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A processual view on the use of problem-based learning in high school physiology teaching

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Abstract

In problem-based learning (PBL), the steps and processes present in the PBL tutorial cycle are essential for constructive, self-directed, collaborative, and contextual student learning. This article presents a procedural study of a PBL tutorial cycle with high school students new to the method regarding human respiration and circulation physiology. We observed group dynamics and the learning process that occurred throughout the PBL tutorial cycle. The results indicate that conceptual changes were close to the planned learning objectives and that students enjoyed studying applying PBL. Moreover, a positive correlation was observed between group dynamics, self-directed learning and learning outcomes. Our results provide grounds for restructuring the tutorial cycle, especially important for novice PBL students, such as problem reformulation and the development and diversification of applied learning scaffolds. We conclude that the qualitative analysis performed herein can yield a deeper understanding of the PBL tutorial cycle and may be used to foster PBL implementation in institutions with little experience with the method and monitor its outcomes in organizations with mature PBL use.

conceptual change; high school; problem-based learning; qualitative analysis

INTRODUCTION

Problem-based learning (PBL) is considered "one of the most popular student-centered pedagogies in use today" in higher education (1). Despite widespread PBL research in undergraduate education (2–4), this is a relatively unknown field at the high school level (5). Some evidence concerning its benefits have been reported (6, 7), as in Biology (8, 9) and Chemistry (10) education. However, fewer examples are available when assessing physiology education in high school settings (11). In a recent systematic review concerning PBL in high schools, Wilder (12) notes that, despite most studies demonstrating positive evidence, caution is recommended, due to insufficient long-term data concerning PBL use at this level. However, considering the almost ubiquitous effects of PBL on communication, interaction, self-directed learning (SDL), and problem-solving abilities (13, 14), it is important to investigate the relevance of PBL use in high schools.

In PBL research, the usually applied method consists in a quantitative data collection at the beginning and end of the activity or coursework (4, 15). Comparisons may also be performed between courses with a structured PBL curriculum and others with distinct approaches. This has been one of the main focuses of academic discussions in the last three decades (16–18). Although extremely important to validate the use of PBL as an instructional methodology, research under this scope does not produce much information on how the processes present in PBL result in positive content acquisition by students (19, 20), which can result in limited PBL functioning understanding (15).

Due to this research bias, studies related to intrinsic PBL processes are scarce (15, 19, 21). Some examples include studies related to the role of the tutor in the tutorial cycle (22), the motivational situation of students throughout the tutorial cycle (23–25), the tutorial cycle process as a whole (26), and the observation of conceptual changes (27). The first studies with a procedural PBL approach exhibited a qualitative character (19, 28), the subject of criticism due to inherent technical and interpretative challenges (4). However, a recent movement has emerged in defense of these practices (18, 29, 30), whose basic purpose is the search of understanding how a successful approach to PBL is effectively applied. In view of this situation, the present study seeks to understand the application of PBL for the teaching of respiratory

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physiology and human circulation in a procedural manner, using qualitative analyses.

MATERIALS AND METHODS

We conducted a case study of a PBL tutorial cycle performed in a second-year high school class at the Federal Institute of Acre (IFAC), located in the city of Rio Branco, Acre, Brazil, between October and November 2016. In Brazil, a high school degree offers general instruction and Biology is part of student formation in the entire 3-yr duration. Therefore, the sampled students have taken Biology classes since their first year of high school. The IFAC is part of a network of public federal institutions present in every Brazilian state that offers vocational courses integrated with high school formation. The IFAC also offers postsecondary education, but these courses are not in the scope of this study. A case study is an empirical investigation of a phenomenon in its real-world context, to verify how and why observed results were produced (31). We focused on conceptual changes that occurred throughout the PBL tutorial cycle. Conceptual changes refer to the knowledge restructuring that occurs in students during the advancement of the educational process (27). In addition, we observed students' PBL perceptions during the case study, by applying a questionnaire survey. This study was approved by Oswaldo Cruz Institute Research Ethics Committee (CAAE 53356115.9.0000.5248).

