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Problems in Physics Aimed at Biology: A Contribution to the Initial Formation of the Teacher through the Complexity in Problems Proposed by Halliday Volume II

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Keywords: *complex problems; physics teaching; biology teacher formation.*

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I. Introduction

The fragmentation of knowledge permeates all levels of education and can be identified in several undergraduate courses within universities. According to Rosnay (2013), this fragmentation can be observed in disciplines worked in isolation in schools, and within universities by the plastered curriculum, which leads to what Morin (2005) calls the fragmentation of identified content, as boxed in disciplines.

It is known that the structure of Brazilian education favors the perpetuation of mechanistic teaching, as its curricular basis is guided by the division of curricular knowledge. In this sense, the contents are mostly presented to students in a disconnected and meaningless way, causing them not to present the ability to raise hypotheses, argue and develop skills to solve problems that arise in their daily lives. The fragility in the division of contents leads to what Rosnay (2013) calls the loss of the global vision of the systems, which causes, within Science, a rupture of the disciplines popularly known as "sisters".

Such division enhances the misunderstanding of complex relationships within Science, in the basic formation of students by subjects such as, for example, Physics, Chemistry, Mathematics and others. According to Rosnay (2013), the disciplinary contents presented in basic education are guided by the microscope and the telescope, forgetting about a much larger world, the macroscope.

This fragmentation is also observed within Universities. Scientific knowledge is presented in parts, and students are not able to reconnect knowledge and envision the whole. Let's take Rosnay's question as an example:

> Why is blood red and the leaves green? Certainly, when asked, students will remember hemoglobin for blood and chlorophyll for plants, but if we think of a more complex relationship, they may never have heard of the porphyrin molecules present in each other that lead to this pigmentation, red and green. From this relationship, one can still explore energy in the biosphere from the Sun, the production and burning of energy by human beings, solar photons, the manufacture of carbon dioxide and sugar, thus exploring various areas of knowledge, and bringing the complex context for the classroom, but unfortunately, we do not find in the vast majority of books approaches of this type, neither in the basic education nor in the undergraduate books. (ROSNAY, 2013, p 496).

This type of problem-situation presented, are those defended by Jonassen (1997), which we call complex problems or without structure that, in addition to mathematical calculation, there is a need to know: Chemistry, Biology, Physics, etc. And for the students this is an unknown process, as they are not used to solving problems with this structure, not having the visualization of the whole process, only its fragmented parts.

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The complexity arises then, in order to reconnect knowledge within the Teaching Institutions and Science. Morin (1994) argues that reconnecting knowledge that has been fragmented is of Paramount importance for the construction of knowledge and deconstruction of mechanistic teaching, and one of the paths that we can follow for this deconstruction is the use of the complex problems brought by Jonassen (1997).

This work presents an excerpt from a more in-depth master's dissertation on the subject, and arises from the interest of researchers in analyzing the complex relationships present in the textbook "Fundamentals of Physics" by HALLIDAY, David; RESNICK, Robert; WALKER, Jearl. The book has IV volumes, and in volume II, there are several complex problems that do not focus only on Physics and permeate several areas, including the area of Biology. And we find it pertinent, for the discussion of complex problems and the initial formation of the teacher, which is our central research concept, since it presents problems related to fluids, which are linked to daily situations experienced by students, such as blood pressure and blood flow. Corroborating the definition of problems without structure defended by Jonassen (1997).

The research was developed at a Public University of Paraná, in a discipline that aims to promote the relationship of complexity and scientific literacy in the initial formation of Biology teachers. The objective, then, is to analyze the relations of complexity that emerged in the process of solving complex problems and their influence on the learning process, starting from the following problem: What is the influence of complex problems in Physicsin the learning process of undergraduate Biology students?

This work seeks to establish a new approach around complex problems, using the Grounded Theory as a methodological basis, which enabled the codification and saturation of data, as well as the analysis of complexity, and its importance in the process of initial formation of future teachers of Biology.

a) *Fragmentation of knowledge*

The curriculum structure of Brazilian education refers to mechanistic teaching, perpetuating the reproduction of knowledge. For students, there is a view of small fractions of knowledge that are unrelated to each other. This corroborates with one of the main problems of articulation of knowledge, since the contents are demonstrated without a real meaning, this lack of significance contributes to the difficulty of seeing the complex.

In the course of the learning process, we take a long time to understand the formation processes to which we were submitted throughout our school experience. Furth (1974) when referring to this process explains that "understanding is much more than transmitting external information. Understanding means restructuring the situation and transforming a given problem in terms of our own balanced internal structure" (p. 263). Thus, because it is an education system, which is often fragmented, it becomes difficult to restructure and see the problem in several dimensions and senses.

This fact goes back to the linear view of Science, and to the fragmented knowledge, exposed in isolated boxes. According to Rosnay (2013) "fragmented teaching leads to the reduction of knowledge to a certain number of disconnected disciplines, isolated from each other, it is an approach of an encyclopedic nature" (p. 494). The author also defines this teaching as analytical, knowledge separated, which separates the student from the totality of knowledge.

As this research aims to study and identify the construction of knowledge during the teacher formation process, let us take as a basis the description of fragmentation within universities, brought by Behrens (2013, p.23), according to this author, "the higher education system favors the fragmentation of knowledge, dividing the whole, dividing the courses into separate disciplines, periods and series. Universities organized themselves by dividing Science into departments, and this robotic process restricted each professional to hyper-specialization, thus causing a departure from reality in all aspects".

According to this author, the teaching system of universities has its methodology based on the creation of specialists in certain disciplines. The problem arises when we adopt this simplistic view, we are delimiting our vision, and not discussing problems with real social potential. This fragmentation of teaching ends up culminating in the reproduction of knowledge, which is characterized by fragmentation, since the pedagogical practice is centered on aspects such as: reading, listening, memorizing and repeating.

b) *The complexity*

The complexity tries to account for the mutilated knowledge within Science, as mentioned by Morin (2005), it struggles against the process of fragmentation and incompleteness of concepts that have a direct link between them, but that due to the mechanization of knowledge ended up being lost.

In this sense, complexity is a means of reconnecting and articulating knowledge, while simplifying thinking separates these different aspects, or unifies them through a mutilating reduction. We know that the education system needs to unify knowledge, bringing contextualization and the possibility of overcoming the barriers that divide knowledge. Lück (1995) defends an integrated teaching, where the subjects support each other, where students "can exercise citizenship critically and when faced with a global view of the world be able to face the complex, broad and global problems of the current reality" (1995 p. 64).

For Morin (2005), we are beings with intrinsic contextualization characteristics. From birth we have an innate curiosity, and we seek to discover and understand situations that surround us. But according to Morin (2013), in educational institutions, we are imposed hyperspecialization (specialization in a single knowledge), and we lose this characteristic, and we start not to group the information in a set, but in a fragmented way.

Morin's thinking (2005) argues that the Sciences must be integrated so that we can unite them and understand the interactions they make with each other. In the case of this research, which is part of a dissertation, even though Physics is the "sister" of the Biology, as Natural Science, at various favorable moments, the two are studied as if they had no relationship.

c) Complex problem solving

According to Jonassen (1997), Problem Based Learning (henceforth PBL) was initially developed in medical education in the 1950s, since students had an unsatisfactory clinical performance, which led to a fragmentation of health science. After the implementation of this technique, it was expanded to the educational area.

