

Article

Self-Regulation and Teacher Feedback in Problem-Based Learning on the Water Hardness

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Abstract: Problem-Based Learning has been recognized as a fundamental approach in Science Education. Studies show that the success of this approach depends on students' ability to self-regulate their learning and on teacher feedback. However, research on how these aspects interact in formal science teaching contexts remains limited. This study aims to address this gap by investigating two questions: (1) What self-regulation strategies are used by different student groups when solving a problem related to water hardness? (2) How do different types of teacher feedback influence students' problem-solving processes? The study involved 27 students and their Physics and Chemistry teacher. Students participated in an activity that required solving a problem related to water hardness. Data were collected through audio recordings, and the content of the transcriptions was analyzed. The results showed connections between self-regulation strategies and teacher feedback during the problem-solving process. Groups with high participation employed diverse self-regulation strategies, successfully solved the problem, and received varied teacher feedback. The group with the lowest participation received the least feedback from the teacher. Future research should focus on examining how different types of teachers' feedback during specific interventions for less-participative groups influence the development of their self-regulation strategies.

Keywords: problem-based learning; self-regulation; teacher feedback; science education; water hardness



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1. Introduction

Over the past three decades, Problem-Based Learning (PBL) has been recognized as an important approach in Science Education (Akçay & Benek, 2024). The literature highlights several benefits of this methodology for students, such as developing critical thinking, decision-making, and communication skills (Hmelo-Silver & Barrows, 2006). When students work in groups, PBL also fosters the development of collaboration skills, idea negotiation, and tolerance (Leite & Afonso, 2001).

Several studies show that engaging students in PBL as a starting point for developing new learning (Leite & Dourado, 2013; Loyens et al., 2008) enables them to exercise their minds and experience a sense of satisfaction from the effort invested in finding solutions (Lambros, 2004). Furthermore, through problem-solving, students learn to reflect and act in challenging situations, applying knowledge that is developed and reinforced during the problem-solving process (Lambros, 2004). During problem-solving, students develop metacognitive skills related to planning, interpretation, reflection, and monitoring (Solaz-Portolés & Lopez, 2007). Throughout this development, new knowledge is incorporated into their cognitive structure and becomes available to address new problem situations,

making them more autonomous, active, and creative in decision-making, both in the present and in the future (Lambros, 2004).

The success of PBL depends on students' ability to self-regulate their learning (English & Kitsantas, 2013). In fact, students with higher levels of self-regulation are more efficient at solving problems compared to those with lower levels of self-regulation (Hmelo-Silver, 2004). However, fostering the development of self-regulation processes during problem-solving can be challenging as students do not always understand these processes and often resist reflecting on their learning journey (Loyens et al., 2008). In an initial phase, the teacher may play a more active role, and students may rely more on external feedback from the teacher. Through co-regulation processes, students progressively learn to self-regulate independently by analyzing their own learning processes and making informed decisions (Azevedo et al., 2007; Dignath & Büttner, 2008). Teacher feedback plays an important role in supporting students' self-regulation when they are involved in PBL. This feedback should be adaptive, i.e., it must be adapted to the specific needs of students and groups at various stages of the problem-solving process (van de Pol et al., 2010).

Despite the recognized importance of students' self-regulation processes and teacher feedback in PBL, research on how these elements interact in formal science teaching contexts remains limited. This study aims to contribute to this understanding and address this gap in the literature by investigating the following questions: (1) What self-regulation strategies are used by different student groups when solving a problem related to water hardness? (2) How do different types of teacher feedback influence students' problem-solving processes?

2. Theoretical Framework

The term Problem-Based Learning (PBL) was introduced as an educational methodology at the Faculty of Medicine at McMaster University, Canada, during the 1960s (Barrows & Tamblyn, 1980). However, the theoretical foundations of learning through problems have already been introduced by other authors. For example, Dewey (1938) emphasized the role of problems in learning, highlighting that they create cognitive conflict in learners, allowing for the construction of understanding and serving as a natural organizer of learning processes. Also, Piaget's (1976) constructivist theory is aligned with PBL principles. The author emphasizes how learners actively construct knowledge through experiences that challenge their previous cognitive structures. Vygotsky's (1978) social constructivist view added another dimension to understanding PBL through the concept of the Zone of Proximal Development. According to Vygotsky's perspective, learners, when solving problems in collaborative processes, can achieve better results than they could individually, especially when supported by facilitators (Harland, 2003).

