

Article

Solving STEM-Relevant Problems: A Study with Prospective Primary School Teachers

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Abstract: Solving a problem requires and promotes a diversity of competencies, which include conceptual knowledge, technical and methodological knowledge, and transversal competencies. Everyday STEM-relevant problems are contextualized, ill structured, and multidisciplinary in nature. By focusing on daily life issues, they promote students' engagement in the problem-solving process and enable them to perceive how science relates to their lives. This paper aims to characterize the processes followed by prospective primary school teachers when solving three STEM-relevant problems that have different features. The qualitative analysis of 77 participants' answers showed that complete problem-solving pathways were one among a variety of other paths identified. Most strategies adopted by the participants led them to ignore the contextual conditions of the problem and to reach solutions that did not attend to them. The affective relationship with the object may increase the problem solver's tendency to ignore the contextual conditions, but this issue deserves further research. The results shed some light on the features of the problems that teacher educators should select if they wish for their prospective teachers to learn and succeed in solving everyday STEM-relevant issues. This is required to promote their future students' engagement in problem-based learning processes.

Keywords: problem solving; STEM-related problems; everyday problems; prospective primary school teachers; science education; problem-based learning



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1. Introduction

We are entering the second quarter of the century, and it continues to be important to argue for the promotion of skills recognized as necessary for 21st-century citizens. There is a need for schools to put 21st-century skills on the agenda. This means that they should educate children to become responsible, active, autonomous, and supportive people, who know and exercise their rights and duties, in dialog and with respect for others and with a democratic, pluralistic, critical, and creative spirit (OECD, 2009, 2023). These skills are required for citizens to engage in individual and collective processes that call for reflection and action regarding problems and dilemmas felt by each individual and society (OECD, 2018, 2023).

Nowadays, the most serious problems affecting society (e.g., climate change, the energy transition, water scarcity, and food provision and security) are partly due to the inappropriate ways in which man has used science and technology developments (Cheng et al., 2021). However, science and technology may offer solutions to these problems (J. Chen et al., 2023; Pickering et al., 2022) if research efforts and good will

allow it. The issue is that some ordinary citizens and politicians avoid facing these problems directly. This is probably because, as some research suggests (Gautam et al., 2021; Moore et al., 2024; Kulin et al., 2021; Huber et al., 2022; Ricart et al., 2019), they are not fully aware of how threatening these problems are for life on Earth. A possible reason for this may lie in the inability of science education to develop the scientific literacy of 21st-century citizens and to equip them with skills that are relevant for every science-literate and responsible person.

More than a decade ago, Dayna Laur (2013) argued that students should engage with complex, action-oriented problems driven by open-ended, real-world questions that promote the development of 21st-century competencies (namely, critical thinking, collaboration, communication, and creativity). Later, the Science Education for Responsible Citizenship Report (European Commission, 2015) added that

“As the world faces these complex challenges, our ability to resolve these issues on our own or within our field of knowledge shrinks. Due to their scale and complexity, these major social and economic problems transcend borders and disciplines and necessitate new ways of thinking and methodological and organizational frameworks”. (p. 20)

The recognition of this need may underlie the growing interest in integrated STEM (science, technology, engineering, mathematics) education, which enables students to engage with complex real-world problems that intersect across multiple fields (Pleasants, 2020); this raises their interest in science, especially if the problem tasks are meaningful to them (Broman et al., 2022). Research (Kennedy & Odell, 2023; Tan et al., 2023) has shown that STEM approaches assume an interrelationship among science, technology, engineering, and mathematics. Everyday problems are ill-structured and encompass decision-making problems and design problems, among others (Walker & Leary, 2009). Decision-making problems require the solver to select from a set of alternatives and to assess the risks and benefits of their choice. Decision-making is an important skill in other more complex and ill-structured problems, such as design problems (Jonassen, 2012). The latter include planning and building a more or less technical product that incorporates knowledge that crosses disciplines (Walker & Leary, 2009).

Pleasants (2020) distinguishes between pure STEM and STEM-relevant problems, considering that the latter retain the contextual dimensions of complex issues (e.g., the social, cultural, political, and ethical dimensions), which the former relegate to the background and transform into context-specific boundary conditions. This difference may explain why STEM problems (based on scientific subject matter and its associated practices) often appear distant to learners (Mauffette et al., 2004) and why learners struggle when they try to make meaningful connections between science and their daily experiences (Tan et al., 2023). Although some students extract multiple pieces of information from the context in which each problem is embedded (Broman et al., 2018) and perceive the contextual information as relevant, others see it as unimportant and claim that it acts as a distractor (Broman et al., 2022) when they try to solve the problem.

Students' ability to extract information from a problem may differ from their level of reasoning and argumentation (Chi et al., 2023); in some cases, the former is greater than the latter. According to Tan et al. (2023), the extraction of information from a problem is influenced by specific words or examples provided in the task. Some students fail to integrate the information extracted and the knowledge that they activate to design a solution for the problem at hand. In addition, only a few students can comprehend the problem fully (Wider & Wider, 2023) due to a misunderstanding of the contextual information provided. Students might need appropriate scaffold prompts to use higher-order thinking and to develop answers that are more complex (Löffler et al., 2018; Tan et al., 2023; Vasconcelos & Pinto, 2023) and that align better with the problem's context and demands. Although most

students can execute a part of the solving process correctly, only a few can obtain the entire solution correctly and reflect on the answers that they achieve (Wider & Wider, 2023).

Integrating STEM-based and problem-based approaches leads students to use sophisticated thinking strategies to process information (Contente & Galvão, 2022) and to improve their problem-solving skills (Ahmadi et al., 2023; Siswanto et al., 2024), with a specific emphasis on problem identification (Ahmadi et al., 2023) and scientific methodology skills development (Contente & Galvão, 2022). Students may also learn ways of speaking, doing, and being, as they solve integrated STEM problems in school (Tan et al., 2023). These transversal competencies are also worth developing in school education, as they are associated with communicating and relating to others and have a sphere of influence that has been increasingly found to cross country borders.

In real life, as in school, when encountered for the first time, a problem offers an obstacle to the problem solver, which the solver does not know how to overcome. However, he/she needs to overcome the obstacle to reach one or more solutions to the problem or to conclude that there is no solution to it (Jonassen, 2004; Neto, 1998; Pozo et al., 1995). Thus, a problem differs from an exercise, as the latter does not offer a meaningful obstacle to the solver, who knows how to solve it after learning the related content. Thus, the main goal of solving exercises is to train using previously acquired knowledge (Jonassen, 1997; Torregrosa, 1987).

Problems may be quantitative or qualitative/conceptual (Maries & Singh, 2023) and open or closed, but a problem statement usually does not include, at least explicitly, all data needed to solve the problem (Neto, 1998; Pozo et al., 1995; Torregrosa, 1987). When the problem solver learns how to solve a problem, it ceases to be a problem for him/her (Jonassen, 1997; Neto, 1998; Torregrosa, 1987), as the obstacle that is unique to the problem no longer exists.

Solving a problem requires and promotes a diversity of conceptual and procedural competencies, ranging from conceptual knowledge to technical and methodological knowledge, including transversal competencies like reasoning, creativity, planning, inquiry, analysis, synthesis (Contente & Galvão, 2022; Maries & Singh, 2023), and evaluation. Problems are more versatile than exercises. Problems may be used before, during, and after teaching the content that underlies them (Leite & Esteves, 2005), thus serving as learning, teaching, and assessment tools (Yerushalmi & Eylon, 2015). Problem-based learning is an example of the use of a problem as a starting point for learning (Boud & Feletti, 1997; Lambros, 2004). This means of using problems differentiates them from exercises, as the latter require previously learned knowledge, while the former may work as a tool to acquire new knowledge.