PBL is concerned with the learning that occurs in everyday life and it states that "by solving the various problems we face every day, we learn" (Barrows & Tamblyn, 1980, p. 10). In this way, we understand that we are in constant learning, as we are faced with the most diverse types of problems every day, and we provide them with different solutions.

For Jonassen (1997) "the few problems students encounter are usually well-structured (history) problems, which are inconsistent with the nature of the problems they need to learn to solve in their everyday lives" (p. 64). In this way, students are rarely adequately formed to solve problems within their social context, and this ends up fragmenting the knowledge that they assimilate during the educational process (JONASSEN, 1997).

Jonassen (1997) describes the problem-solving technique, and separates them into two niches: well-structured problems and those without structure. Well-structured or well-defined problems are those that are linear, and present a simple path to their resolution. Also according to Jonsassen (1997), well-structured problems are usually found at the end of textbook chapters and exams, and require the application of a finite number of concepts, rules and principles being studied in a restricted problem situation. Problems without structure are those that are presented in a complex way, i.e., there is more than one way to solve them, and the student goes through several areas of knowledge before reaching the final solution of the problem.

II. Methodology

For the development and collection of research data, action research was used (Tripp, 2005), associated with the Grounded Theory methodology (Strauss and Corbin, 2008) for data analysis. For action research, participant observation is inserted in order to contextualize and understand the research scenario, and together with Grounded Theory to analyze the data that were collected through the process of the three coding: open coding, axial coding and selective. These three processes, according to Strauss and Corbin (2008), offer subsidies for the anchoring of a new theory around the problem of study.

According to Strauss and Corbin (2008), in open coding, the process of data analysis begins. All the material collected is analyzed and re-grouped. For this moment we use three questions that are part of the process and are described by the aforementioned authors: Does this data refer to this study? What category does this indicator refers to? What is happening? It needs to be taken into account that these questions must Always be guided by the research problem.

In axial coding, the data are regrouped, analyzed in a deeper way, with the intention that the analysis categories emerge. The last coding is the most abstract, the data are analyzed again, and saturated in order to reach the central category, essential for the development of the new theory, which seeks to solve the proposed problem.

a) Research subjects and methodology steps

The research involved 26 undergraduate students from a public university in Paraná, in a discipline that seeks the scientific and technological literacy of students. To develop what we propose, we divided the application of the proposal into five stages, forming a didactic sequence. For this research, all its development took place remotely, within the virtual learning environment platform provided by the University.

The didactic sequence is composed of five steps, developed for the collection and analysis of data. All the steps were designed with the objective of putting the student in contact with complexity, extrapolating disciplinary concepts, so that they could solve complex problems (without structure) presented in different ways, not based only on problems with mathematical calculation, but those that consider, for example, social, historical, cultural, moral and ethical problems.

Step 1: In order to investigate the students' conception of complexity, and the relationship of complex problems, a questionnaire was applied containing five open problems on the aforementioned topic.

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The problems used in the questionnaire are shown in table 01:

Table 01: Questions from the initial survey questionnaire

Do you remember, during graduation, having solved complex problems related to the biological area?
What is a scientific problem? What is a problem?
What are complex problems?
How is a problem solved?

Source: The authors

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The main objective of this questionnaire is to learn about the initial conceptions that undergraduate students, future Biology professors, have on the subject. Then, the theme of complexity was introduced from a contrast between mechanized teaching and complex problems.

Step 2: In this activity, the intention was to incorporate the concept of complexity, during the formation process of the student and future teacher of Biology. The purpose of this activity was to watch a film, called Lorenzo's Oil, which explores the concept of complexity, in a real problem experienced by society, making students create cognitive structures that allow them to discuss the topic. For this moment, the students were instructed to develop a map or mental network around the complex elements observed in the film.

Step 3: To introduce the concept of problem solving and complex problems, a discussion paper called "Toward a design theory of problem solving" and a video entitled "Problem Solving" were used. The problem chosen for this discussion was the complexity involved in Covid-19. The main objective of this activity was to verify if the students had rooted the concept of complexity, and if they had the vision of a real complex problem, its social interactions and their relation with the environment. At this time, there was a discussion of the complexity of Covid-19 through maps and networks around the theme "complex relationships extracted from Covid-19".

Step 4: The objective of this class was to bring students closer to the topic "Blood Pressure", a topic which was taught in more than one discipline during the undergraduate course in Biology. Blood pressure is a very important key concept for the formation of the future teacher because when studying anatomy and cell biology, students explore several concepts such as: veins, arteries, capillaries, venules, heart shape, blood bombardment, which are intrinsically linked to blood pressure.

The use of maps and networks made it possible for us to analyze the change in concepts that are being structured during each activity, and thus have the means to use the Grounded Theory coding processes. Since, at this point, the students have already developed skills to look at the whole, as a whole, not dissociated from the parts.

Stage 5: In this stage, the complex relationships established by the students were analyzed when solving complex problems, present in the textbook of Halliday volume II. The previous steps are implemented as pilot classes, aiming to develop more critical readings of real situations, and possible complex relationships. Ten complex problems of Physics focused on Biology were chosen so that they could solve and extract the relations of complexity. This moment was favorable for the students to use their ability to organize data from the problems, their different readings and interpretations.

Jonassen (1997) argues that using group formation when solving complex problems is a fruitful way of learning. Thus, they were helped on the Moodle platform to enroll in one of the five groups available, choose three complex problems, carry out their resolution, and develop a map, a network, or a flowchart about these relations, so that they could be later discussed with the class.

III. Results

At this point, the report of the activities and the discussion about the data collected regarding the five stages applied are presented, in the form of a didactic sequence. The developed sequences were based on the theme of complexity, using the problem solving theory proposed by Jonassen (1997), and the methodology of the Grounded Theory of Strauss & Corbin (2008).

For the first step, as proposed in the first class, the students answered the initial survey questionnaire. This was the first contact of many with the complexity and discussion of complex problems, which explains the vague knowledge on the subject. It was noticed that the students were not able to answer all the questions accurately, because they lack conceptual background to define the answers. The answers are presented below for each question, identified by an alphanumeric indicator, according to Table 02:

Table 02: Placement of students in solving complex problems

Some students' statements about whether they had solved complex problems
A1: "A complex problem does not come to mind now. Because I can't say what a complex problem is"
A2: "I remember solving problems with definitive solutions, reaching a final conclusion, such as mathematical and physical calculations. But complex problems that generate new questions and do not have a final solution, I have not had the opportunity to experience it yet".
A3: "Yes, in the disciplines of Interdisciplinary Project and CTS, all projects have a problem solved".

Source: The authors

Student A2's answer presents as a reflection the importance of establishing complex relationships, since he claims to have solved mathematical and physical problems, but that he had not yet experienced complex ones. According to Morin (2005) the fragmentation of teaching prevents concepts from being worked on in their entirety. It can be seen that, even without this conception, the student states that problems solved merely with the application of formulas are not complex, approaching the well-structured and unstructured problems described by Jonassen (1997). On the other hand, student A3 states that he has already solved complex problems in the Interdisciplinary Project discipline, and that in all projects that are developed in this discipline, it is necessary to solve some type of complex problem.

According to Jonassen (1997) most students do not solve complex problems. Table 02 shows that students showed difficulty in describing a complex problem, as they had not discussed these relations in the classroom, so the concepts presented were not part of the reality experienced by students in most classes of the Biology course. Such property leads students to a hyperspecialization of their area of knowledge, as defended by Morin (2013). It is important to emphasize that this feeling of not knowing and not having had contact with complexity was already expected, since our objective is to show its importance in the construction of knowledge.