So, building on these theoretical foundations, in the literature, the term "problem" has been widely discussed by various authors (Schoenfeld, 2016; Jonassen, 2011). Among the various definitions, a set of common characteristics related to the individual's reaction to the situation presented can be identified. For example, according to Polya (2003), an individual encounters a problem when they face a question or situation for which they do not have an immediate solution, relying only on the knowledge they have available. Dogru (2008) also argues that a problem is an obstacle that can be overcome by someone with a clear purpose, i.e., is a situation that should present enough complexity to be a challenge but not be so complex that it becomes impossible.

However, it is important to consider that what some perceive as a problem may not be seen in the same way by others. Often, it is unpredictable how a given situation will be viewed by students as this depends on their individual approach, which, in turn, is influenced by their prior knowledge and maturity (Pozo, 1998). Thus, the same situation

may be seen as exercise by some and as a problem by others. The distinction is based on the fundamental question of whether there is an immediate process to solve the situation. If the individual knows this process and can apply it, the situation is considered an exercise. Otherwise, it is considered a problem (Ponté, 2005).

Problem-solving in the classroom was first introduced consistently by Polya in 1945 within a mathematical context. Later, it was extended to other fields, including Science Education (Morgado & Leite, 2001). In the past thirty years, numerous studies have been conducted on problem-solving in educational contexts, specifically on students' cognitive processes when engaged with problems (Zimmerman & Schunk, 2011), the strategies students use to solve problems (Hmelo-Silver, 2004), the learning outcomes and skills developed by students (Savery, 2015), and others.

PBL is currently regarded as one of the key approaches to Science Education and is distinguished from other methodologies by its features, such as starting with a carefully designed ill-structured problem (English & Kitsantas, 2013) that is connected to students' everyday lives or simulates a real-world context (Leite & Afonso, 2001). There is no predetermined path for solving the problem, and its resolution is dynamic, allowing students to become accustomed to uncertainty (Qin et al., 1995). The problem serves as a means for students' learning, which they seek to solve in groups, while the teacher assumes the role of facilitator (Gallagher et al., 1995).

Additionally, it is important for students to employ self-regulation strategies when solving problems (English & Kitsantas, 2013). Self-regulated learning can be defined as a complex, multifaceted process involving cognitive, metacognitive, and affective strategies used by students to regulate their own learning (Zimmerman, 2002; Ng et al., 2024). In this constructive and active process, students set goals, monitor, regulate, and control their cognition, motivation, and behavior (Pintrich, 2000). Studies have shown that self-regulated learning plays an important role in students' academic success (Makhno et al., 2022; Park & Kim, 2022) and to develop their ability to solve problems (English & Kitsantas, 2013). For example, a study conducted by Malan et al. (2014) aimed to examine how the introduction of the PBL approach in classes influenced students' self-directed and self-regulated skills. The study involved 35 students and two mathematics and science teachers. The results showed that the PBL approach allowed students to use deep processing learning strategies and metacognitive self-regulation activities, including planning, diagnosing the problem, testing their outcomes, and adjusting and reflecting on their solutions. To achieve this, it was important to expose students to problems related to their interests, promote group work during problem-solving, and encourage the teacher's role as a facilitator of students' learning. Thus, the results of this study also highlight that in the problem-solving process, teacher feedback is fundamental.

According to Black (1998), feedback provided by the teacher should be short-term so that obstacles can be identified and discussed. According to the author, immediate feedback allows students to improve their knowledge and achieve better learning outcomes. Moreover, when feedback is given during activities, when the teacher holds students accountable for their learning process and provides them with adequate time to improve their work, students' satisfaction and motivation for the subject increase, as does their final evaluation (Black et al., 2003). For instance, a study conducted by Hmelo-Silver and Barrows (2006) aimed to examine the strategies used by a facilitator during a student-centered Problem-Based Learning group. The study involved an experienced facilitator and 35 higher education students. The results showed that the facilitator employed several strategies, such as using open-ended and metacognitive questioning, encouraging students' reflection, summarizing, helping students focus their inquiry, checking consensus on

whether the whiteboard reflected the discussion, and encouraging the construction of visual representations.