The literature shows that people may use diverse approaches (Hsu et al., 2024) and cognitive and affective tools (Hsu et al., 2024; Oh, 2024) to solve problems. This is because problem solving is a complex and nonlinear activity (Price et al., 2021; Wang et al., 2023) influenced by a multitude of factors (Wang et al., 2023). These include the appropriateness of the knowledge and skills that problem solvers activate (Price et al., 2021). To increase the probability of solving a problem successfully, a problem solver should follow a general strategy (Amanda et al., 2021; Çavaş et al., 2023; Lambros, 2004; Leite & Afonso, 2001) composed of four main steps. They are as follows:

- (i) Performing a qualitative analysis of the problem to determine what is given in the problem statement, what the solver already knows about it, and what he/she needs to know and do to solve the problem. This requires the interpretation and extraction of information from the problem statement. This process is influenced by the problem solver's analytical capabilities, level of literacy, previous knowledge, and experiences, as well as his/her interpretation of the problem request.

- (ii) Planning a strategy to move from what is given in the problem statement and known by the solver to what he/she needs to know and do to reach a solution (if there is one) to the problem. This includes planning, identifying specific tasks and relevant factors that may affect the situation described in the problem, locating relevant information sources, and selecting pertinent knowledge. Building an interdisciplinary team may also need to be considered.
- (iii) Implementing the planned strategy and reviewing it if necessary, which requires the continuous monitoring of the development of the tasks, self-monitoring of the problem solver's actions, and the ability and courage to replace any part of the strategy that is not working, if applicable.
- (iv) Evaluating the result against what is given in the problem statement and its perceived goal. This requires a critical examination of the result obtained to judge whether it is reasonable and consistent with the request of the problem.

These four steps are presented sequentially, but it should be stressed that they usually need to be implemented iteratively. They are umbrella steps that can encompass a diversity of strategies that may depend on the content of the problem (Hsu et al., 2024; Oh, 2024; Price et al., 2021).

Research has shown that some students fail to put into practice step (i), as they do not interpret the problem statement properly (Amanda et al., 2021; Maries & Singh, 2023; Silva et al., 2013) or are unable to understand the problem request (Ogunleye, 2009; Reddy & Panacharoensawad, 2017; Saka et al., 2024) or to extract information from it (Broman et al., 2018; Maries & Singh, 2023). These failures interfere with the next steps and may lead to unintended results. This interference is more important in contextualized problems than in academic ones (Salta & Tzougraki, 2010), as, in the former case, the solution needs to be situated in the context given in the problem statement. Research has also shown that many students fail in step (iv), as they do not finalize their reasoning or do not make critical and evaluative judgments of the results obtained (Maries & Singh, 2023; Silva et al., 2013). A consequence of this is that they may present a nonsensical result.

To help students to develop their problem-solving competencies, teachers should be familiar with their students' relevant initial knowledge and literacy levels and select problems that are authentic and relevant to the lives of their students, thus increasing the probability of their participation and motivation (Ayerbe-López & Perales-Palacios, 2023). Research on chemistry education (Broman et al., 2022) suggests that students may perceive science as relevant when they find it worthwhile, meaningful, and important to learn. In addition, teachers should help students to solve problems by providing appropriate scaffolding support (Maries & Singh, 2023). Moreover, teachers should be familiar with the problem-solving process and feel comfortable in solving problems and teaching problem solving. Initial teacher education should prepare teachers for this task. Teachers (Morgado, 2013) and teacher educators (Aidoo, 2023) believe that it is worth including problem-based learning in teacher education programs, but this is seldom implemented in preservice teacher education. Therefore, more research is needed on problem-based learning (Magaji et al., 2024) and the problem-solving processes followed by preservice teachers.

This paper aims to characterize the processes followed by prospective primary school teachers (PPSTs) to solve three everyday STEM-relevant problems, which differ in the information they provide, and the affective relationships that people establish with the key objects mentioned in the problem. The results will demonstrate how PPSTs approach different problems and the obstacles that should be overcome before they solve problems successfully. The results will also shed some light on the features of the problem statements that teachers should select if they wish for their students to learn how to solve

STEM-relevant problems. They will provide useful information for the improvement of prospective teachers' training on problem-solving-related topics.

2. Materials and Methods

2.1. Research Question and Design

In line with the research objective presented in the previous section, this research aims to answer the following question: How do PPSTs approach problem solving in STEM-related contexts?

Answering this question requires PPSTs to solve STEM-related problems. This would offer insights into how each participant approaches each problem based on his/her previous knowledge and experiences. Data were collected in a context that was as natural as possible (their usual classrooms) and no a priori categories were imposed on the data. Hence, our interpretation of the data allowed us to uncover and understand the diverse approaches that the group of participants used to solve the problems. Thus, this study fit into the qualitative paradigm (Sherman & Webb, 2005) and adopted a phenomenography design (Marton, 2005).

2.2. Participants

This study was conducted with undergraduate students attending a Basic Education program at a Portuguese university. Successful completion of this program is required to be admitted to a primary school teacher training Master's to teach 6- to 12-year-old children. Before enrolling in the undergraduate program, the students complete secondary school (12th grade) in a STEM or humanities area. In addition, they have to pass two compulsory national exams: Portuguese Language and Mathematics. During the undergraduate program, starting in the first year, they take Portuguese, Science, Mathematics, History, Geography, Arts, Physical Education, and Education courses. When the PPST were invited to participate in the study, they were enrolled in the third year of their undergraduate studies. To the best of our knowledge, they had undergone no previous formal training in solving problems similar to the ones used in this research.

The 77 students who attended classes on the day that the data collection took place were invited and accepted to participate in the study. This means that they agreed to answer the questionnaire described below. As mentioned above, this study was a qualitative one. However, working with a large number of participants, namely PPSTs, ensured that we achieved data saturation and obtained a good picture of the diversity of the strategies that may be used to solve such problems.

2.3. Technique and Instrument

This research focused on uncovering the processes followed by PPSTs when solving everyday STEM-relevant problems. To do so, it was necessary to have a set of purposefully chosen problems and to ask the participants to solve them individually and in writing. The problems dealt with situations that PPSTs might encounter in their personal or familiar daily lives and were contextualized within normal life. In addition, they required some scientific, mathematical, engineering, and technological knowledge, even though the diverse STEM components could have different weights in the diverse problems. They also had different features concerning data provision and the potential affective link between the individuals and the key object of the problem, as the latter may affect the problem-solving process. Then, it was decided to use three problems with the following general features:

- Problem 1—familiar and emotional object, common situation, with data;
- Problem 2—familiar and emotional object, common situation, no data;
- Problem 3—familiar but neutral place, new situation, no data.

Problem 1 (the hairdryer problem) was adapted from a previous study (Silva et al., 2013) and it was of a decision type (Walker & Leary, 2009). Problems 2 (the computer problem) and 3 (the institute's garden problem) were purposefully designed for this study. The former was of a decision type and the latter was of a design type (Walker & Leary, 2009). Two authors who were experienced in teaching and researching problem-based learning created the problems. Two other authors (one experienced in problem-based learning) commented on the problems for improvement. The improved problems were tested with a pilot group to check their adequacy among people similar to the participants and whether further improvements were needed. For this purpose, a sample questionnaire was applied to another group of 12 prospective teachers at the same university. They were asked to solve the problems, share their feelings on the problems, and comment on the problem statements and problem solving. The information collected and the analysis of the written answers suggested that there was no need for improvements.

The problem statements are given in Figures 1–3. They are written in English but were presented to the participants in their official language, which was Portuguese.

Your mother wants to buy a hairdryer because hers broke down. In a leaflet from a large shopping center, she has found three models (figure below), all at the same price. As she does not understand much about hairdryers, she needs help to choose the most suitable model to use daily.