Tutorial Cycle Application

Initially, we formulated a problem according to the 3C3R model (32, 33). Briefly, this model seeks to ensure the structuring of central components in the problem (the 3 "C's": content, context, and connection), which refers to the adequacy of the problem in providing the knowledge itself, allowing for the achievement of instructional objectives and goals; and procedural components (the 3 "R's": research, reasoning, and reflection). These will, in turn, foster student engagement and the subsequent development of important cognitive processes, such as problem solving and self-directed learning (SDL) skills, which will aid in achieving the expected learning results (32, 34). The applied problem was set as follows, and more details about its formulation can be found in Ref. 34:

> "Today Julius, a 19-yr-old who works as an information technology manager, wants to celebrate his driver's license that has finally arrived. Therefore, he decides to go to Mico's Rock bar with his friend Ed. Excited about the victory and the night scene, Julius cannot resist and drinks a glass of beer. Seeing this, Ed says:
>
> 'Jeez Julius, we were already going, but now we can't, otherwise you'll get in trouble if you have to undertake a breathalyzer assessment!'
> To which Julius retorts:
>
> 'No problem dude, it's just a beer! We'll wait fifteen minutes, I'll wash out my mouth, chew a piece of gum, and this alcohol will be gone in no time!'
>
> Is Julius right? You, as a group, must give the answer. Initially, the Brazilian Traffic Code must be observed. This code does not permit the presence of any trace of alcohol in the driver's body. Any driver caught under the influence of alcohol with up to 0.29 mg of alcohol per liter of exhaled air is committing a "very serious" offense (7 points deducted from the driver's National Driver's License), with penalty fines (R$2.934,70) and suspension of the right to drive for twelve months. The vehicle is also held until the presentation of another person able to drive the driver home.
>
> To examine whether the law is being fulfilled, the police use a breathalyzer to verify the presence of alcohol in exhaled air. The person to be tested must blow into a tube for 5 s. The equipment operates through a chemical reaction between the exhaled air (oxygen gas and alcohol, if the person has been drinking) and a fuel cell, which causes the release of electrons (the higher the alcohol content, the more electrons are released), which in turn generates an electric current that can be encoded by a microchip as information concerning alcoholic concentrations.
>
> Finally, keep in mind the route that the alcohol present in the drink will take. Where does the substance go through, after being ingested? How long will the alcohol remain in Julius' body until it is eliminated? These are the first things to consider. Remember that, although the effects of alcohol on the nervous system are an important and interesting topic, research on that subject now will not aid in deciding if he was right or not in his statement. To check on your work progress, we will get together in five days, and you will report any progress made: how you conducted the research, what you were able to conclude until now and why you came to these conclusions. Get to work!"

The learning objectives of the developed problem were for the students to understand the human respiratory and circulation physiologies, being able to apply this knowledge to understand how ethanol is transported throughout the body until being exhaled. We then performed the seven-step tutorial cycle in the second-year class (35), as presented in Table 1. The tutor was the first author who has taken several PBL courses throughout his doctoral course and has acquainted himself with practical PBL in an incursion to a university that applied PBL for medical formation. The class consisted of 36 high school students (20 males and 16 females, aged 15 to 18 yr old and an average age of 16.3 yr) with no prior experience with PBL instruction. The students were randomized using the Random UX App, separated into 3 groups of 12 people. A precycle meeting was carried out on *day 1*, in which we explained what PBL is and how the activity would be carried out. The beginning of the tutorial cycle involved the first five steps (*day 2*), and each group participated separately in this process (1 1/2 h for each group), which was fully recorded in audio. The students conducted the self-directed study (*step 6*) over 5 days, between *days 2* and *5* and then met again with their group (*step 7*; *day 6*), to integrate the acquired knowledge into a satisfactory explanation for the phenomenon described in the problem (36). The students had 7 days to compile their results, and each group gave an oral presentation, which was fully filmed, and delivered a written report (*Day 12*).

Table 1. *PBL Tutorial Cycle schedule according to the "seven steps"*

Activities	Day			
	1	2-5	6	12
PBL introduction	X			
Step 1: Clarify not readily comprehensible terms and concepts		X		
Step 2: Define the problem		X		
Step 3: Analyze the problem		X		
Step 4: Draw a systematic inventory of the explanations inferred from *step 3*		X		
Step 5: Formulate learning objectives		X		
Step 6: Collect additional information outside the group (SDL phase)		X	X	
Step 7: Synthesize and test the newly acquired information			X	
Result presentation and final discussion				X

See Ref. 35. PBL, problem-based learning; SDL, self-directed learning.

