclidean distance. The dashed line indicates 72.2% similarity of students. Data matrix X (20 × 4).

The mean values for the different data collection tools (Table 6) were calculated from groups formed by HCA (Figure 1). It allowed characterizing groups of students according to their answers on dairy activity.

Table 6 Means and standard deviation calculated for HCA clusters (minimum 1 and maximum 4).

Instrumentos	Group I (n=7)	Group II (n=9)	Group III (n=4)
LOCS questions (initial)	1.1 (0,1)	2.1(0.2)	2.8 (0.0)
LOCS questions (final)	3.3 (0,3)	3.5(0.2)	3.5 (0.2)
HOCS questions (final)	3.3 (0,2)	3.4 (0.1)	3.2 (0.2)
Portfolio (during)	3.9 (0,1)	3.9 (0.1)	3.9 (0.2)

Group I of HCA covers students with low previous knowledge (1.1±0.1) on dairy activity and high performance in the different used tools. Group II includes students with moderate previous knowledge (2.1±0.2) on the subject and also with high performance in questionnaires applied at the end of intervention and portfolio. Group III, on the other hand, is composed of students who had the highest previous knowledge (2.8±0.0) and high performance in questionnaires and development of activities of the island. These results show that the main difference occurred in the performance of students for the initial questionnaire. In this sense, Ulloa, Meraz and Ballesteros (2017) argue that previous knowledge is a complex variable that greatly determines the outcome of student learning in sciences. It is critical to success within the school environment.

These results show that although the students started from different points, they obtained significant gains in terms of learning and problem- solving skills on the subject of the study situation. It occurs especially because teachers have considered the different conceptions during classes, correcting incomplete or wrong previous knowledge so that students could learn new concepts. According to Lazarowitz and Lieb (2006), students may present many misunderstandings that could result in potential learning difficulties. Testing before starting a new subject can provide instructors with valuable information on previous knowledge, misunderstandings, and learning difficulties, in addition to serving to identify areas of potential learning to be explored (Lazarowitz and Lieb, 2006).

In short, the results of this research show that the student-centered learning environment provided through interdisciplinary rationality islands contributes to promote the learning of scientific concepts and develop skills necessary for the exercise of citizenship. According to the literature, it results in deeper learning than with lectures (Wilke 2003; Smith et al. 2009; Knight and Wood 2005) because of the involvement of students in academic activities and responsibility for their learning (Jones 2007; Monteiro and Smole 2010).

6. Conclusion

This research presented results obtained from the development and application of a didactic intervention using the methodology of interdisciplinary rationality islands. Three questions were expected to be answered: What is the relationship between students and dairy activity? Have the problems proposed in the study situation contributed to the promotion of scientific and technological literacy? Have students mastered scientific concepts and developed higher-order cognitive skills?

Most students had a direct bond to dairy activity (60%) although they had little previous knowledge on the technical and scientific aspects of milk. Regarding the second question, the results demonstrate that this initiative of innovation through islands has moved towards promoting scientific and technological literacy. In addition, the results also demonstrated significant gains in terms of learning and higher-order cognitive skills.

This set of results evidences the contribution of the present proposal in promoting the scientific and citizen formation of students through the study of concepts and themes that are part of their daily life. It allows students to develop the ability to express and position themselves in situations that require a critical and reflective understanding of scientific concepts. Thus, this proposal allowed leaving teaching based on memorization and reproduction of information and still fragmented and disciplinary, i.e., teaching that does not value life experiences of students.

The need for new studies on teaching methods that enable the academic development of students through stimuli to critical and creative thinking and collaboration between them is reinforced with this research perspective. They should be extensively investigated in the literature to break with the traditional teaching, the teaching of past centuries. Increasing the dialogue between the researches carried out in the area of education and schools is necessary to achieve this goal.

Finally, the investigation proposed in this study can easily be adapted to other levels of education and educational contexts.