Which of the hairdryers (A, B, or C) would you advise your mother to buy? Describe in detail the process you followed to make the choice, as your mother wants to understand exactly why she should choose one of these hairdryers.

Figure 1. The hairdryer problem (*antes* = before; *agora* = now).

In your family, there is a person who is very friendly with you, who has money but is very careful in how he manages and uses this money.

When you finish the course, this person wants to offer you a new laptop. The computer must be useful, not only for communicating but also for your work as a teacher.

As your family member does not know which computer to buy for you, you must prepare a well-founded proposal for the computer to be purchased by your relative.

Do not forget that you need to convince the person in question that this is the most suitable type of computer for them and that the cost is justified.

Describe in detail, giving reasons, the process that you would have to follow to prepare this proposal.

Figure 2. The computer problem.

The IE presidency has decided to renovate the interior garden, on the presidency side (next to the larger auditorium), with plants that make it attractive, provide pleasant aromas, and improve the environmental conditions.

The presidency does not want the garden to require much maintenance and wants it to have an irrigation and a lighting system.

A competition will be opened and competitors who wish to submit a proposal can visit the site and speak once with the president.

Describe in detail, giving reasons, the process that you should follow to prepare a written proposal to be submitted to the competition.

Figure 3. The garden problem (IE = Institute of Education).

The hairdryer problem (Figure 1) focused on three hairdryers. They were on sale, had different power levels, and had the same sales price but different normal prices. For each hairdryer, the prices both before (*antes*) and during (*agora*) the sale were given, together with the hairdryer power (P). Based on previous research (Jee, 2021; Santani et al., 2015), being on sale was expected to interfere with the PPSTs' answers. Hairdryers are items that people use very often. The physical interaction with the hairdryer may induce positive relationships between the user and the product (Han et al., 2023), and this may have interfered with the answers. Each PPST was required to choose the best hairdryer to recommend to his/her mother for daily use. To do this successfully, he/she had to consider the data and contextual factors included in the problem statement and collect information on his/her mother's hair and hairstyle, which was not given in the problem.

The computer problem (Figure 2) was a science and technology-related problem that asked each participant in the study to prepare a well-founded proposal to provide advice to a relative willing to offer him/her a computer (laptop). A computer is an emotionally charged object (Afrashteh & Razzaghi, 2022), especially for young people. The proposal was required to satisfy a condition—that is, the computer had to be useful, not only for communicating but also for the PPST's work as a teacher after the completion of the initial teacher education program. No data were given, but the information indicated that the relative was a person with money who was highly concerned about financial management and expenditure. Hence, there had to be good justification for the cost of the computer. It was expected that the PPSTs would be sensitive to brands (Muller & Klerk, 2020) and provide a proposal based on the positive aspects of a certain brand (Namiranian, 2006), rather than on the contextual information provided.

The garden problem (Figure 3) focused on an open-air garden surrounded by the Institute of Education (IE) building. This place was familiar to the PPSTs, as they were used to attending classes in the IE building. The problem asked the PPSTs to prepare a proposal for the renovation of the garden. This is a complex task, as setting up a garden requires a multiplicity of competencies from the STEM area (Gulhan, 2023) and from other areas, like drawing, landscape architecture, economics, etc. Based on previous research (Corrochano et al., 2022; Eugenio-Gozalbo et al., 2020; Gulhan, 2023), it was expected that the PPSTs would experience some difficulty in using the variety of knowledge required to complete the task. The environmental features (e.g., sunny or shady), as well as the shape and the area of the place, were not given, but the respondents were told that they could visit the place and talk once to the president of the IE. Visiting the place enabled them to collect relevant environmental data.

2.4. Data Collection Procedures

Data were collected in 2023/2024 using a printed and anonymous questionnaire that included the three problems, as shown above, and two questions on some personal data (age and gender), which were not used. Two co-authors were responsible for face-to-face data collection during class time. They explained the aims and conditions of the research, ensured that the students understood that their participation was voluntary, and asked them to sign the informed consent statement. The University Ethics Council validated this statement and the project that constituted this research (CEICSH 146/2023). Afterward, they handed out the anonymous questionnaire to the PPSTs. Then, they asked the PPSTs to solve each problem and explain the solving process as best as possible. The PPSTs completed this task individually and without a time limit. The answering time ranged from 25 min to 60 min. Conversations between the PPSTs and access to printed or digital information were not allowed. The option to provide individual answers was due to our interest in obtaining information about the processes followed by each prospective teacher. The option for a written questionnaire (instead of a digital one) was given because the PPSTs may have needed to create diagrams, drawings, flowcharts, etc., which is easier to perform using a printed questionnaire.

2.5. Data Analysis

Two researchers, experienced in PBL teaching and research, qualitatively analyzed the answers to the three problems. They sought to identify the main characteristics of the processes followed by each PPST when solving each problem, without looking for *a priori* problem-solving strategies. The objective was to identify and understand the strategies used, rather than to compare them with a model or to count their frequencies. This necessitated using a thematic analysis to uncover the main strategy (or strategies) spontaneously used by the problem solver, which emerged from his/her answers to the problems. To carry out the qualitative and inductive data analyses, for each problem, they started by reading the answers separately. This ensured familiarity with the raw data and allowed some insight into the different strategies used by the participants in the study to solve each problem. Afterward, they read again the answers to each problem separately. This was intended to uncover the different strategies used by the PPSTs and to register illustrative examples of each strategy identified for each problem. After completing this second stage, they discussed the strategies used for each problem and the examples selected to illustrate them. This discussion aimed to reach a consensus on the different strategies spontaneously used by the participants in the study to solve each problem. All decisions on this matter were reached by consensus. It is worth stressing that each student used only one of the strategies listed. The next section will show, for each problem, the strategies and illustrative examples that they agreed on, after translation into English. These examples also show how the respondents solved the problems. One of the authors translated the illustrative answers from Portuguese to English (avoiding improvements to the wording) and another checked the translated answers to ensure that they complied with the original. One or two answers are used to illustrate each strategy, depending on the existence of variations in the implementation of the strategy and the illustrative power of the answers.

3. Results

The results of the qualitative data analysis will be presented problem by problem, with each problem given in a separate section. Some illustrative examples (after translation into English) support the inferences about the processes followed and the strategies used by the PPSTs to solve the problems.

3.1. The Hairdryer Problem

An analysis of how the PPSTs solved the hairdryer problem (see Figure 1 above) revealed seven overarching strategies. Five of them did not consider their mother's hair when making the choice, one strategy considered a typical mother's hair, and another strategy considered the respondent's mother's hair. Each PPST used one of the strategies. The seven different strategies were as follows:

- (i) ignore the target and focus on accessories;
- (ii) prioritize the inclusion of accessories;
- (iii) prioritize the previous highest price;
- (iv) prioritize the power;
- (v) consider a combination of discounts and accessories;
- (vi) consider one mother's hair;
- (vii) consider his/her mother's hair.

One of the strategies (v) combined strategies (ii) and (iii) as the PPSTs considered both aspects to make their choices. These strategies will be presented below, and selected answers will be used to illustrate them.

- (i) Ignore the target and focus on accessories

The problem stated that the respondents should give advice to their mothers on which hairdryer to buy (see Figure 1), but the PPSTs in this group based the decision on themselves, without any reference to their mothers' hair.

"The price of the three hairdryers is the same, so I would have to look at other aspects. I consider hairdryer B to have a reasonable and necessary power for everyday life, especially if there is a need to dry long hair. In addition, it offers a useful tip to diversify hairstyles. So, dryer B would be my choice." (S37)

Instead of choosing a hairdryer for their mothers, the PPSTs in this group seemed to consider choosing a hairdryer for someone that they did not even know and thus preferred a versatile one that could be adapted to changes in style.