The oral presentation should contain: *1*) the process by which they identified the relevant knowledge and found the solution to the problem; *2*) the hypotheses they worked with; *3*) the topics they researched; and *4*) the conclusions they came to. The report included data common to all students in the group (hypotheses, development, and conclusion) and a section in which each student described what was researched and how this research contributed to the final conclusion at which the group arrived (adapted from Ref. 37). At the end of the tutorial cycle, a round of final discussions was held, aiming to foster the reflective component of the 3C3R model (32, 33). It is important to state that, of the 36 initial sample, only 28 students (15 males and 12 females, aged between 15 and 18 yr old averaging 16.3 yr old) participated in the entire PBL tutorial cycle (i.e., performed all activities present in Table 1) and were considered in the study.

Descriptive Tutorial Cycle Analysis

The tutorial cycle was analyzed considering the audiovisual material and the reports of the collected groups, comprising two research *foci*: *1*) the student learning process throughout the cycle, observing the initial group hypotheses concerning ethanol transportation throughout the human body and the conceptual change provided by the tutorial cycle; and *2*) the interpersonal dynamics among the participating students, aiming to verify how they affected the cycle in general, as well as the learning process. To increase reliability, the analysis was performed independently by two researchers who met at the end of the evaluation period to verify the similarities and differences between what had been found and produce a final compilation (adapted from Ref. 38). From this analysis, we created an illustrative scheme concerning the alcohol trajectory in the human body in relation to the hypotheses created by the groups and the knowledge demonstrated after the tutorial cycle.

Student Perception Questionnaire

At the end of the tutorial cycle, students were asked to voluntarily and anonymously answer a questionnaire. Of the twenty-eight students that complete the PBL Tutorial Cycle, one male student refused to answer the questionnaire, with 27 students remaining in the sample. The questionnaire consisted of 11 objective questions and an open question, aiming to observe general student perceptions concerning the method. Some questions were adapted from Ref. 39 and others were conceived based on Ref. 37. The answers to the objective questions comprised a five-point Likert scale (40), ranging from 1 (strongly disagree), 2 (disagree), 3 (does not agree nor disagree), 4 (agree), and 5 (strongly agree). A graph displaying the box plot for each statement was created using the Prism v.5.01 software (Irvine, CA) to facilitate the visualization of agreement differences between statements (41). Regarding the open question, answer categories were created through a content analysis and answer quantifications for each category were plotted.

RESULTS

We expected students to be able to understand ethanol transportation throughout the body until its exhalation with the tutorial cycle, as well as the required processes (diffusion, for alcohol transportation between different media, and Boyle's law concerning alcohol transportation from the alveoli to atmospheric air). Figure 1 exhibits an illustrative scheme of alcohol transportation throughout the human body in relation to the hypotheses created by the groups and their knowledge demonstrated after the tutorial cycle created from the descriptive analysis of the tutorial cycle.

Among the student hypotheses concerning how alcohol is exhaled into the breathalyzer, *group A* formulated the hypothesis of "gaseous alcohol": the alcohol would somehow undergo a chemical reaction in the stomach, which would not cause any structural molecular changes (that is, the ethanol would continue as ethanol) but would transform the alcohol into a gas state, which would lead to its reverse trajectory to the mouth, "as well as the driver's breath" (student's own words). This hypothesis, created by one of the students, was not accepted at first by the others, but after a brief discussion, the group members agreed to at least investigate it.

Another hypothesis was proposed by *group C*, which established a relationship between blood and saliva components, as follows: if alcohol is present in the blood, it would also be in the salivary glands, which would produce alcohol-containing saliva. This saliva would then be detected by the breathalyzer. We believe that these hypotheses motivated students to search for information in the SDL phase, especially among those who made the suggestions.