3. Study Context

3.1. Methodology

This is a qualitative study, adopting an interpretative orientation (Erickson, 1986). Interpretative research is a powerful tool for examining pupils' meaning construction and thinking. This is particularly important within this study as the study was based on a constructivist view of learning that considers that knowledge is constructed by individuals based on their interpretations of experiences and interactions with others (Carlson et al., 2003).

3.2. Participants

This study involved a teacher and 27 students from a school in the Greater Lisbon Metropolitan Area. The teacher holds a degree in Physics and Chemistry education and has twenty-two years of professional teaching experience. The students are from 8th grade and their ages varied between thirteen and fifteen. Of these 27 students, 15 are female, and 12 are male. In general, the students show an interest in Physics and Chemistry and are active participants in the classroom. The students were involved in solving a real-life problem related to water hardness and its influence on the condition of washing machine parts. They worked in groups, forming seven teams (six teams of four students and one team of three students) (Table 1).

Table 1. Teams that developed the learning sequence.

Group	Number of Students	Gender (M/F)
1	4	2 M; 2 F
2	4	2 M; 2 F
3	4	3 M; 1 F
4	4	1 M; 3 F
5	4	1 M; 3 F
6	4	2 M; 2 F
7	3	1 M; 2 F

The groups were organized by the teachers, and this method of working in groups was already familiar to the students.

3.3. The Problem of Water Hardness

The students were involved in an activity that required solving a problem related to water hardness in different regions of the country and the condition of washing machine parts. More specifically, the students were presented with the following context and problem: WashEngineering, a leading company in the manufacturing of washing machines, has hired your team of young scientists to solve a mystery. Identical machines, made on the same date and used with the same frequency, show very different levels of wear depending on the region of Portugal in which they are used. Your mission is to investigate the following question: Why do parts of identical machines degrade differently in various regions of the country? The company's management has also asked you to propose solutions to ensure the durability of the machines in all regions.

To support the students in solving the problem, two tables were provided: one with data on the condition of the machines after 6 years of use in each region of the country and another with the average water hardness by region. They were also allowed to conduct research on the internet. The problem-solving process lasted for a 90 min class. The students

had not yet covered the scientific concepts related to water hardness in the classroom, so the problem served as the starting point for developing learning about this topic.

3.4. Data Collection and Analysis

The data collected through audio recordings took place in each of the working groups while they were solving the problem. As [Patton \(1990\)](#) describes, such recordings are important instruments when conducting qualitative research. During the group work, students engaged in group interactions and used self-regulation strategies to solve the problem. The teacher also interacted with the different groups, providing feedback. These recorded conversations served as an important data source for addressing research questions ([Carlson et al., 2003](#)). The study collected seven audio recordings in total, one from each working group. The researcher fully transcribed these recordings and analyzed their content ([Cohen et al., 2007](#)). Specifically, the method of constant questioning and comparison was used. According to [Strauss and Corbin \(1998\)](#), this method is an analytical process used to stimulate thinking about the properties and dimensions of categories. So, this method was used to code and categorize the data. For analyzing data concerning students' self-regulation strategies, we used categories described in the literature ([Freire et al., 2013](#); [Montague, 2008](#)), and some categories emerged from the analysis of the audio records (Table 2).

Table 2. Categories concerning students' self-regulation strategies.

Categories	Description
To read for understanding (Ra)	Analyze the problem (Have I understood the problem? What am I supposed to do?) Identify the starting point (What do I already know and can mobilize to solve the problem?)
To paraphrase using own words (Pa)	Underline the important information. Put the problem in my own words (What am I looking for?)
To plan to solve the problem (Pl)	Decide the steps that are needed to solve the problem (What do I need to do? Which are the best options?)
To regulate the process of solving the problem (Rg)	Redefine strategies (Which other option do I have to solve the problem?) Mobilize knowledge (What do I know that can be useful for correcting mistakes or overcoming difficulties?) Add or search for additional information (What do I need to know more to overcome difficulties?) Call to others for help (e.g., teacher)
To check during and after solving the problem (Ch)	Check the goals and plan (Did I reach goals? Have I checked every step? Were strategies efficient?) Check that everything is correct (Is my answer correct? If not, did I go back?)

The level of students' participation during the problem-solving process was also assessed using the following criteria: (i) whether the problem was solved; (ii) the number of self-regulation strategies employed by the groups. Based on these two criteria, three groups were formed: high participation, referring to groups that successfully solved the problem and used more than twenty strategies, either the same or different; medium participation, referring to groups that successfully solved the problem and used between ten and twenty strategies, either the same or different; low participation, referring to groups that did not solve the problem and used fewer than ten strategies, either the same or different.