- (ii) Prioritize the inclusion of accessories

The PPSTs in this group opted for hairdryer B because it had some accessories. They did not realize that the hairdryer was for their mothers, as they simply discussed "the mother". They did not consider how useful the accessories would be for their mothers; they seemed to believe that the more items the hairdryer had, the better it was for an unknown mother. As illustrated by the following answer, there was no reference to the mother's type of hair (e.g., thin or thick), hairstyle (e.g., straightened hair, wavy hair), or amount of hair (e.g., a lot or a little), which should have been considered.

"I would advise the mother to buy dryer B, because although it is not the most powerful hairdryer, it is the most complete one, as it contains one more object. Thus, as the three hairdryers are at the same price, it makes sense for the mother to buy B." (S5)

Of course, the PPSTs whose mothers enjoyed, for example, drying their hair naturally could consider the inclusion of accessories; those whose mothers wore straightened hair should not have decided based on this aspect, as the diffuser would not have been useful to their mothers.

- (iii) Prioritize the previous highest price

The PPSTs in this group opted for hairdryer B because it was the most expensive before the sale. As the sales price was the same for the three hairdryers, hairdryer B had the highest discount. For these PPSTs, the higher the hairdryer price, the higher the quality.

As illustrated by the answer below, their decisions depended on the difference between the previous prices and the sales price.

“The hairdryer that I would recommend purchasing, taking into account the available data, would be hairdryer B.

The reasons for choosing it are:

- *Hairdryer B is the same price as the others;*
- *Typically, in products sold to the public, a higher quality product is obtained for a higher base price.” (S44)*

Thus, hairdryer B was chosen based on the price, ignoring its (intermediate) power and the features and style of the mother’s hair.

(iv) Prioritize power

Hairdryers have different power levels, and the PPSTs in this group considered the hairdryer power as the key datum when making a decision, as opposed to its accessories or previous price, but they did this in two different ways. Some of them believed that the higher the power, the better the hairdryer, regardless of the features or style of their mother’s hair. The two answers below illustrate these ideas:

“Although the discount on hairdryer B is greater and it comes with an accessory, I would advise my mother to choose hairdryer A, as it has greater power (2100 W) and would be more useful in her daily life than hairdryer B with its accessories.” (S13)

“I would choose hairdryer A. It has the highest power. Even though it wasn’t the most expensive before, it would be a waste to choose, for example, hairdryer B, with all its accessories because my mother wouldn’t use them.” (S6)

In both illustrative examples, the PPSTs mentioned the price before the sale and the accessories of hairdryer B, but they decided based on the power. However, they did not explain why greater power was important for their mothers or why the accessories were useless for them.

Other PPSTs believed that the lower the power, the better, because they felt that lower power would result in lower energy use and, therefore, the hair-drying process would be cheaper or more environmentally friendly, as illustrated below:

“I would advise my mother to buy hairdryer C. As they are all at the same price at the moment, it makes more sense to buy this hairdryer, due to its power being 1600 W, which means that, when you are using it, you won’t use so much energy, and, even though it has low power compared to the other two hairdryers, it manages to fulfill its function.” (S27)

“Based on the fact that all hairdryers are now at the same price, I would advise purchasing hairdryer B. This is because we know that hairdryer C is the one that uses the least energy (1600 W) but this also makes it the hairdryer with the lowest power and therefore the hairdryer that, from the outset, will take longer to dry your hair, which may not be viable daily due to time constraints. Then, the options left are A and B, which differ in power by only 100 W; thinking more sustainably, hypothesis B ends up being the one with an intermediate quality–price rate. It is not the one that uses the largest amount of energy but it seems to have reasonable power and would be practical and functional in everyday life.” (S68)

These PPSTs established simplistic relationships between power and energy use, without considering the time needed to dry a given person’s hair using each hairdryer. The first one ignored the time spent drying the hair; the second one mentioned it implicitly (the lowest power would take longer) but made a poorly explained decision between the

hairdryers with the highest and intermediate power levels in favor of the latter, allegedly for sustainability reasons.

(v) Consider a combination of discounts and accessories

Other PPSTs combined two of the previous ideas to prepare the advice for their mothers and opted for the hairdryer with the largest discount and more accessories, i.e., hairdryer B. Hence, the notions of “the most expensive, the best” and “the more accessories, the better” underlaid their decisions.

“I would recommend hairdryer B, because, despite having only 100 W less than A (but more than C’s 400 W), it comes with accessories that help with some hairstyles and can be quite useful, something that does not happen with the other two. Furthermore, it is the one with the biggest discount (in EUR) (almost EUR 10).” (S49)

“I would advise my mother to buy hairdryer B because, in addition to having a complementary object, it has good power, and the price was previously EUR 34.8 and is currently EUR 25. Dryer B is the one that pays off the most on all levels.” (S35)

The members of this group did well in the sense that they combined two factors, but they did not (at least explicitly) consider their mothers’ hair. It is possible that their mothers did not need the accessories but required a different power level.

(vi) Consider one mother’s hair

In the problem, the hairdryer was for the student’s mother. As mentioned in the Methodology section, different hairdryers may be more appropriate for one type of hair than another. Therefore, the choice of the hairdryer had to consider the PPST’s mother’s hair type and hairstyle. However, some of the PPSTs considered an unspecified mother, rather than their own (real) mother’s hair, whose style they should have been familiar with (unless they had lost their mothers). The following answer illustrates this.

“The hairdryer choice would depend a lot on its purpose; that is, if the mother had curly hair, she would automatically recommend buying hairdryer B, as it is accompanied by a diffuser that is normally used to dry this type of hair. However, this hairdryer can also be used without this diffuser; that is, it becomes the most versatile hairdryer among the three. If my mother had little hair or short hair, I would tell her to buy hairdryer C, as you don’t need a dryer with as much power to dry your hair daily; this way, the daily energy consumption would also be lower. Hairdryer A would be one of the last options to recommend, as it has a lot of power, which means more energy and, consequently, money spent. I believe that, if possible, if it meets the needs, the ideal would be hairdryer C. I think the environment would be grateful.” (S26)

This student appeared to be concerned about environmental sustainability (the reason for choosing the lowest power) but ignored the fact that lower power may require the hairdryer to work for longer.

Other PPSTs chose an (imaginary) mother too, but they planned to collect information from the mother about several issues beyond hairdryer use, as illustrated below:

“In this process, we have to take into account several factors:

- 1—we have equal prices for the 3 hairdryers (A, B, and C);*
- 2—power, whether used or not, in the form of electricity;*
- 3—the existence of drying components (as in image B);*
- 4—the discount/best deal, e.g., price drop to EUR 25;*
- 5—the mother’s hair type and other relevant information about her hair and skin;*
- 6—the apparent size of the hairdryer*

These are some factors that I would use as criteria to help the mother to make the choice. A first step would be to ask the mother directly for information: how many times she dries her hair per day/week; what type of hair she has (dry, straight, curly, dyed, etc.), how much space she has to store the hairdryer; what is her pre-purchase budget (regardless of the price being equal to EUR 25). With this information, I would draw a table to register information and carry out research on the efficiency and quality of the hairdryers, the type of hair, and the temperature it uses. The table would be:

Criteria A B C

[...]

In this table, I would also write information on the criteria that I mentioned initially and, after collecting information, would add up the scores. Afterward, there would be a discussion with the mother to see whether the selection based on the score would meet the initial specifications. If not, the choice could be made based on what seems to be the best deal: B has the biggest discount, average power compared to the other two, and extra components.”. (S12)

These PPSTs tried to identify relevant factors and use data systematically collected on them (they even planned to organize the data in a table) to select the best hairdryer for an imaginary mother (as they never referred to “my mother” or showed an awareness of the mother’s hairstyle, amount of hair, etc.). However, if they felt that this plan would not work, they would decide based on a criterion, namely the amount of discount, with the choice being hairdryer B, which had the largest discount.