A consensus was noted for the groups concerning the premise that alcohol would be transported from the digestive system (whose correct trajectory they did not know, although the subject was addressed in previous series) to the

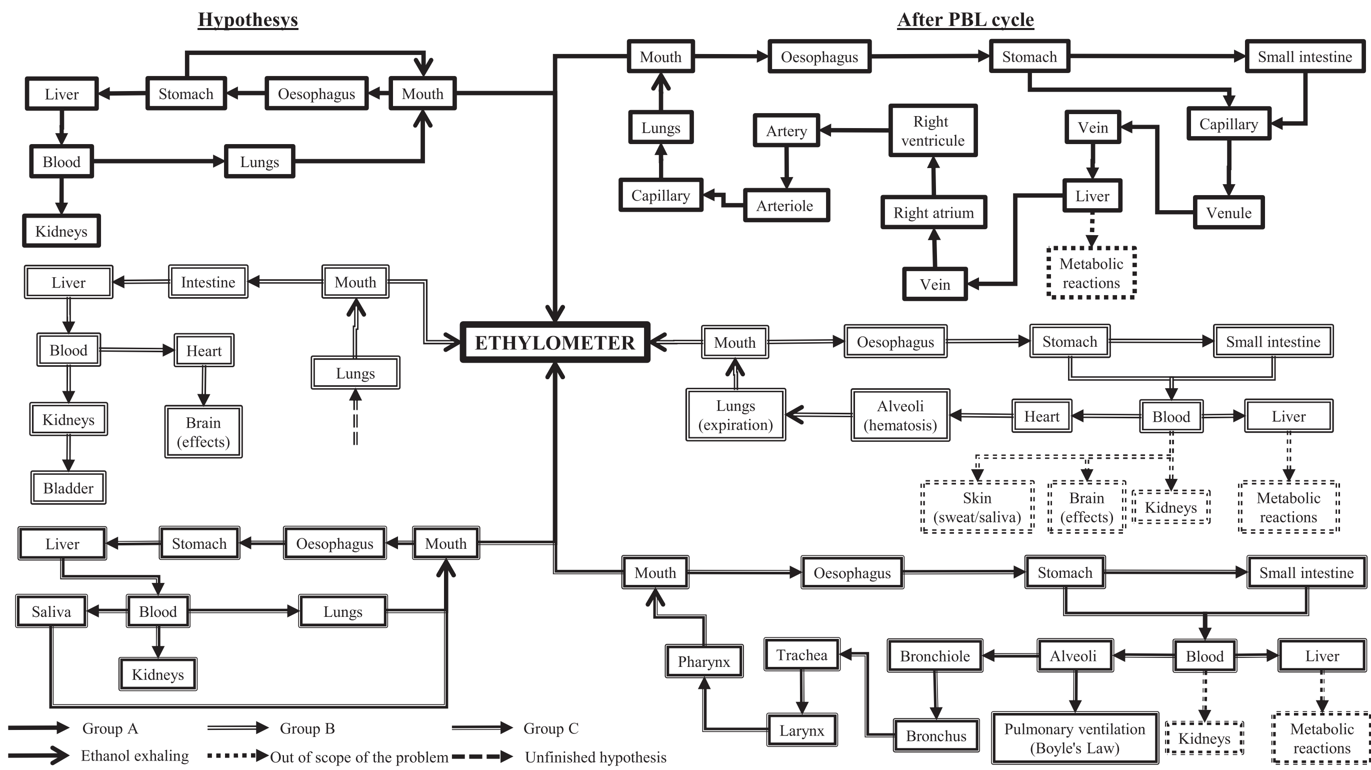

Figure 1. Illustrative scheme concerning the hypotheses generated by the groups (*left*) and subsequent explanations at the end of the tutorial cycle (*right*). PBL, problem-based learning.

liver, although they were not sure how this would occur. We assume that this hypothesis is due to the fact that some students had the prior knowledge (common sense) that the excessive and continuous use of alcohol can result in liver diseases. We did not plan to work with the hepatic portal system in this tutorial cycle. The original idea was that students understood that alcohol would spread from the digestive system, more specifically, the stomach and duodenum, to circulatory system vessels. However, due to the difficulty in explaining this trajectory in the initial phase of the tutorial cycle, some students explicitly reported the motivation to seek explanations in the SDL phase.