The teacher's feedback was analyzed based on the number and the type of teacher's feedback in each group. The categories related to the type of feedback were adapted from the study by [Koyuncu et al. \(2023\)](#) and [Baptista et al. \(2017\)](#), and additional categories emerged from the analysis of the audio recordings (Table 3).

Table 3. Categories of the teacher type of feedback.

Type of Feedback	Description
Encouragement (En)	Points out the positive aspects of students' intervention (well done) and encourages improvement of the work.
Prompting the mobilization of evidence, arguments, and justifications (EAJ)	Encourages answering "why" by mobilizing data, presenting arguments, and justifying the response.
Prompting the mobilization of scientific knowledge (SK)	Encourages the use of scientific knowledge. Identifies scientific inaccuracies and suggests strategies for improvement.
Prompting the presentation of clarifications and elaborations (CE)	Encourages answering "What is this?" and "What does this mean?"
Prompting the presentation of information and solutions (IS)	Encourages students to research information from various sources to present solutions to the problem.
Discussion guidance (DG)	Refers to group work and the discussion of ideas among group members.
Process guidance (PG)	Guidance on how to organize the response and which resources to use.
Confirming (Co)	Validates the students' response by expressing agreement (yes).

4. Results

4.1. Self-Regulation Strategies

The analysis of the audio recordings reveals that only one group did not complete the challenge (G2) and used a low number of self-regulation strategies (fewer than 10 strategies). The remaining groups had medium (G3, G4, G5, and G7) and high (G1 and G6) levels of participation (Table 4).

Table 4. Characterization of the student groups based on the completion of the problem-solving task and the level of participation of the groups.

	G1	G3	G4	G5	G6	G7	G2
Level of participation of the groups	H	M	M	M	H	M	L
Conclusion of the problem-solving	yes	yes	yes	yes	yes	yes	no

The results show that students used five types of self-regulation strategies during problem-solving: to read for understanding (Ra); to paraphrase using their own words (Pa); to plan to solve the problem (Pl); to regulate the process of solving the problem (Rg); and to check during and after solving the problem (Ch) (Table 5). The analysis of the groups' interactions reveals that around half of the students used the Rg strategy (46%) during problem-solving. This strategy involves actions such as analyzing the problem-solving process, redefining strategies, mobilizing knowledge, adding or searching for additional

information, and seeking assistance from others (e.g., the teacher). In contrast, the least-used self-regulation strategy was to read for understanding (Ra), employed by only 7% of the students.

Table 5. Frequency and percentage of self-regulation strategies used by students during problem-solving.

Self-Regulation Strategy	Total
Ra	17 (7%)
Pa	21 (9%)
Pl	67 (28%)
Rg	109 (46%)
Ch	24 (10%)
Total	238 (100%)

This pattern differs across groups. For example, G2, which did not complete the problem-solving, as well as two groups with a medium level of participation (G3 and G5), did not employ the Ch type of self-regulation strategy. Furthermore, the groups that employed a higher number of self-regulation strategies, whether the same or different, and had medium to high participation levels were the ones that used all five types of self-regulation strategies (Table 6).

Table 6. Frequency of the types of self-regulation strategies used by each group of students.

Self-Regulation Strategy	G1	G2	G3	G4	G5	G6	G7	Total
Ra	3	3	2	3	2	2	2	17
Pa	4	3	2	2	4	3	3	21
Pl	12	4	7	9	10	17	8	67
Rg	29	6	14	12	7	23	18	109
Ch	10	0	0	4	0	8	2	24
Total	58	16	25	30	23	53	33	238

Groups G1 and G6, characterized by a high level of participation, began the problem-solving process using the Ra self-regulation strategy. That is, they started with problem analysis and brainstorming about what they already knew and could mobilize to solve the problem. Despite their similar starting points, G1 used this strategy more frequently than G6 and made greater use of the Pa, Rg, and Ch strategies. In contrast, G6 relied more often on the Pl strategy compared to G1. Compared to the other groups, these two groups most frequently employed the Pl, Rg, and Ch strategies. The following excerpt from G1's interactions provides examples of the self-regulation strategies they used (Table 7).