(vii) Consider his/her mother’s hair

A couple of PPSTs took their mothers’ hair explicitly into account when deciding on the hairdryer to recommend. They considered either the hairstyle or the amount of hair, as illustrated below:

“I would advise my mother to buy dryer A.

Although hairdryer B has more functions, that is, it brings a curling tool, as my mother doesn’t need it, as she has straight hair; also, if you look at the previous price, this one (B) was the most expensive, I don’t recommend it because she won’t use the curling tool.

Hairdryer A seems the most suitable for my mother as it has greater power than the others have, which is an advantage, as it dries the hair faster.” (S25)

“I would recommend choosing hairdryer B. I would not consider hairdryer C since, compared to the other hairdryers, it has low power, and the prices are the same. Although hairdryer A has greater power than B, hairdryer B includes more hair-finishing tools than A. Therefore, hairdryer B would be more beneficial for my mother, and the difference in power between A and B would not make a difference to my mother because she has little hair, but the power of C would be too low. The accessories of hairdryer B are useful for drying straight or wavy/curly hair. I would not include the previous prices of the dryers in the evaluation process, since the markets often do not set the original prices but use others to make the promotion more eye-catching.” (S55)

These groups of PPSTs were the only ones that explicitly chose a hairdryer for their mothers and considered their mothers’ hair when deciding which hairdryer to recommend to her.

The quotations given above show that some PPSTs’ solving processes (e.g., S49 and S68) drew heavily and explicitly on quantitative data (on the price and power) extracted from the problem statement. Others (e.g., S37 and S44) did not base their decisions on quantitative data, even though they considered them when solving the problem.

The qualitative analysis of the problem statement is a critical step in the problem-solving process. Reading some of the quotations from the PPSTs' answers given above (for instance, S13, S27, S44, and S55), one can see the omission of a qualitative analysis of the problem. Such an omission may have been due to the strategies encountered, which did not consider, for instance, the PPST's mother. Other quotations contain some evidence of an elementary qualitative analysis. The quotations from S68, which starts with a short framing sentence, and S12, which includes a few initial framing sentences, illustrate this group. The PPSTs extracted information about the power of the hairdryers from the problem. However, some of them lacked knowledge of the power concept, as illustrated, for instance, by S26, who stated, *"you don't need a dryer with as much power to dry your hair daily"*.

Another key step in the problem-solving process is the evaluation of the solution regarding the problem's context and conditions. Some quotations, like the one from S12, mention the need to check *"if the selection [...] would meet the initial specifications"*. However, many of the other quotations presented above, like the ones from S26 and S44, do not show evidence of this process. They do not indicate a return to the problem conditions to check whether the hairdryer chosen is suitable.

3.2. The Computer Problem

The analysis of the strategies that the PPSTs used to solve the computer problem (see Figure 2 above) revealed five overarching strategies that encompassed choice procedures that, in most cases, lacked detailed information and systematic needs analysis. Hence, five strategies were found in the respondents' answers:

- (i) present the steps to follow;
- (ii) choose by brand;
- (iii) prioritize the features of the computer;
- (iv) prioritize the features over the price;
- (v) prioritize the teacher's needs.

When using most of these strategies, the PPSTs ignored what they would need from a computer in the future as teachers and based their proposals explicitly or implicitly on emotional aspects. Some of them described what they would do, step by step, and others were not so systematic; however, systematicity is not synonymous with unbiased choice, as it will be shown below. In addition, the information given on how their relative managed money was seldom considered.

- (i) Present the steps to follow

The PPSTs in this group presented a sequence of steps. Each step focused on a parameter, without explicitly relating these parameters to their future needs as professional teachers. In addition, they either did not make clear what they would propose (did not finalize their reasoning) or planned a proposal but tried to impose their preferences. The following answers illustrate these ideas.

"Step 1—Check the memory I need to work on the computer.

Step 2—View processing speed.

Step 3—Take into account price quality.

Step 4—See the diversity of brands.

Step 5—If it is a computer to take around, it should be light, to not make me feel tired.

Step 6—If it is possible to combine the useful with the pleasant, the aesthetic aspect also matters [and should be considered]." (S4)

“Firstly, I would try to understand to what extent the person offering me the computer would have, a priori, settled on a budget or price range. If so, I would start investigating prices and computer models within that range.

Secondly, I would choose the most suitable model or models based on price/quality.

Finally, I would introduce them to my friend [relative], so that we could decide on the best option to choose together. If the person needed a more detailed explanation, this would be the time to do so and make my opinion clear.” (S45)

In these answers, it is unclear how the parameters considered would work as factors enabling the PPSTs to make a choice and provide a rationale for it. The first answer does not explain how the issues mentioned should influence the final proposal. For instance, it does not indicate whether the processing speed should be high, medium, or low. The second one is similar but it ultimately imposes the author’s opinion, probably to satisfy his/her preference, despite the attention that the respondent seems willing to give to his/her relative.

(ii) Choose by brand

The respondents in this group appeared to have chosen in advance, in favor of a brand (brand X) that they fully trusted (the brand name was omitted to prevent advertising), and did not feel the need to look for information about other brands. Therefore, they failed to prepare a good rationale for their proposal. The following answers illustrate these ideas.

“Since I don’t know much about computers, I would use an argument based on aesthetics and also the reputation it has, to convince this relative to offer me a ‘brand X’ computer.” (S7)

“The most suitable computer for my profession is the ‘brand X’, as it is the most rapid on the market and has large memory, most applications only work properly on its software, it has an excellent battery, and it comes in several colors. Furthermore, it is still tactile and easy to carry due to its small size and thickness.” (S23)

In any case, these PPSTs ignored the fact that they were asked to prepare a good rationale for the proposal to present to their relative/friend who was concerned about financial expenditure. Moreover, they did not consider that other people might be unaware of the relative advantages of brand X and that they may need to provide convincing information about brand X and other brands.

Other PPSTs in this group described the features that they believed that a teacher’s computer should have, but, in the end, they simply imposed their preferences for a “brand X” computer.

“When purchasing a computer, particularly for a teacher, the computer must be light, as the teacher walks a lot in the school, and it must have plenty of storage to have space to store many test files, assessments, etc.

It must be able to run programs such as spreadsheets and PowerPoint, among others.

In my opinion, these are some important points that a teacher’s computer should have.

Then, a search must be carried out to immediately exclude those that do not have those characteristics.

Having said that, the most suitable computer is the ‘brand X’, as it has the qualities and I am used to the ‘brand X’s’ devices.” (S64)

Knowledge of the brand and, in this case, experience with it eliminated the need to perform a comparison of the brands and models. There were other participants who started by presenting the brand (brand X) that they wished to try and put forth arguments to justify their choice.

“To convince the person that my choice is the right one and duly considered, I would make a list of pros and cons to prove that the computer in question was the best choice. Therefore, I would say that the selected computer is a ‘model y’ of ‘brand X’ computer with the M1 processor (2023) for the value of EUR 1050 and I would present the following list.

‘Brand X’, ‘Model Y’

Pros | Cons

[.....]

After presenting the list [5 pros, 1 cons], I would analyze each point in more detail, saying:

- ‘Brand X’ or an element of it has/does

- ‘Brand X’ offers a EUR 100 discount for students and teachers [. . .] goes from EUR 1150 to EUR 1050.” (S17)

The respondents in this group presented information (e.g., price, processor) about the computer that they desired (brand X) and an analysis of its advantages and disadvantages (with more advantages than disadvantages), instead of performing such an analysis for some different brands and models to select the one that best fit their needs.