Data coding during questionnaire analysis

In Grounded Theory, Strauss and Corbin (2008), describe the three questions that should be asked when starting the data collection process through open coding, which are:

(i) Does this data refer to this subject?
(ii) What category does this indicator refer to?
(iii) What is happening?

To start the open coding, referring to the answers of the initial survey questionnaire of the 26 students, the authors use the title of this work, aiming to identify the first categories of analysis. These steps are described in Grounded Theory, defended by Strauss and Corbin (1990), according to table 03:

Table 03: Initial analysis categories

Search Title	Analysis Categories
Complexity Relations in Solving Physics Problems Proposed by Halliday – Volume II: Assumptions for Initial Teacher Formation	(green) Teacher Formation; (yellow) Problem Solving; (red) Complexity.

Source: The authors

After defining the categories of analysis, the structuring of the 130 responses obtained in the application of the questionnaire was followed. Subsequently, the verification was carried out to see whether each answer met one, one, two, or the three defined analysis categories.

The open and axial coding categories were defined by colors, for better visualization, as can be seen in table 04.

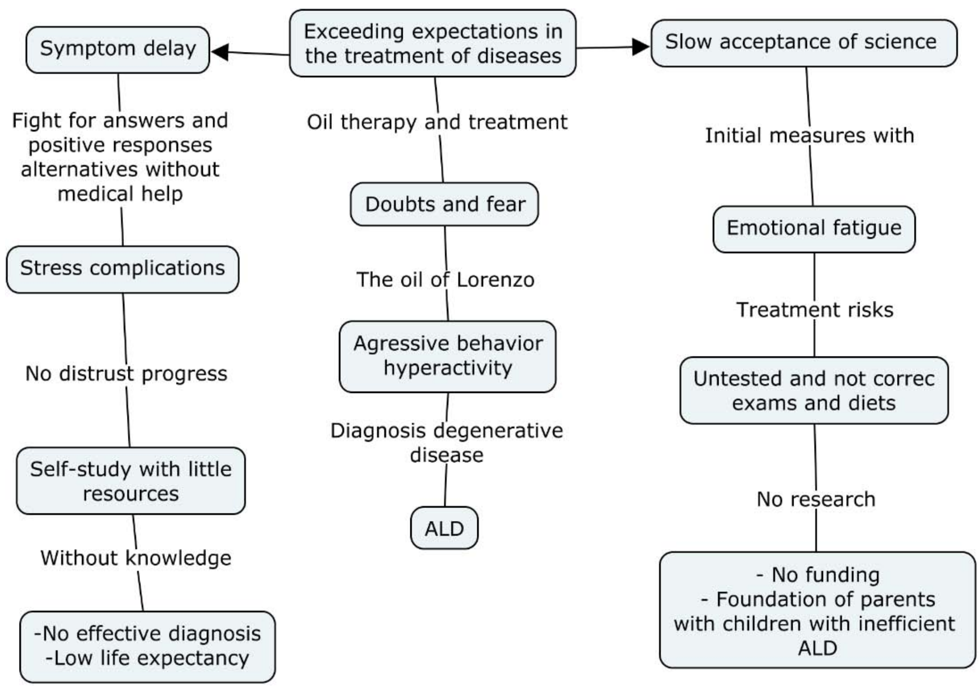
Responses that did not meet any of the categories were discarded.

Table 04: Open and axial coding for the questionnaire question

Open coding	Codes/Categories	Axial coding/Subcategories
A1: I don't have enough basis to distinguish that it was in fact a complex problem.	What would that base look like?	Search Investigation Theorical knowledge
A2: Even if they are not resolved, I believe that complex problems generate new questions and do not have a final solution.	What makes you have this concept of a complex problem, if you haven't solved any yet?	
A3: Normally at APCC (practical classes as a curricular component)	The disciplines being the same for all students, what could be used to root this conception? *Emerging code:* Importance of disciplines that encourage critical thinking and student development.	

Source: The authors

In step two, the activity was the discussion of maps and networks about the film "Lorenzo's Oil". Below are some of the selected maps (Figure 01) in order to guide the discussions and analysis of the results, which were part of the data collection and analysis



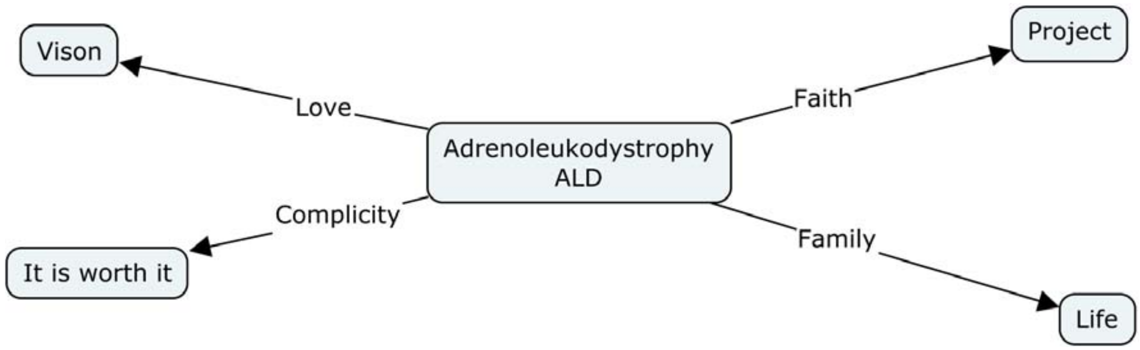
Source: Student A1 (2021)

Figure 01: A1: Complex relationships "Lorenzo's Oil"

Student A1 while analyzing the complex relations presented in the film, made some complex connections such as: the delay in the disease Adrenoleukodystrophy (ALD) due to the lack of research; lack of funding; the fear of the family that culminated in psychological exhaustion; and a slow science, which delayed the study of disease. In the speech of student A1, it is possible to analyze that, although he showed doubts about the concept of complexity, during the discussion of the maps, he understood that the approach is beyond internal discussions, i.e., it is centered on the discipline, corroborating with Morin (2005), who argues that complexity is a global view of the world. According to student A1:

> I tried to extract the complex relations from the film, but I still wasn't sure what those relations were. [...] I researched a little, and I think I understood a little more. Now lisstening to your explaination, I'm starting to understand what complex relations mean. I had thought it was just internal relations, but it is much more than that ... (AUDIO TRANSCRIPT BY THE AUTHORS DURING THE VIDEOCONFERENCE CLASS, A1 – FIELD JOURNAL dated 9/25/2021).

In figure 02, the analysis of student A2 is presented through the network of concepts, and through its collaboration we extract the relations for the analysis.