Table 7. Excerpt from G1's interactions.

Excerpt	Self-Regulation Strategies
S1 We need to analyse the data from the two tables and establish connections. I think that's the first thing we should do. Don't you agree? And after comparing, we can carry out some research.	Pl
S2 Think, S1! I think we should start with research to figure out what's going on with the parts, and then we'll know more, giving us the knowledge to analyse the data in the tables.	Pl

Table 7. *Cont.*

	Excerpt	Self-Regulation Strategies
S1	But how do you want to research without knowing what to do first? I don't think we'll get anywhere like this. This doesn't seem right!	Ch
S3	Yeah... I also think we need to compare first, then do the research, and during the research, we can gather information to draw conclusions. We first need to look at the data in the tables.	Pl
	(...)	
S4	From the table analyses, we've already compared them, and it's because of the water hardness in different regions (...) Here it says that water hardness is a chemical characteristic and refers to the amount of mineral salts dissolved in water, such as calcium and magnesium ions. And that's why it accumulates in the machines.	Rg
S3	Accumulates? Accumulates what? Should we call the teacher? Teacher...	Rg
S1	We've already studied precipitates. Could this be one? (...) In this text, it says: Temporary hardness can be eliminated by heating water to its boiling point, which causes calcium carbonate and magnesium carbonate to precipitate. Permanent hardness, however, cannot be eliminated by boiling but can be removed by adding substances that prevent the reaction of calcium and magnesium ions with soaps: anti-scale agents.	Rg
S2	Oh! Right... The TV ad mentions those anti-scale agents. That's why we need to use them in machines. Look, we've got it! We figured it out! Machine parts degrade more in the south of the country because of water hardness. Isn't that, right? Yeah... the water is hard in the Algarve, according to the table values. And... we can use more anti-scale agents in the Algarve to prevent damage to the machines.	Rg Ch

The previous excerpt illustrates that G1 successfully developed a process of co-constructing knowledge by using three types of strategies: Pl, Rg, and Ch. It is evident from the excerpt that S1 initiated a cycle by introducing the steps they considered necessary for solving the problem. S2 then continued with the Pl self-regulation strategy but proposed an alternative way to organize the steps. S1 disagreed with S2's proposal and employed the Ch self-regulation strategy, encouraging the group to reflect and discuss whether S2's proposed steps would be the most effective solution. This is evident in the question, "But how do you want to research without knowing what to do first?" as well as the following statement: "I don't think we'll get anywhere like this. This doesn't seem right!" S3 then agreed with S1 and used the Pl self-regulation strategy to finalize the group's plan.

As the group continued to solve the problem, all four students also used the Rg self-regulation strategy. The excerpt shows that S4 introduced information obtained from online research. Then, when S3 struggled to interpret the information provided by S4, they decided to call the teacher for clarification ("Should we call the teacher? Teacher..."). The group's interaction became more complex, with S1 adding additional information and S2 integrating prior knowledge to address the problem, using the Rg self-regulation strategy. Furthermore, the statement "Look, we've got it! We figured it out!" by S2 indicates that they checked the solution and confirmed that they had reached a conclusion.

This excerpt shows that the group demonstrated effective self-regulation strategies. The students consistently defined the steps needed to progress in solving the problem, added information through online research, mobilized knowledge to overcome challenges, and successfully reached a conclusion.

Groups with a medium level of participation (G3, G4, G5, and G7) also exhibited differing patterns among themselves. G4 and G7 used all five types of self-regulation strategies and displayed a higher frequency of strategy use than G3 and G5. G5 is the only group that employed Rg less frequently than Pl, while G4 is the only group that used Ra less frequently than Pa. The following is an excerpt from the interactions of G4 (Table 8).

Table 8. Excerpt from G4's interactions.