(iii) Prioritize the features of the computer

The PPSTs in this group concentrated on the general features of the computer, without explicitly considering what they would need as teachers. The following answer illustrates this.

“I need a good computer. It does not need to be top of the range or have a specific brand. The most important aspect is that it has good memory, a good processor (above 5-core), and a good video card. This is because, more than beauty, the computer should not crash and should perform tasks properly. Furthermore, excessive weight and a very small size can compromise quality.” (S50)

The members of this group of PPSTs wished for a good computer, with no suitable justification and without considering whether their future tasks would require a good computer.

(iv) Prioritize the features over the price

The PPSTs in this group mentioned some computer variables that they believed were important in a computer, without stating how or why they mattered to a teacher. Afterward, they considered the price as a tiebreaker criterion.

“Considering the nature of the gift and the person offering it, it should never reach an exorbitant amount.

However, it will have to have certain characteristics:

- Memory capacity*
- Presentation ability*
- Ability to create teaching resources*
- Ability to access information quickly*
- Product durability*
- Ease of mobility*

When finding a computer that meets the listed characteristics, the price should be chosen to be as low as possible, respecting whoever offered it.” (S44)

Although considering the price as a tiebreaker criterion in the case of similar features is wise, the answers should have been more explicit about how and why the features mentioned were relevant for a teacher.

(v) Prioritize the teacher's needs

The PPSTs in this group used teachers' needs as the rationale for their computer choices, although they did not fully explain how it worked, as shown below.

"For me, a computer, or the most important thing in a computer, is its storage capacity and memory, as we have many tools, documents, and programs, which are very "heavy", and if the computer does not have a large memory capacity, it will cause problems. . . it becomes slow and even blocks, sometimes it no longer even supports some programs that we need to install. Another strong point of the computer is the graphics card, to support visual arts programs, for example, to explain subjects through these programs to students with good image resolution so that they are clear and perceptible. And lastly, it must be light, as we always carry a lot of material, including books, and it is more convenient to be small and light, yet with great autonomy to last for a long time without a need to carry the charger." (S25)

In this answer, the function of the computer graphics card and the storage capacity are reasonably explained but other features are not.

Other PPSTs recognized that they were not experts in computers and therefore they would need to obtain information on computers. Hence, they decided that they would ask for help to determine the model to suggest to their relative. The following answer illustrates this procedure.

"To begin with, and as I wouldn't understand much about the subject, I would go to a store where they sell computers, and ask a technician what would be the ideal computer to buy based on my needs. Given the information collected, I would then decide which computer to choose and understand how it differs from the others. After analyzing all the details, I would look for the same computer in different stores, to understand if the prices differ from one store to the other and if this would be the ideal computer. Finally, after choosing the computer and the buying location, I would present the proposal to my relative." (S28)

The PPSTs in this group recognized the need to collect information on different brands and to compare it in order to prepare a proposal to present to their relative. After deciding on the required features, they would look for the computer of their choice at the lowest price. For these PPSTs, the selection should be based on relevant features, and the price served as a tiebreaker.

It is worth noting that some PPSTs did not consider that they did not possess sufficient knowledge to choose the computer, while others did. To make an informed decision and prepare a proposal, the latter claimed that they would make brand-based decisions (S7) or ask for a third person's help (S28) instead of looking for information.

Some transcriptions showed that the PPSTs mentioned quantitative variables and data (e.g., S4, S17, and S45), while others (e.g., S7, S23, S50, and S64) referred to qualitative comparisons, without mentioning or arguing for the need for quantitative data.

Some transcriptions from the students' answers showed that the PPSTs used information taken from the problem statement, without globally analyzing the context that it described. For instance, S4, S17, and S23 put forward ideas about computer features without explicitly relating them to their future needs as teachers; S25 and S50 did not consider that the computer would be on offer, which should have fulfilled some conditions. S44 and S64 extracted information from the problem context but did not explicitly use it to decide. Their transcripts—for example, those of S17, S25, and S50—do not provide evidence of the completion of the problem, as there is no mention of the proposal or evidence of an awareness of its absence. This suggests that the PPSTs did not perform a qualitative analysis of the problem statement and did not critically analyze the solution. The latter would

have allowed the PPSTs to perceive that the proposal was missing and the problem-solving process was incomplete.

3.3. The Garden Problem

An analysis of the strategies used to solve the garden problem (see Figure 3 above) revealed four overarching strategies. Some strategies did not answer the problem, as they showed a sequence of recommendations or steps to follow in renewing the IE garden. However, others moved beyond this, as they planned data collection or considered how to use the data collected. The four strategies identified are as follows:

- (i) make recommendations instead of a proposal;
- (ii) list the steps to follow;
- (iii) collect additional information;
- (iv) collect and use additional information.

As with the previous problems, these ideas will be further developed and illustrated with selected answers.

- (i) Make recommendations instead of a proposal

The PPSTs in this group created a list of recommendations for the IE to follow, instead of describing how he/she would prepare a proposal that complied with the terms of reference mentioned in the problem statement. The following answer illustrates this.

In my opinion, the education institute should opt for plants that do not exactly have a season, that is, that are only beautiful in summer or winter. I think they should choose to create several beds with cactus plants, as a cactus does not require maintenance or a lot of water. They should put more tables so that everyone can enjoy the garden. Cacti should be of different colors surrounded by black or white little stones, thus creating a welcoming atmosphere. (S21)

This PPST is an example of one who did not perceive that he/she should present a concrete proposal for the garden, instead of creating recommendations to propose to the IE.

- (ii) List the steps to follow

The PPSTs in this group created a list of steps to follow to answer the problem, although the list was incoherent or incomplete. The following answer illustrates a case in which the sequence of steps lacked underlying logic.

“Start by thinking about what plants you could place, following the criteria that the presidency of the Institute of Education wants.

Afterward, visit the place to see what it is like and so on, and speak to the president to clarify any doubts that might emerge or so.

After visiting the place and having a conversation with the president of the Institute of Education, agree on all the initial ideas.

And finally, submit the written proposal to the competition.” (S61)

Selecting plants before visiting the place is illogical. Similarly, visiting the place “to see what it is like” fails to take full advantage of the visit or to consider the importance of data (e.g., dimensions) in preparing a good proposal.

Other answers in this group omitted relevant steps/procedures needed to prepare the proposal, as illustrated below.

“Initially, I would have to go to the site to understand the current state of the garden. From there, I would think, based on the demands/requests made, I would research and study the best way to respond to the request, with the lowest possible budget and in the

most beautiful way. From there, I would make a budget and present it to the IE presidency with a physical model that I would prepare too.” (S2)

It is unclear whether information collected onsite (on the current state of the garden) would be used to build the physical model to propose for the garden and submit to the contest.

(iii) Collect additional information

This group included answers that listed steps to follow and information to collect from the president (as suggested in the problem statement), but they did not describe how the information collected would be used. The following answer illustrates this idea.

- “- Plan possible questions to ask the presidency before visiting the site.*
- During the visit, carefully observe the facilities and assess the needs of the space taking into account the requirements mentioned.*
- Find out which materials are suitable and what the different prices are.*
- Establish a budget based on the differences in proposed solutions found, explaining the advantages not only in cost but also in the quality and durability of the product, as well as the possibility of requiring less or more maintenance.*
- State which proposals you consider most appropriate given the information provided.*
- Show availability to clarify doubts.” (S65)*

The answers in this group considered posing questions and performing observations, but it was unclear how the data collected would be used to create the proposal. An analysis of some of them suggested that the information collected would simply be put together and submitted for the contest. This idea is illustrated by the following answer.