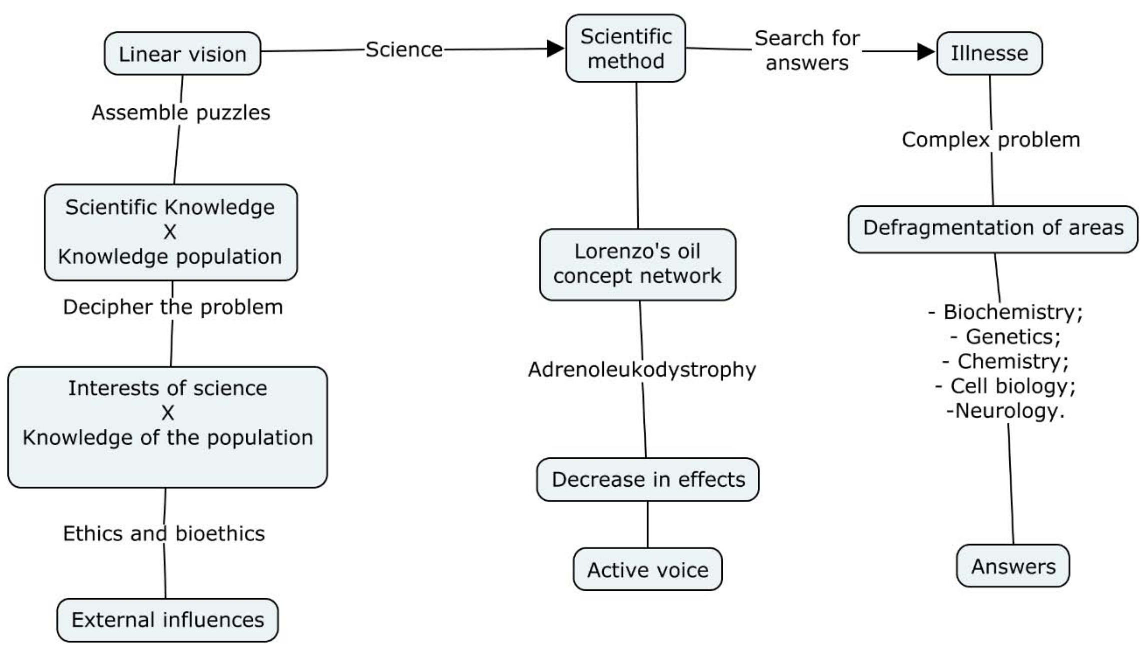


Source: Student A2

Figure 02: A2: The complex relationships "Lorenzo's Oil"

Student A2 did not extract deep complex relations. According to Jonassen (1997), this type of failure is common, as students are not familiar with the topic. Their relations focused on the feelings that emerged in the family during the struggle to find a cure, not extrapolating linear relationships.

On the other hand, we observed that student A10 (figure 03), through the presentation of the content of the previous class, obtained a broader analysis, he was able to see beyond the complex biological processes, and the interactions between areas of knowledge, such as Chemistry, Biochemistry , Genetics, Neurology, among others. The student described a linear view of Science in relation to the disease, which fragmented knowledge so that it was not possible to assemble the puzzle, emphasizing that in order to solve the problem, it was necessary to defragment the areas.



Source: Student A10

Figure 03: A10: Complex relationships "Lorenzo's Oil"

In the A10 student network, it is possible to identify complex relations and, as Morin (2005) defends, a broader view of the problem. However, as there is no familiarity with the topic (Jonassen, 1997), the concepts are still shallow. This is in line with what Blumer (1969) defends, that the more contact human beings have with certain situations, the more schemas will be consolidated. In table 05, it is possible to analyze the speeches referring to this process of discussion of maps and networks during the discussion of the groups.

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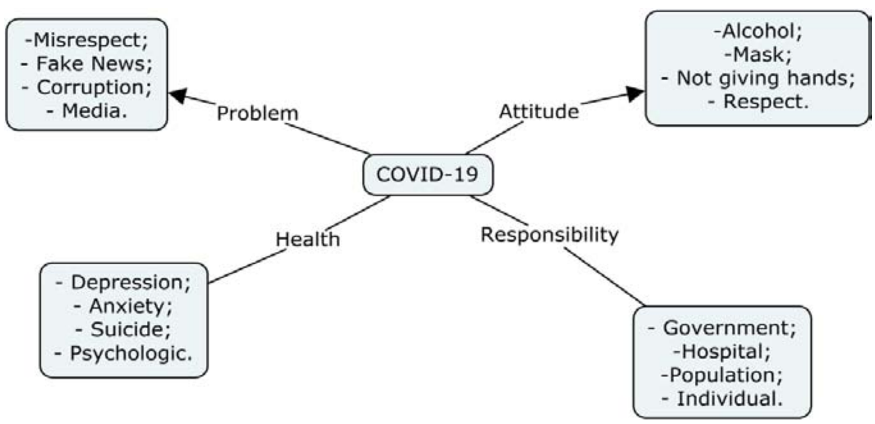
Table 05: Open and axial coding of Lorenzo's Oil film.

Open coding	Codes/Categories	Axial coding/subcategories
A1: I related the term with CTS, because I already took this course [...] I also read Edgar Morin, the study textbook, Reconnection of Knowledge	The importance of the STS discipline for critical training	• Teacher training • Concrete examples
A2: I was in doubt, I remembered the example you gave, the porphyrin molecules, explaining several concepts, and so I think I managed to open the box a little	Importance of concrete examples	

Source: The authors

The emerging categories at this step, analyzing the maps, and the students' speech fragments, show a need for concrete examples to understand the complexity, as well as a deeper relation with the disciplines, which can be solved with teacher formation. Figure 04, as part of step three, it shows that the relations of complexity began to be deepened by the students.



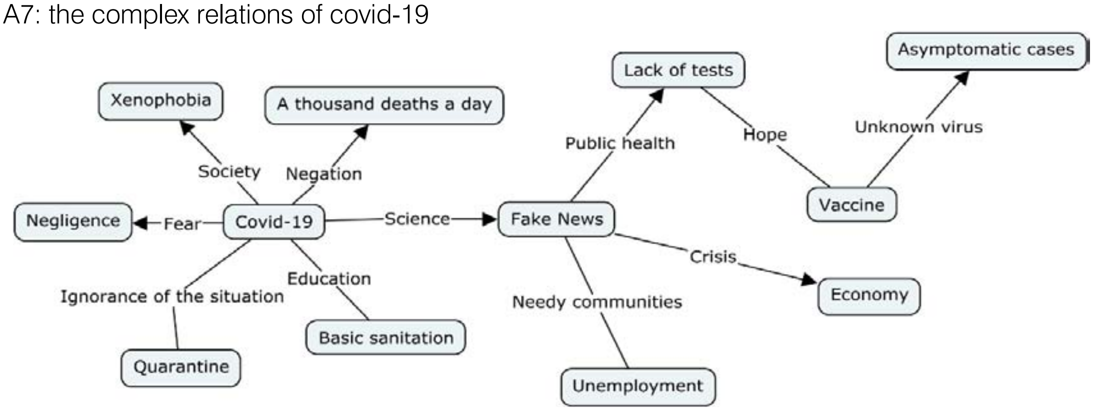
Source: Student A1

Figure 04: A1: The complex relations of covid-19.

In the scheme of student A1, the expansion of concepts in relation to complexity can be seen, as the student managed to leave the general theme, and establish relations with other areas of knowledge. This fact is explained by Morin (2013), who states that by extrapolating disciplinary concepts, we reconnect lost knowledge in several areas of knowledge. It is possible to notice that the student organized the problem and delimited the complex relations, placing the first relations of health, demonstrating the problems that worsened such as: suicide, depression and anxiety.

Figure 05. A7: the complex relations of covid-19

In figure 05, as in student A1, a broader theorization of concepts can be seen, which according to Jonassen (1997), shows that the more complex problems are analyzed, the more concrete concepts will emerge in the process.