	Excerpt	Self-Regulation Strategies
S13	So, what do we need to do? (...) Maybe it's one of the chemical reactions we've studied. I'm not sure I understand.	Ra
S14	[reads the problem again] I don't know if I've fully understood the problem or what we need to do. S15, do you have any brilliant ideas about chemistry?	Ra
S13	Right... we need to take on the role of scientists and figure out why machines in different parts of the country have some parts that are in good condition and others that aren't (...) we need to think about this and then come up with solutions, ideas for what we can do to prevent the machines from breaking down.	Pa
S15	I think that's it. Right, it's two things. Yes, two things. We need to see if there's a pattern based on location in the country and whether the parts degrade more or less and then figure out what we can suggest preventing the damage. Those are the two things we want to address, and now we need to decide what to do.	Pa
	(...)	
S15	Let's start with the tables. In this table, where do the parts degrade more? [They analyse the table.] See, it's here in the Algarve and Alentejo, and there are fewer damaged parts in the North. Now, the other table is about water hardness. I don't know what this is... but the hardness is higher in the Algarve. Should we ask the teacher what water hardness means? Teacher, can you come over here?	Pl Rg
S13	You're right, S15. What we need to do is look at both tables and then draw our conclusions. We could also do an experiment with the chemical reactions to see in which region of the country the parts degrade the most.	Pl

G4 began problem-solving by using the Ra self-regulation strategy. However, at the beginning, the group did not have a clear understanding of the problem or what they needed to know, as evidenced by the initial contributions of S13 and S14. Therefore, it was central for them to use the Pa self-regulation strategy. Specifically, S13 and S15 were able to

extract the important information and restate the problem in their own words. Using Pa helped them overcome their initial difficulty in understanding the problem and allowed them to define new goals and steps aligned with those goals, as seen when S15 remarked the following: “Those are the two things we want, and now we need to decide what to do”. The students then employed the PI self-regulation strategy to outline the necessary steps for solving the problem and sought help from the teacher (Rg). Notably, their use of the PI strategy involved building upon each other’s ideas, specifically from S15 to S13.

Regarding the group with the lowest participation (G2), many of their interventions were parallel. On several occasions, their interventions were disconnected, with no response to each group member’s contributions. In other words, one group member initiated a self-regulation strategy that was not linked to the strategy previously used by another group member. Additionally, they employed Rg without first using a PI strategy, which led them to conduct internet searches that took them away from addressing the initial problem. The following excerpt from G2’s interactions (Table 9) illustrates this issue.

Table 9. Excerpt from G2’s interactions.

	Excerpt	Self-Regulation Strategies
S5	You are part of a group of scientists, and your mission is to investigate: why do parts of identical machines degrade differently in various regions of the country?	Ra
S8	What I’m going to do is be a scientist and check if the machine parts are degraded. I’ll see if they are damaged here in Lisbon or in Porto. What will I do? I’ll look for solutions to prevent the parts from degrading so much.	Pa
S6	[Researching on the internet] Washing machines, if placed in the wrong spot, can cause drainage issues, they get damaged, and the parts become defective. Teacher. . . [Calls the teacher]	Rg
	(. . .)	
S8	What we’re going to do is look at the two tables and find the answer to the problem.	PI
S5	What we need to do is investigate: why do parts of identical machines degrade differently in various regions of the country? The company’s management has also asked you to propose solutions to ensure the machines’ durability in all regions.	Ra

In terms of self-regulation strategies, G2, despite S5 starting by reading the problem or part of the problem (Ra) and S8 restating the problem in their own words (Pa), the subsequent strategy used by S6, in addition to being disconnected from the Ra and Pa strategies used by S5 and S8, takes the group further away from solving the problem. Furthermore, instead of involving the group in their research, S6 opts to call the teacher, using the Rg self-regulation strategy. The next intervention by S8, using the PI self-regulation strategy, could have helped the group move forward in addressing the problem. However, it is clear from S5’s next intervention that the group returns to understanding the initial problem, using the Ra strategy.

4.2. Teacher's Feedback

The analysis of the teacher's feedback reveals that she provided procedural guidance (21%), encouraged most of the groups (18%), prompted the mobilization of scientific knowledge (15%), prompted the mobilization of evidence, arguments, and justifications (13%), prompted the presentation of clarifications and elaborations (15%), confirmed students' ideas (10%), and provided discussion guidance (8%) (Table 10).

Table 10. Frequency and percentage of the teacher's feedback type.

Type of Feedback	Total
Encouragement (En)	11 (18%)
Prompting the mobilization of evidence, arguments, and justifications (EAJ)	8 (13%)
Prompting the mobilization of scientific knowledge (SK)	9 (15%)
Prompting the presentation of clarifications and elaborations (CE)	9 (15%)
Discussion guidance (DG)	5 (8%)
Process guidance (PG)	13 (21%)
Confirming (Co)	6 (10%)
Total	61 (100%)

Furthermore, the comparison of the feedback provided by the teacher to the different groups reveals that the number of interventions directed at the groups, as well as the quality of those interactions, is different (Table 11).