“To prepare the written proposal to submit to the competition, it is important to visit the space where the intervention will take place and evaluate the level of attractiveness and attendance by students at the Institute of Education.

If possible, I could talk to students who use this space and ask what they would change/add to make the space more enjoyable to use.

After this space assessment process, the cost assessment process follows regarding the installation of an irrigation and lighting system, together with the assessment of the cost of the plants to be placed and any extras/materials suggested by the students (e.g.: garden benches, set of tables and chair).

After this intensive process of evaluating costs on the various surfaces/decoration items and the budgets given by professionals installing irrigation and lighting systems, it is important to gather all this information in a document and communicate the results obtained, as well as the proposal to be made most advantageous to the presidency of the Institute of Education.” (S4)

This answer states that *“it is important to gather all this information in a document and communicate the results obtained”*, but the results should be used to prepare the garden project and not simply handed to the president of the institute.

(iv) Collect and use additional information

The answers in this group described the collection of information and the use of such information, albeit not always in an explicit way. Some PPSTs planned to collect information from the president only, but others considered other individuals, like students or community members. The following answers illustrate these situations.

“1st—Visit the space, take measurements, see sun exposure, analyze the type of soil, and the use it will have after renovation.

2nd—Taking into account the results obtained in the 1st step, select the species most suitable for the space and that meets the intended renovation requirements; drawing up a space plan taking into account sun exposure and the function to be performed (e.g., whether it will be a leisure and/or rest space).

3rd—In the garden plan, place the selected species and forecast the evolution of the space [...], include the rule points and how it will work [...], and include the lighting system [...].

4th—Prepare a report including the research work, the final space plan, and the approximate budget of the proposal.” (S43)

“1. Visit the place in the morning.

2. Interview some members of the community that use the place.

3. Visit the place in the afternoon.

During these visits and having my notes, I would make a preliminary proposal based on the ambiance, luminosity, thermal comfort, and users’ opinions on what would please them more or less, what they expect, etc.

Once this is in place, I would meet with the presidency, to align the proposals and “smooth out the edges”, seeing what can be done to please most of the interested parties. Finally, I would submit the proposal to the competition, after, of course, having studied the costs and trying to rationalize resources. (S50)

According to these answers, only a single person would propose a garden. However, other PPSTs recognized that this would be a challenging and demanding task and planned to use a multidisciplinary team, as shown below.

“Firstly, it involves the formation of a multidisciplinary team in the areas of landscaping, botany/gardening/irrigation systems/person connected to the Institute (but not linked to the presidency) [to assist in preparing the proposal].

In the first phase, the team’s initial ideas and possible problems were discussed [→ preparation for the visit to the place and conversation with a member of the presidency].

Following the visit and collection of information, the team would again assess problems and solutions. The possibility of involving the educational community through a survey would be considered.

As a result, the proposal that was already being prepared would be reviewed; there may be more moments of inquiry or conversation with members of the presidency, if possible; which would lead to the final proposal.”. (S12)

To comply with the call’s terms of reference, a multidisciplinary team would be required, which would perform a variety of specialized tasks (e.g., creating a plan for the garden, selecting plants, and choosing lighting and watering systems), as argued by S12. However, reading the transcripts above, it can be found that some PPSTs planned to complete all tasks themselves, as illustrated by S2. Others used a non-personal writing mode, which did not indicate whether they were conscious of the task’s demands. In any case, it was unclear whether they were aware of the diversity of knowledge and abilities required and whether or not they possessed them.

Some transcriptions (e.g., S21 and S61) indicate that the PPSTs did not mention or feel the need for quantitative variables and data. Others mentioned quantitative items, like the area of the garden (S12), the budget (S43), and the costs (S50), but did not develop them.

An analysis of the transcripts presented above indicates that S4 started by mentioning the proposal, while the others do not. There is some evidence that the PPSTs read the problem statement, as they mentioned some items included in it. However, they did not

explicitly indicate their knowledge of the problem and what they needed to know or do to solve it. Some PPSTs showed planning abilities (e.g., S12, S43), as they mentioned what they would need to do. Some transcripts showed that the PPSTs failed to address the objective as they did not mention the proposal (e.g., S21), while others understood that they had to prepare a physical model (S2). Other transcripts indicated that the PPSTs mentioned the proposal's submission but showed no evidence of the proposal's revision considering the data given in the problem statement or collected (e.g., S61). These findings reveal that a critical analysis of the problem's solution against the problem's demands was not performed.

4. Discussion

This research aimed to characterize the processes followed by PPSTs when solving three STEM-relevant problems, which had different features. A qualitative analysis of the PPSTs' answers was performed to identify the overarching strategies underlying their problem-solving processes. The large number of answers analyzed suggests that saturation was reached. This means that the diverse range of approaches adopted by similar participants to solve these problems was probably identified.

An analysis of the overarching strategies followed by the participants when solving the three problems shows that the PPSTs used a variety of approaches when solving each problem, as expected based on previous studies (e.g., [Hsu et al., 2024](#); [Oh, 2024](#)). In contrast to what is required when solving a complex and interdisciplinary problem ([Price et al., 2021](#); [Wang et al., 2023](#)), the PPSTs' approaches were, in general, linear, and the PPSTs did not return to the problem statement, even to perform a critical analysis of the results. [Price et al. \(2021\)](#) argue that appropriate knowledge and skills influence the problem-solving process. Some PPSTs' answers indicated a lack of relevant knowledge, which they seldom acknowledged. Most of the strategies identified depended on product attributes ([W.-L. Chen & Chiang, 2010](#)), hedonic factors ([Jee, 2021](#); [Santani et al., 2015](#)), i.e., smart shopping perceptions, and brand factors ([Muller & Klerk, 2020](#)), although those factors influenced the PPSTs in different ways.

Problems 1 and 2 were related to purchasing objects. According to [W.-L. Chen and Chiang \(2010\)](#), "Consumers' purchasing behavior is affected not only by cultural, social, personal and psychological factors but also, most importantly, by the consideration of product attributes" (p. 396). In the case of the hairdryer problem, most of the strategies focused on the product attributes and price, i.e., on the hairdryer's power (strategy iv), accessories (i and ii), or accessories combined with a discount (v). These strategies were influenced by the product features, as could be expected based on [W.-L. Chen and Chiang \(2010\)](#), and they did not consider the target user of the hairdryer (the problem solver's mother). Strategy (iii) appeared to be driven by hedonic benefits ([Jee, 2021](#)), a behavior associated with sales that leads to choosing the item with the largest discount, due to the self-perception of being a smart shopper (e.g., [Jee, 2021](#); [Santani et al., 2015](#)). Quantitative information on the power and price explicitly underlaid three strategies (iii, iv, and v) and seemed to influence the others, namely strategy (i). This may have been because the students were used to solving algorithmic ([Salta & Tzougraki, 2010](#)) instead of decision-making problems, which require making choices and assessing the risks and benefits of alternatives ([Walker & Leary, 2009](#); [Jonassen, 2012](#)). A hairdryer is a product that is often used in people's daily lives. Therefore, some people may exhibit strong physical interactions with hairdryers. As [Han et al. \(2023\)](#) argue, this physical interaction may induce a positive relationship between the user and the product, which may override other key elements. These positive relationships and the PPSTs' difficulty in integrating the information extracted in the problem-solving strategy ([Broman et al., 2018](#); [Maries &](#)

Singh, 2023; Tan et al., 2023) may explain why all but one (vii) of the strategies ignored the fact that the hairdryer was for the problem solver's mother. Instead, they focused on choosing a product as if it were for themselves or for a non-identified mother (as seen in strategy vi). Despite these difficulties, all strategies led to a final result, although there was little evidence of a critical analysis of the latter, which several authors (Çavaş et al., 2023; Lambros, 2004; Leite & Afonso, 2001) consider an important step.