References

Andrade, H. G. 2005. Teaching with rubrics: The good, the bad, and the ugly. College Teaching, 53(1): 27-31.
Auler, D., and Delizoicov, D. 2001. Alfabetização científico-tecnológica para quê?. Ensaio – Pesquisa em Educação em Ciências, 3(2): 122-134.
Bardin, L. 1977. Análise de conteúdo. Tradução de Luís Antero Reto e Augusto Pinheiro. Paris: Edições 70.
BRASIL. Ministério da Educação. 2018. Base Nacional Comum Curricular. Retreived on from: http://basenacionalcomum.mec.gov.br/wp-content/uploads/2018/12/BNCC_14dez2018_site.pdf
Cajas, F. 2001. Alfabetización científica y tecnológica: La transposición didactica del conocimiento tecnológico, Enseñanza de las Ciencias, 19(2): 243-254.
Cohen, B. H., and Lea, R. B. 2004. Essentials of statistics for the social and behavioral sciences. Hoboken: John Wiley & Sons.
Fourez, G. 1997. Alfabetización científica y tecnológica: Acerca de las finalidades de

la enseñanza de las ciencias. Buenos Aires: Ediciones Colihue.
Fourez, G., Maingain, A., and Dufour, B. 2008. Abordagens didáticas da interdisciplinaridade. Lisboa: Instituto Piaget.
Holbrook, J., and Rannikmae, M. 2009. The meaning of scientific literacy. International Journal of Environmental and Science Education, 4(3): 275-288.
Johnson, R. B., and Onwuegbuzie, A. J. 2004. Mixed methods research: A research paradigm whose time has come. Educational Researcher, 33(7): 14-26.
Jones, L. 2007. The student-centered classroom. Nova York: Cambridge University Press.
Lazarowitz, R., and Lieb, C. 2006. Formative assessment pre-test to identify college students' prior knowledge, misconceptions and learning difficulties in biology. *International Journal of Science and Mathematics Eduction*, 4(4): 741–762.
Knight, J. K., and Wood, W. B. 2005. Teaching more by lecturing less. *Cell Biology Education*, 4(4): 298-310.
Monteiro, L. P., and Smole, K. S. 2010. Um caminho para atender às diferenças na escola. *Educação e Pesquisa*, 36(1): 357-371.
Moran, J. M. 2017. Como transformar nossas escolas. In: M. Carvalho (Ed.), *Educação 3.0: Novas perspectivas para o ensino* (p. 63-91). Porto Alegre: SINEPE.
Moreira, M. A. 2011. Abandono da narrativa, ensino centrado no aluno e aprender a aprender criticamente. *Ensino, Saúde e Ambiente*, 4(1): 2-17.
Pereira, J. C. R. 2004. *Análise de dados qualitativos: Estratégias metodológicas para as ciências da saúde, humanas e sociais.* São Paulo: Edusp.
Roitman, I. 2009. Ciência para os jovens: falar menos e fazer mais. In: Werthein, J. Cunha, C (Eds.), *Ensino de Ciências e Desenvolvimento: O que pensam os cientistas* (pp.133-141). 2.ed. Brasília: UNESCO, Instituto Sangari.
Salvadó, Z., Casanoves, M., and Novo, M. 2013. Building bridges between biotech and society through STSE education. *International Journal of Deliberative Mechanisms in Science*, 2(1): 62-74.
Santos, H. G. *Ilhas interdisciplinares de racionalidade e o ensino de ciências da natureza*: construindo um ambiente de aprendizagem investigativo e interdisciplinar sobre a atividade leiteira. Mestrado Profissional em Ensino de Ciências- Universidade Federal do Pampa, 2019.
Sesen, B. A.; Tarhan, L. Active-learning versus teacher-centered instruction for learning acids and bases. *Research in Science & Technological Education*, 29(2): 205-226, 2011.
Sivan, A., Leung, R. W., Woon, C. C., and Kember, D. An implementation of active learning and its effect on the quality of student learning. *Innovations in Education and Teaching International*, 37(4): 381-389, 2000.
Smith, M. K., Wood, W. B., Adams, W. K., Wieman, C., Knight, J. K., Guild, N., and Su, T. T. 2009. Why peer discussion improves student performance on in-class concept questions. *Science*, 323(5910), 122-124.
Wilke, R. R. 2003. The effect of active learning on student characteristics in a human physiology course for nonmajors. *Advances in Physiology Education*, 27(4): 207-223.
Ulloa, L. H. A., Meraz, G. M., and Ballesteros, A. C. V. 2017. Test design to assess the qualities of science students' prior knowledge. In: *Handbook of Research on Driving STEM Learning With Educational Technologies* (p. 278-296). IGI Global.
Zoller, U. 1993. Are lecture and learning compatible? Maybe for LOCS: unlikely for HOCS. *Journal of Chemical Education*, 70(3): 195-197.
Zoller, U. 2000. Interdisciplinary systemic HOCS development–the key for meaningful STES oriented chemical education. *Chemistry Education: Research and Practice in Europe*, 1(2): 189-200.