An explanation that alcohol elimination would occur essentially via the renal system also emerged in all groups. However, at that time the tutor's intervention was required to suggest that the discussion be limited to alcohol elimination via the respiratory system. *Groups A* and *C* were able to establish the hypothesis that a relationship between the circulatory and respiratory systems exists, placing such a hypothesis as one of the points to be studied. In *group B*, the students did not establish this relationship, indicated by the dotted arrow (Fig. 1), so the hypothesis was then directly suggested by the tutor.

The schemes concerning the group explanations made at the end of the tutorial cycle (Fig. 1) provide evidence that groups discussed the metabolic reactions that occur in the liver, now in more detail thanks to the self-directed study, although this was not a predicted focus for this tutorial cycle. It was evident that the students refined the explanation of how alcohol enters this organ, especially *group A*, which even went into greater detail concerning the hepatic portal system.

Although we pointed out that metabolic reactions and other means of alcohol elimination were not the focus of this tutorial cycle, the groups also brought this information. This is not a problem, if they also exposed the correct understanding of the learning goals at the end of the cycle. In this regard, *Groups A* and *C* brought complementary information, i.e., some conceptual contents that were insufficiently discussed by one of the groups were satisfactorily presented by the others (Fig. 1). *Group B*'s performance, however, was worrying, as the students' explanation of the problem fell short of what was expected. Considering the audiovisual material collected, it is noteworthy that this was the group whose initial discussion was considered the least productive, either due to low student participation or because of a lack of objectivity when discussing the problem, implying a potential causal relationship between these factors.

At the end of the group presentations, we held a final discussion, in which the tutor performed interventions and theoretical explanations seeking to highlight the observed learning gaps and brought in additional discussion points, aiming to foster the reflective component of the 3C3R structure. We subsequently administered the questionnaire concerning student perceptions regarding PBL.

Figure 2 presents the box plots for the objective question answers on the Likert scale (answer frequencies are presented in Supplemental Table S1; all Supplemental material is available at https://doi.org/10.6084/m9.figshare.14648904). The questions with the highest agreement value were those

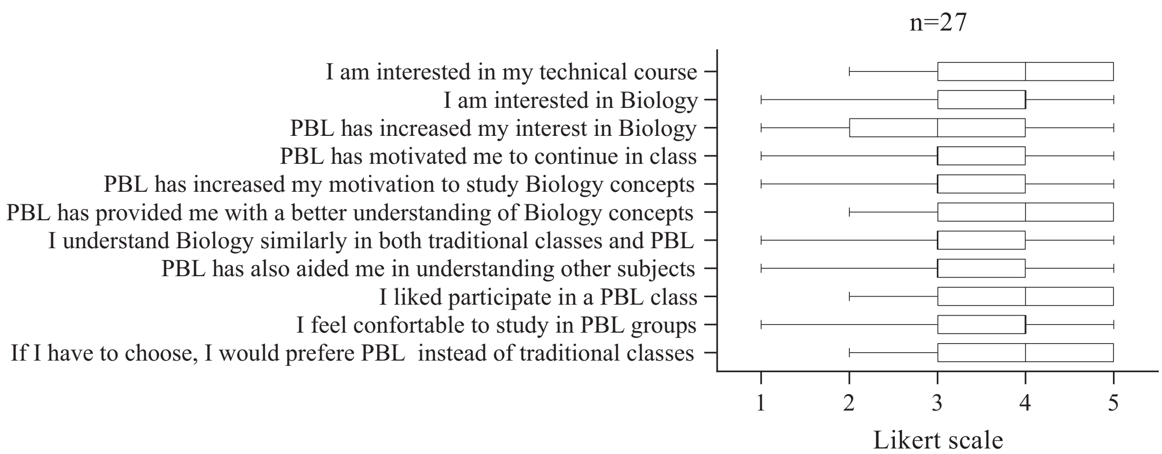

Figure 2. Likert scale values concerning student responses to the questionnaire regarding the use of problem-based learning (PBL), presented as box plots. Whiskers represent the minimum and maximum values and are presented as a line inside the box. When the 2nd and 3rd quartiles exhibited equal values, the median is represented by the thickest end.

related to the student's interest in the course and positive PBL impression statements, such as having liked participating in the tutorial cycle, greater understanding provided by the methodology, and that, if they could choose between PBL and traditional education, they would choose the former. The statement with the lowest value in the first quartile was the one that explored the idea that they would increase their conceptual Biology understanding by applying PBL (Fig. 2, "PBL has increased my interest in Biology").