Source: Student A7

Figure 05: A7: The complex relations of covid-19

An important fact about the Covid-19 problem that student A7 demonstrated was the reflection on Fake News, which delay knowledge about the disease, since during the pandemic several theories emerged against the development of the vaccine and Science. At this stage, based on Jonassen (1997), complex relations are developing, and students are already able to discuss the topic in question. Then, in Table 06, the moments of open and axial coding of the Covid-19 problem, and their reflections are presented.

Table 06: Open and axial coding of the Covid-19 problem

Open coding	Codes/Categories	Axial coding/Subcategories
A1: I remembered the STS teacher's classes, some discussions of other disciplines, and reading I realized how complex this problem is, so I was able to see more things, and I also researched a lot on the subject.	The importance of the CTS discipline, for a more critical view	• Teacher training • Search • Empirical knowledge
A2: I related to several things that I saw, the government saying the virus in China, saying that there is no research at a public university.	Dexterity, when formulating relationships through observations of real situations	

Source: The authors

At this step, the importance of teacher formation is shown, whereas during this process, the student relates complex issues such as Covid-19 with the CTS class, when the student starts to organize the relations, avoiding the fragmentation of knowledge as evidenced by Morin (2013).

In step four, in regard to the discussion of complex blood pressure relations, it was one of the most problematized moment, where more questions arose, which involved basic physics, applied physics, biological sciences and fluids I, the students already had theoretical knowledge of the theme, and there were reports of greater difficulty. We can observe the map of student A2 (figure 06), and A3 (figure 07).

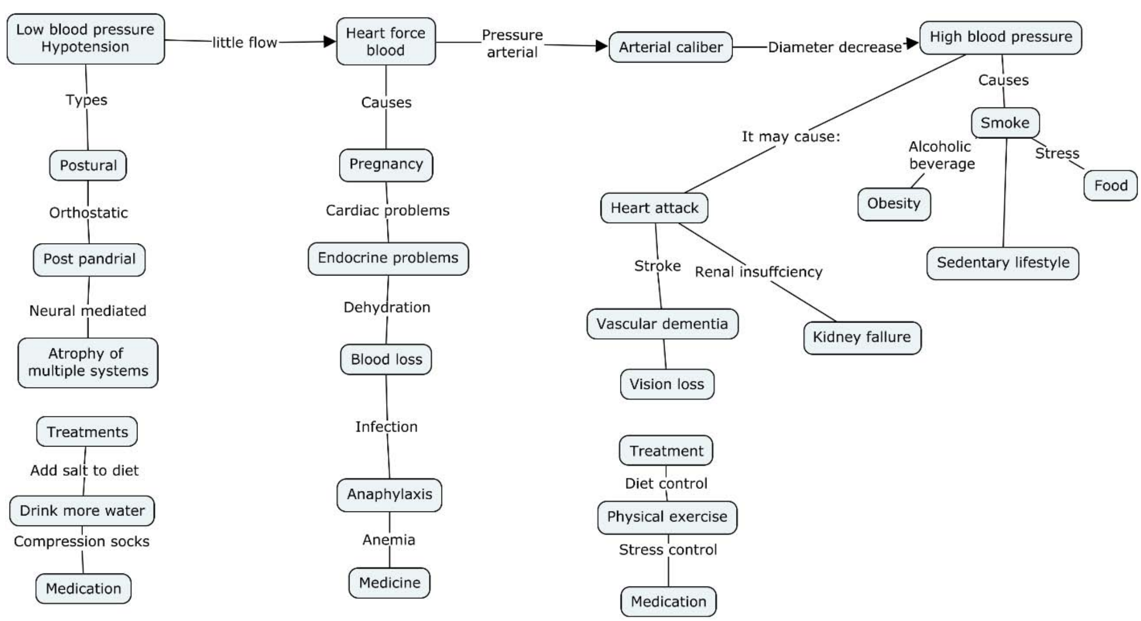
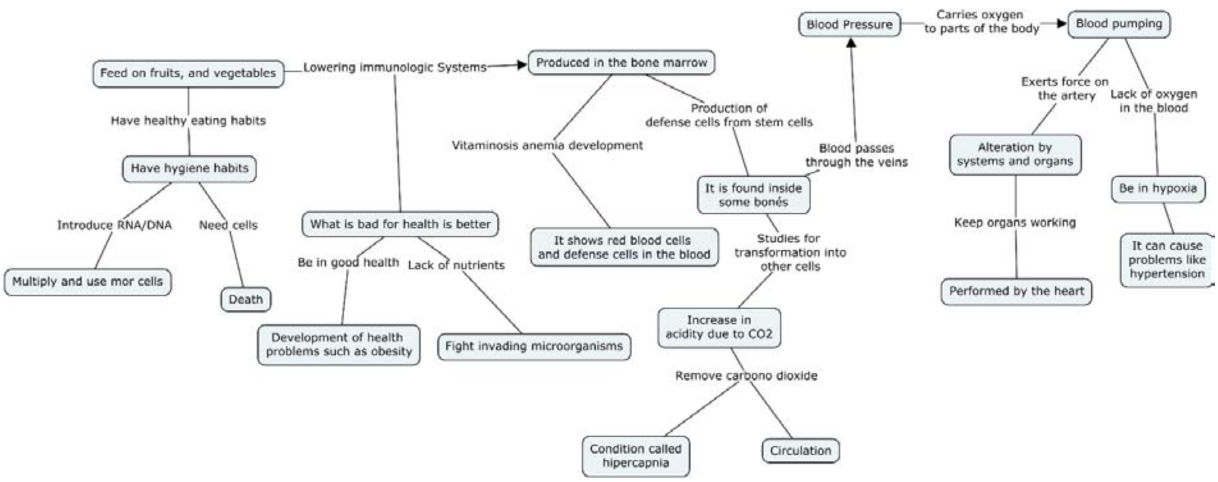


Figure 06: A2: Complex blood pressure relations



Source: Student A2 and A3

Figure 07: A3: Complex blood pressure relations

In both A2 and A3 student relations, a large number of more in-depth complex relations stand out when compared to the first maps. That is, the ability to solve complex problems begins to emerge (Jonassen, 1997). Table 07 presents the speech of students A2 and A3, during the dialogue used in the process of open and axial coding, and their reflections.

Table 07: Coding open and axial blood pressure

Open coding	Códigos/Categorias	Codificação axial/subcategorias
A2: We study pressure in Physics and Biology and in none of the disciplines do we address the history and development of blood pressure [...]	Awareness that complex concepts are not addressed in the classroom.	• Curiosity • Search • Historical Appreciation
A3: I knew what blood pressure, systole and diastole were, but I had never stopped and thought about other relationships. [...] so I researched more, and saw a lot of interesting things from the history of the development of the sphygmomanometer, I think this complex relationship of science caught my attention.	Knowledge of the topic, but without the establishment of complex relationships Search for a better understanding of the concept and science.	

Source: The authors

In the speech of student A2, the conceptual domain of the problem discussed through the research is noted, in his map we see the relations between the discipline of Physics and Biology, and the interest in the historical development of the sphygmomanometer (curiosity and historical appreciation). In the speech of student A3, the complex approach was not explored in the classroom.

Thus, in relation to step five, the problem solving step, ten complex problems were used in the dissertation, listed in table 08:

Table 08: Complex Halliday Problems

Complex Problems	
1)	A novice diver, practicing in a pool, draws in enough air from the tank to expand his lungs before leaving the tank at depth L and swimming to the surface. He ignores instructions and does not exhale during the ascent. Upon reaching the surface, the difference between the external pressure to which it is subjected and the air pressure in the lungs is 9.3 kPa. How deep did it start? What risk are you taking?
2)	The femur, which is the main bone of the leg, has a minimum diameter, in the male adult of approximately 28 cm, what is the value of the compressive load necessary to break it?