Table 11. Frequency of the teacher's feedback types by group.

Type of Feedback	G1	G2	G3	G4	G5	G6	G7	Total
Encouragement (En)	1	2	2	2	2	1	1	11
Prompting the mobilization of evidence, arguments, and justifications (EAJ)	2	0	0	1	1	3	1	8
Prompting the mobilization of scientific knowledge (SK)	2	0	1	2	1	2	1	9
Prompting the presentation of clarifications and elaborations (CE)	3	0	0	1	0	3	2	9
Discussion guidance (DG)	0	1	2	1	0	0	1	5
Process guidance (PG)	1	3	2	2	2	1	2	13
Confirming (Co)	1	0	1	0	1	1	2	6
Total	10	6	8	9	7	11	10	61

As for G2, with low participation and fewer self-regulation strategies used, it was the group with the fewest interactions from the teacher (6). The feedback provided by the teacher covered three types: PG, En, and DG. Compared to the other groups, G2 received the highest number of interventions from the teacher focused on the PG type of feedback. The following example shows three interactions between the teacher and G2 (Table 12).

Out of the groups G3, G4, G5, and G7, with medium participation, G7 had the same number of interactions as G1 (high participation), while for G3, G4, and G5, the number of interactions ranged from 7 to 9. These three groups received feedback En, SK, and PG type. G4 was the only one of the three groups that received feedback of the CE type. Feedback of the EAJ type was given to G4 and G5, the DG type to G3 and G4, and the Co type to G3 and G5. Below is an excerpt of the feedback given by the teacher to G3 (Table 13).

Table 12. Teacher’s feedback to G2.

Excerpt	Teacher Feedback
Teacher: Very well, you’ve already done some research on the internet. Let me read [Teacher reads what the students have written]. Doing the research is important, but let’s see if we are answering the problem. It might be better to use other search terms or define another way to start. Keep going...	EN
S6: Teacher, but what words could we use? Are the parts of the washing machine degraded?	
Teacher: What do the other group members think? Could it be? What do you think? S8, what do you think? Would starting with the research be the best option?	DG
S8: The machines are broken; we researched that.	
Teacher: You haven’t looked at all the data you have in the activity yet. Look at the tables with the data you have, analyse them, and see how the data there can help you find answers and pathways. Start with analysing the tables.	PG

Table 13. Teacher’s feedback to G3.

Excerpt	Teacher Feedback
Teacher: [The teacher reads the answer written by the students] We are on the right track, now let’s move forward. You compared the two tables. But why is one water harder than the other? Why is it harder or softer? You can complete your answer and search for what is still missing.	EN
S10: Okay, Teacher. We will look it up on the internet and...	SK
Teacher: Then complete the answer. Work as a group, S12 help your team with the research.	DG

G7 and the two groups with high participation (G1 and G6) were the ones that received the most feedback from the teacher, i.e., the highest number of teacher–group interactions. G1, G6, and G7 were the three groups that received the most feedback of the CE type, and G1 and G6 also received more feedback of the CA and EAJ types. It is also noteworthy that the most-used type of feedback by the teacher for G1 was CE, and for G6, it was CE and EAJ. The following is an excerpt from the interaction between the teacher and G6 (Table 14).

It is evident from the previous excerpt that the feedback that the teacher provided to G7 allowed them to progress in solving the problem. More specifically, the teacher gave them feedback about the evidence and justifications they needed to include in their response (“you can justify your answer by looking at the numbers”) and asked them to include scientific concepts in their answer (“the scientific meaning of this”). Additionally, the teacher encouraged clarification and elaboration of their response by questioning the students (“Are you sure about what you mean? What is this? Is that really it?”). To further support them in reaching a solution, the teacher provided process guidance about websites where they could research information on the variation of water hardness across the country. To conclude, the teacher states “Yes, now it’s correct,” confirming G6’s response.

Table 14. Teacher’s feedback to G6.