The answer categories created from answers to the open-ended questions are presented in Table 2. We grouped and quantified student responses in each of the categories, expressing answer frequencies in absolute values and percentages in relation to the total number of given responses. An initial observation indicates a clear division between positive (81.5%) and negative (18.5%) impressions regarding PBL.

Among positive impressions, many students (25.9%) addressed the idea that working as a group during the tutorial cycle was good for content understanding. The responses also highlighted that the methodology is motivating (18.5%)

Table 2. *Categories of answers given by students to the open question*

Categories	Total (%)
Positive feedbacks	
Overall positive impressions	2 (7.4)
Studying with PBL was motivating	5 (18.5)
Studying with PBL improved understanding	2 (7.4)
Group discussions improved understanding	7 (25.9)
Self-directed studies improved understanding	2 (7.4)
PBL was better than traditional methods	4 (14.8)
Negative feedbacks	
Overall distress with PBL	2 (7.4)
Difficulty with PBL group discussions	2 (7.4)
Traditional classes are better because I am used to them	1 (3.7)
Total	27 (100.0)

Open question was "Why would you like to continue, or not continue, taking classes applying Problem-Based Learning in your course?" Answers were obtained through a content analysis ($n = 27$). Answers were separated between positive and negative feedbacks, and the totals in each category are presented as total and percent values. PBL, problem-based learning.

and better than traditional education (14.8%), corroborating the high Likert scale values obtained for similar questions (Fig. 2). Negative impressions (Table 2) included reports about the difficulty of working with the methodology (and in groups) and that it was better to continue to undertake classes that apply the traditional method, because this is the usual educational experience.

DISCUSSION

We observed how a PBL tutorial cycle is undertaken by high school students who have little experience with this method. Regarding conceptual change results, although none of the groups achieved all learning objectives, we consider that conceptual changes resemble what was observed in the scarce procedural PBL analyses found in the literature, in which differences between learning objectives and what knowledge students actually acquired are also reported (15, 42). However, using this approach, mainly concerning conceptual changes and student-student and tutor-student interactions, we consider that some points in the tutorial cycle planning and application can be reviewed, increasing the chances of an even greater approximation to learning the set objectives and developing conceptual changes. These points will be discussed from the perspective of problem formulation, group work, and the use of scaffolds.

The quality of the problem affects student learning processes (43, 44). We elaborated the problem according to the 3C3R model (32, 33), adapting it to our study participants. Despite this, when observing the conceptual changes occurred in each group and analyzing the formulated problem, we found that some procedures required adjustments. The last paragraph of the problem, which aimed to overcome the lack of student problem-solving and SDL skills (33), could be further structured, so students would not deviate so much from the proposed learning objectives. A new paragraph could highlight the points for debate and include more points to avoid discussions outside the scope of the problem. This new paragraph is transcribed below, with new statements in bold and underline:

> "Finally, keep in mind the path that alcohol present in the drink will take:
>
> Where does this substance go after it is ingested?
> **How does alcohol reach the breathalyzer?**
> How long will alcohol remain in Julius's body until eliminated?
>
> These are the first questions to consider. **Also consider that**, although the effects of alcohol on nervous system **and alcohol metabolization in the body** are an important and very interesting topic, researching them now will not help to conclude whether Julius was correct or not in his statement. Get to work!"