3)	The cross-sectional area A_0 of the aorta (the largest artery emerging from the heart) in a normal person at rest is 3 cm², and the velocity u_o of the blood is 30 cm/s. A typical capillary (diameter 6μm) has a cross-sectional area of 3.10^{-7} cm² and a flow velocity v of 0.05 cm/s. How many capillaries does this person have?
4)	During World War II, a damaged freighter barely able to float in the salt waters of the North Sea was wrecked as it sailed up the Thames towards London docks. Why?
5)	Blood takes about 1.00 s to pass through a 1.00 mm long capillary in the human circulatory system. If the diameter of the capillary is 7.0 μm and the pressure drop is 2.60 kPa, determine the viscosity of the blood. Assume laminar flow.
6)	A fish maintains itself at the same depth in fresh water by adjusting the amount of air in porous bones or air pockets to make its average density equal to that of water. Assume that, with empty air pockets, a fish has a density of 1.08 g/cm3. To what fraction of its new volume must the fish inflate the air pockets to make its specific gravity equal to that of water?
7)	Divers are advised not to travel by air for the first 24 hours after diving because the pressurized air used during diving can introduce nitrogen into the bloodstream. A sudden drop in air pressure (such as when an airplane takes off) can cause nitrogen to form bubbles in the blood, capable of producing painful or even fatal embolisms. What is the pressure change experienced by a special operations soldier who dives to a depth of 20 m one day and parachutes from an altitude of 7.6 km the next day? Assume that the average density of air over this range of altitudes is 0.87 kg/m³.
8)	Argentinosaurus blood pressure. (a) If the head of this gigantic sauropod was 21 m high and the heart 9.0 m high, what gauge (hydrostatic) pressure was needed at the height of the heart so that the pressure in the brain was 80 torr (enough to supply the brain)? Assume that the density of Argentinosaurus blood was 1.06 × 10³ kg/m³ (b) What was the blood pressure (in torr) at the animal's feet?
9)	In a giraffe, with the head 2.0 m above the heart and the heart 2.0 m above the ground, the gauge (hydrostatic) pressure of the blood at the level of the heart is 250 torr. Assume the giraffe is standing upright and the specific gravity of the blood is 1.06 × 10 3 kg/m³. Determine the arterial (manometric) pressure in torr (a) in the brain (the pressure must be sufficient to supply the brain with blood) and (b) in the feet (the pressure must be compensated by the stretched skin, which behaves like an elastic stocking).). (c) If the giraffe were to lower its head sharply to drink water without spreading its legs, what would be the increase in blood pressure in the brain? When a pilot takes a very sharp turn in a modern fighter plane, the blood pressure in the brain drops and blood stops supplying the brain. If the heart maintains the gauge (hydrostatic) pressure of the aorta at 120 torr when the pilot undergoes a horizontal centripetal acceleration of 4g, what is the blood pressure in the brain (in torr), located 30 cm from the heart towards the center of the curve? The lack of blood in the brain can cause the pilot to see in black and white and the visual field to narrow, a phenomenon known as "tunnel vision". If it persists, the pilot may suffer the so-called g-LOC (g-inducedlossofconsciousness — loss of consciousness induced by g). The specific mass of blood is 1.06 × 10³ kg/m³

Source: The authors

Of these ten problems, two of them are systematized here. The choice was made because they are the problems with the most complex relations formed, i.e., the problems in which students most identified relations outside physics, and identified several areas of knowledge, which were the most discussed ones during the resolution step, as according to the concept of complexity brought by Morin (2013). At this point, Jonassen's (1997) problem solving steps are presented, in which students developed skills in extrapolating complex problems, as mentioned by Morin (2005). Students began to observe the whole, and not just the fragmented and separated parts in isolated boxes.

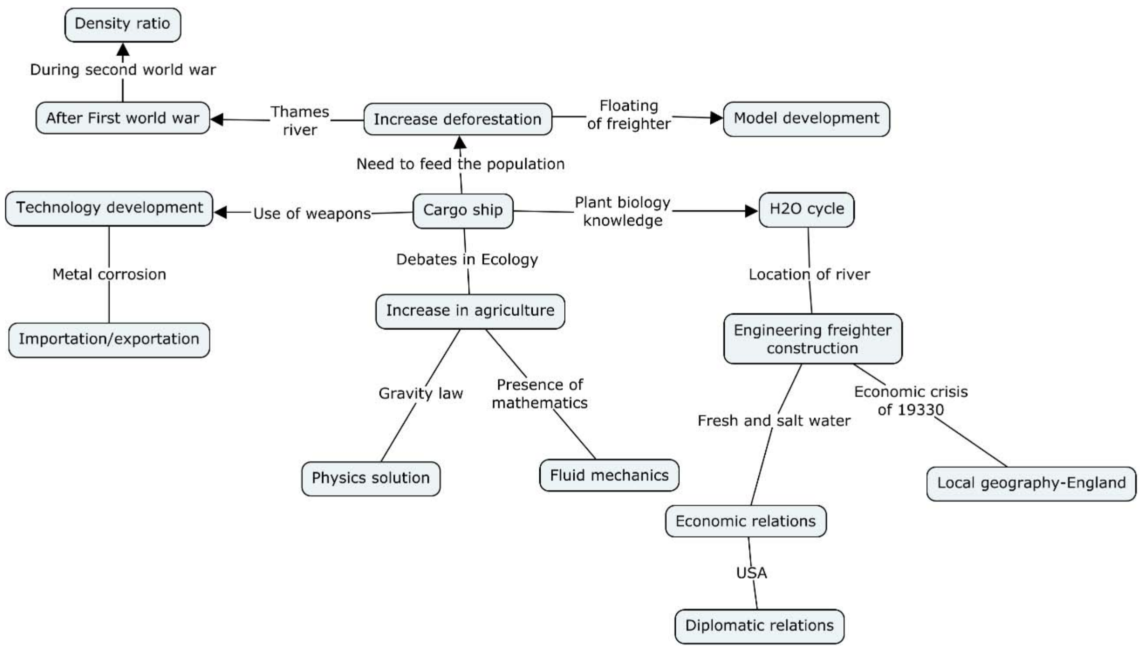
Problem 1: During the Second World War, a damaged freighter that was barely able to float in the salty waters of the North Sea, sank because it went up the Thames towards the London docks. Because?

Complex relations:

- History;
- Geographic;
- Social;
- Economical

Resolution:

The freighter sank due to the difference in density between salt and fresh water. As fresh water is less dense than salt water, the freighter was able to float smoothly. Already, when it started to navigate in salty waters, the ship sank, not being able to maintain the necessary balance to float at a greater density.



Source: Student A1

Figure 08: A1: Freighter Problem 1

In figure 08it is noticeable from a simple problem of density difference, that student A1 was able to formulate several complex relations, before reaching the resolution of the physics present in the problem. The student established relations with the economy of the time, the geography of the place, the First and Second World Wars, and the influence of the USA during this War process, the development of new technologies, the relations of the ecology, fauna and flora of the place, as well as several other complex relations that the reader can analyze on the map, and which were extrapolated by the most different areas of knowledge, leading us to what Morin (2013) calls the reconnection of knowledge. Diversified knowledge, aligned for the construction of scientific knowledge, i.e., lost knowledge that were unified and woven together, for the observation of a whole much greater than the sum of the parts (MORIN, 2005).