Excerpt	Teacher Feedback
Teacher: You started with the analysis of the tables. Can you justify your answer by looking at the numbers? Go ahead...	EAJ
S22: Is it about relating the numbers? We look at the average water hardness value and...	
Teacher: It’s looking at the numbers, but then you need to go further and explain what it means. It’s not enough to just relate them; you must understand the scientific meaning of it.	SK
S24: Okay, let’s do this. (...)	
S23: [Calls the Teacher] Teacher, can you check if this is correct? [The teacher goes to the group]	
Teacher: Let me see what you wrote [reads what the students wrote]. I don’t quite understand your answer: “Soft water increases the density of soap bubbles and is found in the North.” Did you get this from the internet? Are you sure about what you mean? And what connection are you trying to make between the North of the country and soap bubbles? What is this? Is that really it? Try looking on another website, maybe the websites for the Northern and Algarve water companies might have something. That could be a good idea...	CE PG
(...) [The teacher goes to the group] Teacher: Let me read what you have [reads what the students wrote]. Ah! Yes, now it’s correct.	Co

5. Discussion

The results show that the student groups participated in the problem-solving task about water hardness in different ways, with two groups exhibiting a high level of participation, four groups with a medium level of participation, and one group with low participation. Groups G1 and G6, which used self-regulation strategies more frequently (either repeating the same strategies or employing different ones), achieved the highest participation levels. In contrast, the group with the lowest participation was also the one that used fewer self-regulation strategies and did not complete the problem-solving (G2). These results align with previous studies showing that the diverse use of self-regulation strategies is positively correlated with students’ success in PBL (Zimmerman & Schunk, 2011). Furthermore, the groups with the highest levels of participation demonstrated distinct patterns of interaction and knowledge construction compared to G2. While G1 demonstrated an effective process of knowledge construction with interconnected interventions built upon prior contributions, G2 exhibited parallel and disconnected interventions. This difference highlights the importance of group functioning, emphasizing the need for a good group dynamic to help students overcome the challenges they encounter throughout their work and collectively construct knowledge (Zhu, 2007). Thus, the results underscore the importance of collaborative knowledge construction in PBL, as highlighted in previous studies (e.g., Hmelo-Silver & Barrows, 2008).

Additionally, the results show that the self-regulation strategy most frequently used by the groups was regulating the process of solving the problem (Rg, 46%), followed by planning (Pl, 28%). In contrast, the least-used strategy, which was only employed by three groups (G1, G6, and G7), was checking during and after solving the problem (Ch, 10%). These results suggest that the groups with higher levels of participation are also the ones

that developed their metacognitive abilities more, using verification strategies (“Did I reach goals? Have I checked every step? Were strategies efficient? Is my answer right?”) (Freire et al., 2013; Montague, 2008). Most of the groups with a medium level of participation, as well as the group with low participation, did not mobilize this type of strategy, indicating difficulties in checking during and after solving the problem.

Regarding the teacher’s feedback, the results show that the number and type of feedback provided by the teacher varied. The groups with the highest participation received more feedback from the teacher, while the group with lower participation received the least feedback. These results indicate that, on the one hand, the teacher adapted her feedback to the specific needs of each group. For the group with lower participation (G2), the focus was on process guidance and encouragement, while the groups with higher participation (G1 and G6) received more feedback geared towards clarifications and elaborations. This differentiation in the type of feedback is consistent with the “adaptive scaffolding” model proposed by Wood and Wood (2016), where the level and type of support are adjusted according to the competence demonstrated by the students. According to Lin et al. (2018), this adaptation is important for promoting students’ progressive autonomy. However, on the other hand, in the case of G2, the interaction with the teacher was insufficient for them to reach a solution to the problem. These results suggest the need for the teacher to provide more frequent and targeted interventions for less-participative groups.

6. Conclusions

This study revealed connections between self-regulation strategies and teacher feedback during the problem-solving on water hardness. High-participation groups employed diverse self-regulation strategies, successfully solved the problem, and received varied teacher feedback. In contrast, the group with the lowest participation received the least feedback from the teacher, suggesting a bidirectional relationship: student participation influences teacher feedback, and teacher feedback affects student participation. This pattern emphasizes the importance of the teacher having more interactions with groups with lower participation to help them develop their self-regulation abilities. Additionally, this study highlighted the need for teachers to provide differentiated feedback based on each group’s specific needs. The groups with higher participation received feedback directed towards clarifications and elaborations, while most of the groups with medium and low participation received more feedback aimed at encouragement and process guidance. Future research should further investigate these less-participative groups, developing specific interventions focused on PBL, and examine how different feedback influence types influence self-regulation strategy development in these student groups.

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