Concerning the PBL tutorial cycle, we observed that the tutor played a major role in ensuring the fluidity of group discussions and student participation. As students had no experience with PBL, it was important for the tutor to guide and motivate them to achieve their learning goals (22, 45). However, there were moments in the SDL phase when student interactions may have impaired the learning process. Despite the possibility of greater learning process autonomy at this stage, high school students often exhibit reduced experience in exercising autonomy (46), which can hinder the process as a whole. Some evidence that autonomy probably resulted in inefficiency in some cases were observed, such as certain answers to the open question of the questionnaire, where some dissonant answers about group dynamics were noted, as follows:

> *Student A*: "I would not like to continue, because group work is very complicated, some members do not have time to do the work or complete it, other members do not even care to be present in group meetings."
>
> *Student B*: "Yes, because the discussions we had in the groups contributed and facilitated the understanding of the subject, and, to me, it is a good methodology, and I would like for it to continue to be applied."

Regarding the difficulties of working as a group, it is important to consider that this process is highly dynamic and may create many variables that can affect learning outcomes (47, 48). Optimal group dynamics are basically achieved through a rich interaction and interactive discussions and negotiations among participants, which are not always achieved, due to cognitive, social and motivational factors (49). The instruments used in this study did not allow for us to assess those factors, but based on the account of some students (e.g., *student A*), it is possible to infer that some problems, at least with regard to social interactions, were present. Another aspect is the number of students in each group. Although there are situations in which the sporadic use of PBL in large classes is favorable (39), the ideal number of students in a group for the tutorial cycle revolves from around six to eight students. Exceeding this number could facilitate the occurrence of students who do not participate, either due to inhibition or cunning (36). Although the groups did not contain many students, only one had the ideal number of participants, due to the absence of some students, and student PBL inexperience may have caused the above-mentioned problems.

In addition to intragroup interactions, a relevant issue concerning the conceptual change asymmetries observed between groups (Fig. 1) is the type of applied scaffold. Scaffolds relate to a temporary support provided by the tutor to assist students during the tutorial cycle, and their presence is one of the main differences between PBL and discovery learning (50, 51), considered a minimally guided instruction that can bring difficulties to the learning process (52). Scaffolds can be flexible, related to tutor actions during the cycle, or developed in advance, based on expected difficulties (4). We used a flexible scaffold, but perhaps a rigid scaffold would be more interesting, since it has been demonstrated that students with little PBL experience benefit from this type of scaffold (53, 54), especially high school students, in which novice PBL characteristics such as low group autonomy and problem-solving expertise are commonly present (46).

Despite the reformulations considered after the assessments, it is important to highlight the conceptual change that occurred, which was close to what has been reported in other assessments (27) and the positive impressions in relation to group work and motivation (Fig. 2 and Table 2), in accordance to other PBL studies in various settings, such as in isolation (10, 39) or under curricular scenarios (37, 55). Among the potential developments of this practice, the problem itself is able to promote interdisciplinarity (56), addressing the same problem in other disciplines, while the continuous use of PBL is also able to improve abilities such as communication, group work and SDL (13, 14). These results may facilitate student adaptations in higher education courses that apply PBL.

Regarding the methodology applied herein, this case study was effective for observing conceptual changes and group dynamics throughout a PBL tutorial cycle. This supports our argument that situational observation, specifically through qualitative analyses, should also be an important focus of PBL research, as suggested previously (18, 30). This approach can also support PBL use in institutions with no prior experience in its application to verify which points of the tutorial cycle should be improved and may even serve to provide suggestions for changes in institutions that already apply PBL on a regular basis but that present problems (36), which may be noted in qualitative analyses that would not be systematically observed otherwise.

This study provided a procedural observation of a PBL tutorial cycle, which allowed not only for assessments concerning the conceptual change process but also an intense reflection of what can be done to improve PBL practices in a specific situation of PBL implementation in high school. This perspective was only possible due to the performed qualitative analyses. Future studies may focus on whether the results reported herein would be similar to those from elsewhere, generating robust knowledge on what the best initial PBL implementation conditions are.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

L.A.d.P., L.A.A., M.W.C., and R.M.L. conceived and designed research; L.A.d.P. performed experiments; L.A.d.P., M.W.C., and R.M.L. analyzed data; L.A.d.P. interpreted results of experiments; L.A.d.P. prepared figures; L.A.d.P. and R.M.L. drafted manuscript; L.A.A., M.W.C., and M.R.L. edited and revised manuscript; L.A.d.P., L.A.A., and R.M.L. approved final version of manuscript.

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