Problem 2: Argentinosaurus blood pressure. (a) If the head of this gigantic sauropod was 21 m high and the heart was 9.0 m, what gauge (hydrostatic) pressure was needed at heart level for the pressure in the brain to be 80 Torrs (sufficient to supply the brain)? Assume that the specific mass of Argentinosaurus blood was 1.06×10^3 kg/m^3 (b) What was the blood pressure (in Torrs) at the height of the animal's feet?

Complex relations:

- Historical;
- Blood circulation;
- Animal kingdom;
- Paleontology;
- Geology / Earth formation
- Mesozoic era
- Triassic, Jurassic and Cretaceous.

Resolution

head height = 21 m→ p?

heart height = 9,0 m→ $p = torr \rightarrow 10665{,}8\ Pa$

The gauge pressure is given by:

$$p = p_o + \rho . g . h$$

Where p_0 is the pressure in the brain

- $\rho = \ Especific\ mass\ \rightarrow \rho = 1{,}06.10^3 \frac{kg}{m^3}$
- p= heart pressure.

$$p_{heart} = 10665{,}8\ Pa + \left(\frac{1{,}06.10^3 kg}{m^3}\right).\left(9{,}8\frac{m}{s^2}\right).\ (21m - 9m)$$

$$p_{heart} = 10665{,}8\ Pa + \left(\frac{1{,}06.10^3 kg}{m^3}\right).\left(9{,}8\frac{m}{s^2}\right).(12m)$$

$$p_{heart} = 10665{,}8\ Pa + 124{,}656.\ 10^3\ Pa$$

$$p_{heart} = 135321{,}8\ Pa = 1{,}4.\,10^5\ Pa\ ou\ 1{,}0.10\ \ torr$$

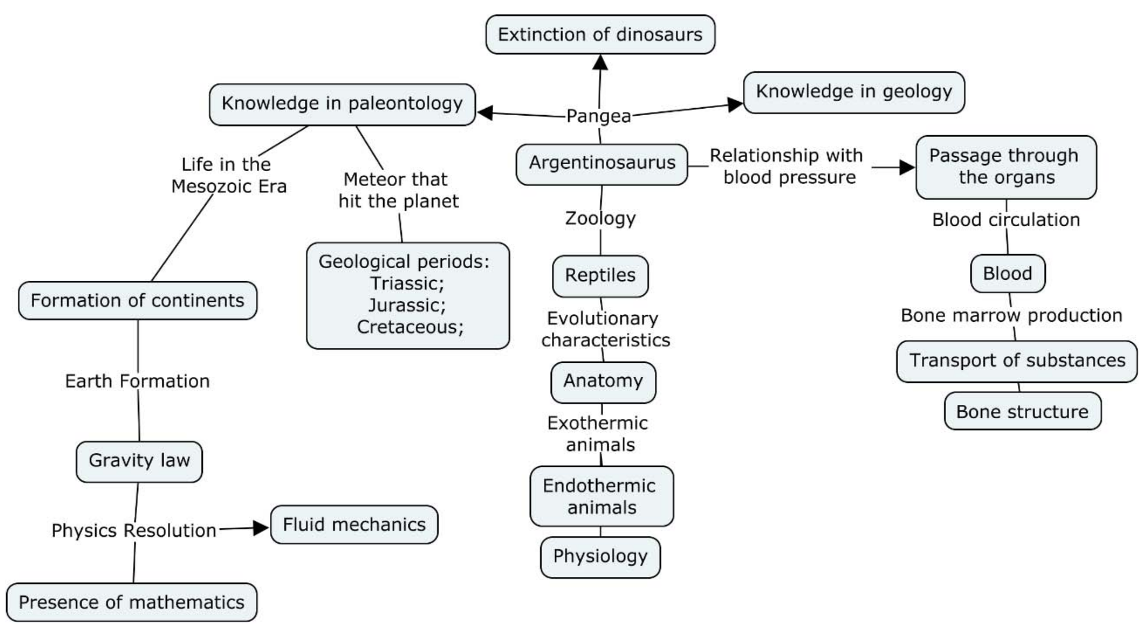
b) $p_{feet} = p_{brain} + \rho . g . h_{head}$

$$p_{feet} = 10665{,}8\ Pa + \left(\frac{1{,}06.10^3 kg}{m^3}\right).\left(9{,}8\frac{m}{s^2}\right).\ (21m)$$

$$p_{feet} = 10665{,}8\ Pa + 218{,}48.10^3\ Pa$$

$$p_{feet} = 228.813{,}8\ Pa = 2{,}3.\,10^5\ Pa\ ou\ 1{,}7.10^3\ torr$$

Figure 09: A2: Complex relations of Argentinosaurus –problem II



Source: Student A2

It is notable the presence of several complex relations in figure 09, of student A2, and its complexity relations with various areas of knowledge. It is important to point out that even though some problems were repeated in the teams, the mathematical resolutions were the same, however, the complex relations established are completely different. This aligns with what Jonassen (1997) proposes, when he states that students are individuals who have individual skills, and therefore, putting them to solve problems without structure (complex), as a team, brings out the best that each one has to offer, corrobohating what Morin (2005) who describes it as thinking outside the box, building knowledge in various different ways, since the proposal of using problems of this type is to demonstrate that the calculation itself is not enough, there is much more to be explored.

It is possible to verify an "outside the box" thinking both in the network in figure 08 of the freighter, and in the network in figure 09 on the problem of Argentinosaurus. The students make connections with knowledge that would not be discussed if the focus of this work was not driven towards complexity. Students showed a greater interest in discovering different relations within the problems they are solving. In the network that relates to Figure 09, the change of conception that the students had is clear, we identified several complex relations, such as those related to the biosphere, the atmosphere, the layer of gases, the lithosphere, in order for them to be able to build a resolution to the problem.

For Morin (2005), complexity gives students meaning and leads them to reflect on the real problems of their daily lives. "It is necessary to say that it is not the amount of information, nor the sophistication in Mathematics itself that can provide relevant knowledge, but the ability to put knowledge in context" (MORIN, 2005, p. 37). Reinforcing the importance of working with problems that are part of the students' daily life, as pointed out by Jonassen (1997).

The two problems highlighted present a simplistic solution from a mathematical point of view, and it could be solved only with the direct application of physical formulas, but the act of extrapolating to different situations such as the role of ships during World War II, of relating a shipwreck with water pollution, with the birthplace of an ecosystem for new fish, with the political situation in Brazil, shows that when they developed the key concepts for the answer to the problem, they passed through other areas, building a knowledge that made sense. As student A1 reports:

> We didn't find it a difficult exercise, you know, it took a while to pay attention to the density of the water, and to relate it to the shipwreck. But I don't think we would think about the other things if we weren't studying complexity. We would describe the difference in density and that's it. (AUDIO TRANSCRIBED BY THE AUTHORS DURING THE VIDEOCONFERENCE CLASS, A1 – FIELD JOURNAL OF 10/23/2020).