A computer is a technological product that students (including PPSTs) use daily. Computer users develop attachments to them, mostly related to their utilitarian aspects (Afrashteh & Razzaghi, 2022). This attachment is often assessed based on emotionally perceived performance. According to Han et al. (2023), attachment may cause an emotional bond that may override other features or contextual factors. Emotional bonds may underlie strategy (iii), which focused on the computer's features without considering its future purpose. Young people are sensitive to brands associated with good performance and consider "status indicators" (Namiranian, 2006). Hence, a brand's name influences their choices (Muller & Klerk, 2020) and works as a choice simplifier and a guarantee that a product can be relied upon (Namiranian, 2006). One of the overarching strategies (ii) was based on faith in a given brand (name omitted), which resulted in the perception of good performance and fulfilled a desire for status, as the brand in question was more expensive than the others. The brand-driven choice, alone or together with the difficulty in interpreting the problem (Maries & Singh, 2023; Silva et al., 2013) and extracting information from the problem (Broman et al., 2018; Maries & Singh, 2023), prevented some problem solvers from considering two of the contextual conditions of the problem. These were the fact that the computer had to be useful for their work in the future (as teachers) and the fact that the person who was offering them the computer was concerned about spending money. This required the solver to compare the information provided by different brands. Some years ago, Namiranian (2006) concluded that young people wish for brands to provide information that enables them to compare the alternatives available easily and simply. Some participants described a set of steps to follow (as in strategy i), which may include a brand comparison (as in strategy ii), but they did not explain how this should be performed. In some cases, this procedure seemed to be an excuse to impose the solver's preferences, probably based on an affective bond with a given brand or model. They failed to make critical and evaluative judgments of the results obtained, which are relevant procedures in problem solving (Maries & Singh, 2023; Silva et al., 2013). Strategy (iv) prioritized the features over the price and used the price as a tiebreaker; this would be reasonable in light of the contextual information given. However, the importance of the prioritized features was not fully explained. Omitting a good analysis and explanation of the relevant features would result in a weak proposal. Only strategy (v) presented a reasonable explanation. It drew on information from different brands and used the price as a tiebreaker. In this strategy, the brand did not override the price or the computer's features.

Settling and keeping a garden is a demanding task that requires and promotes the development of relevant knowledge, skills, and attitudes under the scope of STEM disciplines and other knowledge areas (Gulhan, 2023). This is why garden-based education has been described as having educational value for several school levels (Eugenio-Gozalbo et al., 2020; Kong & Chen, 2023), including for preservice teacher education (Corrochano et al., 2022). It should be stressed that a garden is an "object" that can be approached at different levels of complexity, thus serving a diversity of purposes. The problem used in this work complied with the conditions acknowledged by Ayerbe-López and Perales-Palacios (2023) for a problem, as it had a high level of complexity and required knowledge of a diversity of disciplines, including the STEM disciplines, drawing, landscape architecture, economics, and others. Strategy (i) indicates that the problem solvers did not understand the goal of the

problem, as was seen in previous research (Ogunleye, 2009; Reddy & Panacharoensawad, 2017; Saka et al., 2024). In addition, strategies (i) and (ii) do not demonstrate the ability of the respondents to identify the knowledge required, which is one of the demands of the problem-solving process (Çavaş et al., 2023; Lambros, 2004). While the users of strategy (ii) put forward some steps to follow, they did not present concrete descriptions of the tasks that they would include or the information that they would look for. As in other research studies (Maries & Singh, 2023; Silva et al., 2013), the participants did not finalize their reasoning and failed to consider the design of a project for the garden. Although strategy (iii) considered collecting additional information, it was unclear what this information would be used for. The participants perceived the target as the contest, rather than the design of the proposal. This indicates that the PPSTs did not understand the problem, as was found by other authors (Ogunleye, 2009; Reddy & Panacharoensawad, 2017; Saka et al., 2024), and they did not perceive it as a design problem that required the incorporation of knowledge across several disciplines to develop a product (Walker & Leary, 2009), namely the garden project. Strategy (iv) was better aligned with the goal of the problem, as it considered a logical path to follow, acknowledged the need for a variety of knowledge, as pointed out by Gulhan (2023), and considered the usefulness of a multidisciplinary team.

From the above, it seems that external factors, rather than the problem itself, influenced most of the strategies used by the participants to solve the three problems. As expected, data influenced the problem-solving process when provided (as in the hairdryer problem), but the participants did not show a strong ability to identify data in the other problems. The influence of external factors led to solutions that did not satisfy the problem's goal, lacked scientific support, and depended on brands and attachment. In addition, two key steps of the general problem-solving strategy described in Section 1 were not present in the problem-solving processes of the PPSTs, as shown in the previous section. As in other studies (Amanda et al., 2021), these steps were the first (qualitative analysis of the problem) and the last (critical analysis of the solution) ones. They were identified (Pozo et al., 1995; Torregrosa, 1987) as problematic because of the types of problems that students are usually asked to solve in school. The structure of school problems may lead to success without a careful analysis of the problem statement (Salta & Tzougraki, 2010). Success in similar conditions is not possible with ill-structured and contextualized problems, which research (Amanda et al., 2021; Maries & Singh, 2023; Silva et al., 2013) shows are challenging for problem solvers to interpret. The absence of a critical analysis of the solution was reported in the literature (Maries & Singh, 2023; Silva et al., 2013) as a reason for incomplete problem-solving. Again, school problems are straightforward and usually have a (single) solution (Maries & Singh, 2023; Pozo et al., 1995). These features lead to success even without analyzing the problem statement or the result obtained, but they should be rejected for the benefit of students of all school levels.

5. Conclusions

This paper describes qualitative research aiming to characterize the processes followed by prospective primary school teachers when solving three STEM-related problems. The research was based on data collected by a questionnaire at one higher education institution and focused on three STEM-relevant problems. The participants used a variety of strategies to solve each problem, most of which did not lead to a complete answer. The influence of external factors (e.g., hedonic factors, attachment, and brands) and the omission of some key steps of the problem-solving process (i.e., a qualitative analysis of the problem statement and a critical analysis of the results) were observed in most strategies used by the problem solvers. This means that, when teacher educators train prospective teachers to solve problems, they should use ill-structured STEM-relevant problems, which require their

students, either prospective teachers or other students, to use and develop cross-discipline knowledge and to plan, implement, and assess a problem-solving strategy. In addition, teacher educators should focus on the key general steps of the problem-solving process, as advocated for by several authors (e.g., [Amanda et al., 2021](#); [Çavaş et al., 2023](#); [Lambros, 2004](#)), paying specific attention to the analysis of the problem and the critical analysis of the results. They should also consider the internal and external factors ([Jonassen, 2000](#)) that may affect the problem-solving process, including the context of the problem ([Salta & Tzougraki, 2010](#)), emotional issues ([Afrashteh & Razzaghi, 2022](#); [Jonassen, 2012](#)), brands ([Muller & Klerk, 2020](#)), and hedonic factors ([Jee, 2021](#)). Unfortunately, science education pays little attention to these factors.

As with other research studies, our work has some limitations. We developed our interpretations of the transcripts without consulting the participants. Interviewing some participants about their answers would have increased the reliability of the data analysis. Moreover, using pairs of problems with similar features would enable the analysis of the consistency of the participants' answers across problem contexts. Conducting quantitative survey-like studies would allow researchers to identify which strategies prevail. Such studies should include participants from different institutions so that their results are generalizable. It would also be worth determining whether students of other cultural contexts and school levels use the overarching strategies identified. This would provide a better basis for the development of educational strategies that address the tendency to allow external factors to override the data and the contextual information provided in the problem statement.

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