In the reports, we identified a broader view of complexity and its relations, since at the beginning, students had difficulty articulating the concepts studied with complexity, and could not relate to the biological concepts that they had already studied in the classroom. This fact can be observed in the first map, on the film Lorenzo's Oil (figure 02). By comparing it with the network of complex problems (figure 08), it is notable that there was an evolution in the conception of complexity, in conformity with Jonassen (1997), when stating that the resolution of problems without structure (complex), happens in stages.

Also, future Biology teachers, who have never had contact with complex problems, as detected in the collected data, were able to identify the relations and they realized the importance of this approach in the classroom, as demonstrated by the speech of student A2:

> I never thought about solving problems of this type, at first I found it very difficult, because I couldn't see the complex relations, but then I realized that complexity is in our daily problems, and that we can use these situations to teach the most diverse content in the classroom. (AUDIO TRANSCRIPT BY THE AUTHORS DURING THE VIDEOCONFERENCE CLASS, A2 - FIELD JOURNAL OF THE DAY, 10/23/2020).For all the data in this research, the moments of open and axial coding were performed, to arrive at the emerging subcategories, presented in table 09.

Table 09: Codingopen and axial to complex problems

Open coding	Codes/Categories	Axial coding/Subcategories
A1: It's different to solve it that way, because you organize things, you see that it's not just numbers, there are things behind it. When would we research the political relations of the time? Or look over the Themes	Organization of problem-solving steps; Importance of research for discovering complex historical relationships	• Resolution Strategies (blue) • Search (purple) • Historical Appreciation (pink)

Source: The authors

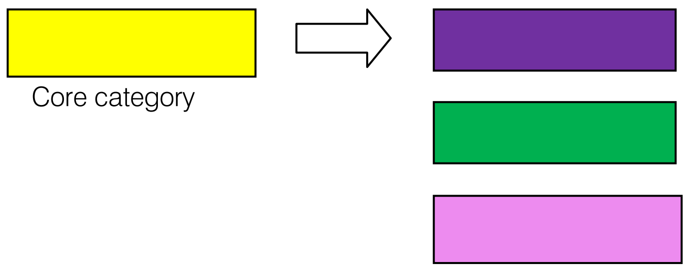
The importance of three codes during the problem solving step is highlighted: research, resolution strategies and historical valuation. All these codes were refined again in selective coding, which is described below, as a result of the theoretical contribution, according to Grounded Theory carried out.

a) The theoretical contribution around complex problems

The last step of Grounded Theory data encoding is selective encoding. In this step, all the codes that we identified in the previous steps are saturated so that we can highlight the central category, and around it describe our theoretical contribution to complex problems.

Our phenomenon of study is complexity. The research phenomenon is the learning relations built by Biology students when solving complex problems. The context is Biology students and the strategies used to achieve the objectives, i.e., all the processes described in the results, to reach the central category, which is the use of Grounded Theory for new approaches to complexity in problem solving.

The research contribution around the resolution of complex problems, starts from the following codes confronted with the situations described above, and sustained by Strauss and Corbin (1990).



Source: The authors

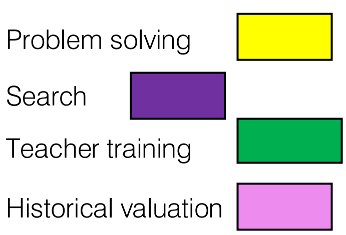


Figure 10: Central category after selective coding.

The central categories, which emerged from the research, prove to be valuable in solving complex problems for teacher formation. And this relation emerged from the speeches, networks and problem solving made by the students. It is important to note at this point that we will not rely on any theoretical aspect, as we aim to present theoretical support, through data from this research. The problem solving theory proposed by Jonassen (1997) was developed by Biology students in solving complex problems. The problems are not equivalent in] terms of form and resolution process, as shown in the students' maps, networks and flowcharts, in which complexity relations prevailed. The theoretical concept of complexity (MORIN, 2013) enabled students to build complex relations, opening the door to different resolutions and types of problems, followed by creations, schemes and new possibilities in problem solving.

Jonassen (1997) states that in order to solve a problem without structure, that is, a complex one, the students need to recognize the complexity of the problem, exercise varied reasoning according to the context, be familiar with what is solved, develop a cognitive structure respecting the culture and the context they experience. In order for students to be familiarized with approaching complex problems, it is necessary to invest in their formation, in order to overcome the mechanization of teaching and encyclopedic classes.

Also, in the course of problem solving, it is possible to perceive the contact students have with CTS and Scientific and Technological Literacy through the discussions they presented in the discipline - Interdisciplinary Projects V.

This discipline enhances in the students the treatment with the resolution and visualization of complex relationships, seeing the whole. This indicator reflects the importance of this type of formation, so that students may be successful in approaching complexity, in varied problems, describing a learning relation, developed by the students themselves, and the need for disciplines that awaken such conceptions.

Another indicator, which reflects a learning relationship, is the historical valuation of the problem. In the HALLIDAY textbook, D; RESNICK, R; WALKER, J, volume II, there are very rich problems for this purpose. The students' reports show that working from complex situations is new, and that they motivate thinking beyond the discipline in the process of forming the education professional. Historical appreciation is important in the construction of knowledge, as it signals that the concepts were not generated in a linear way, but that there are adverse situations, relations to bem ade with other theorists, representations within art, music, which enrich the discussion, which may make students more interested in the subject, as they are able to see that beyond mathematics, there is a chronological order that is not addressed in class. This question, as it is possible to observe in the coding processes, was created by the students, who delimited that this is an important fact, that they needed to know the history in order to have a broader view of the problems.

Another indicator refers to a learning relationship in the construction of knowledge: research. Analyzing the questionnaire, the networks and the speech fragments, we identified the term several times. Showing that students established research as a means of organizing relationships and understanding problems. The networks built, all the knowledge involved was beyond Biology. The topic addressed generated several ramifications on the same problem, validating the importance of research in the learning process, as it contributed to the non-reproduction of content, and to a broader learning of the complex concepts of Physics. Thinking about teaching complexity encompasses a teacher formation that allows students to relate the production of knowledge in the most diverse areas, as discussed here: Science, History, Art, Music, Theater, Ethics, Geography, etc. Although this relation appears to be difficult, it is possible.

Problem solving, as the central category of this research, was only satisfactorily developed by the support of the three categories, which are: research, teacher formation and historical valorization, which together aimed at expanding the students' worldview, future teachers. It is clear that the act of solving complex problems puts the focus on making sense of the solution and not simply applying to it a mathematical equation. Unlike what happens with well-structured problems, complex problems cannot be solved through impartiality, but it aims at a social, historical logic, one of affective relationships, one which aims at knowing how to act in the face of pre-defined knowledge.

VI. Conclusion

The relations of complexity obtained during the problem solving process, culminated in the change of students' conception around complexity; the use of pilot classes on the theme of complexity; and Halliday's complex problems enabled the construction of knowledge around complexity, as well as extrapolation in relation to the construction of concepts beyond mathematics.

Complex problems showed a strong influence on the students' view of the whole, and not the fragmented concept, so that when solving the problems, the students themselves defined the paths for solving them, and understand the relations of complexity through from Grounded Theory. Halliday's textbook was of fundamental importance, because in addition to underpinning physical concepts, it showed that it is possible to establish several complex relations, and to teach Biology and Physics, together with the most diverse areas of knowledge.

In this way, the mechanization of teaching can be modified with the use of complexity and with a greater investment in the formation of future Biology teachers, in regard to the preparation of these professionals inside and outside universities, who, when knowing the complexity and complex problems, without structure, can thus broaden their view of the world.

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