STEM in the classroom through problem solving on bacteria and drugs

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Abstract

The Spanish curriculum for School Science establishes some objectives related to the development of various scientific practices: raising problems, formulating hypotheses, constructing models, designing resolution strategies, analysing results, etc. Furthermore, it suggests the convenience of proposing relevant contexts from a personal and global perspective (environment, frontiers of science and technology, health, and disease, etc.), in order to show the impact of these disciplines in social development. In addition, the evaluation criteria of School Mathematics, the main focus of this work, include use of problem-solving strategies and generalisation of mathematical research, application of mathematisation processes in everyday contexts, and assessment of modelling as a tool for problem solving, being aware of its effectiveness and limitations. Nevertheless, and despite this curricular development, Spanish students scored below the OECD average in Mathematics and Science in PISA 2018. In this contribution, we present a descriptive analysis of the obstacles faced by 16–17-year-old students when dealing with a contextualised problem about growth of bacteria and how two drugs can help to partially eliminate them. In addition, we analyse the potential of a teaching and learning strategy based on modelling, mainly mathematical, to integrate knowledge about different disciplines. The problem allowed students to work on a variety of concepts and procedures: bacteria and viruses, infection models, numerical successions, resolution of logarithmic and exponential equations, graphic representation of functions, etc. During the development of the activity, several intermediate questions were posed to facilitate its understanding and interpretation, delimiting and structuring the problem. The use of the GeoGebra software was also considered.

Keywords: *Problem solving, STEM, contextualised problem*

1. Introduction

Since 2000, the OECD has been conducting triennial studies on the skills that 15-year-old students must acquire in three areas, reading comprehension, Mathematics and Science, leading to the PISA reports that can serve as a basis for the design of improvement policies. These tests allow reflection on the international learning situation and the exchange of experiences to improve some educational indicators in all participating countries [1]. They aim to determine whether students are able to apply what they have learned in the classroom in different situations, both in their own schools and in real life, which requires reasoning skills instead of well-defined procedures that are only helpful to answer direct questions. [2]. In our context, Spanish students scored below the OECD average in both Mathematics and Science in PISA 2018 [3].

Despite these results, the Spanish curriculum [4] includes objectives related to the development of various scientific practices: posing problems, formulating hypotheses, proposing models, designing strategies for solving them, analysing the results, etc. [5]. Furthermore, teachers are required to propose relevant contexts from a personal and global point of view (environment, frontiers of science and technology, health and illness, etc.), which show the impact of these disciplines in social development.

On the other hand, if we focus on the subject of Mathematics, the Spanish curriculum includes the use of problem-solving strategies and the generalisation of research, the application of mathematical processes in everyday contexts or the valuation of modelling as a resource for solving problems, with an awareness of its effectiveness and limitations.

In order to understand and promote the interaction between the disciplines of Science, Technology, Engineering and Mathematics, as well as the associated vocations, in the 1990s the term STEM emerged from the field of education, as an acronym for Science, Technology, Engineering and Mathematics [6]. In the STEM framework, apart from understanding concepts about Science, Mathematics or Technology, it is of utmost importance to solve real-world problems by "thinking like" mathematicians, scientists and engineers, and being aware of the interconnections between these disciplines [7].

For all the above reasons, in this paper we aim to analyse the obstacles faced by students when tackling a contextualised problem about the growth of bacteria and the decision to choose between two drugs, a task which integrates knowledge from the previous areas.

2. Method

This research follows a qualitative design to explore how Secondary Education students approach the resolution of a problem contextualised in Science and Technology, in which a variety of mathematical concepts and procedures are involved.

For this purpose, eight 16–17-year-old students from a technological high school in Spain were selected. They were finishing the first year of post-compulsory secondary education and worked in pairs to solve the problem.

2.1. Proposed problem

We proposed the following problem to the students:

On January 1st (Monday) at 0.00 am, one million people were infected with a certain bacterium. Two pharmaceutical companies are trying to combat a situation that could trigger a humanitarian disaster. The first pharmaceutical company has manufactured a drug that reduces the number of bacteria by 62.5% each time it is given; and can be injected every six hours. The second pharmaceutical company has made a drug that reduces the number of bacteria by 72% and can be injected every 24 hours. On the other hand, a laboratory has started to study the reproduction of these bacteria. It has found that at a temperature of 36.5°C (human body temperature), the number of bacteria doubles every 6 hours. Medical research has shown that, if people have more than one million bacteria in their body, they die, but if they are able to keep the number of bacteria bellow that quantity for 10 days, they survive and are immunised for life. What drug would you use to alleviate this infection? Justify your answer.

2.2. Scaffolding

To facilitate problem solving, students were guided to structure the problem in several steps or stages. In addition, a set of questions were provided to promote reflection on the necessary contents, procedures and strategies [8]. These questions were linked to the following four blocks:

Table 1. Proposal of blocks for the problem and associated Mathematics, Science and Technology contents

Block	Mathematics content	Science content	Technology content
I.Reproduction of bacteria (drug-free)	- Numerical sequences - Arithmetic calculations - Exponential functions - Algebraic expressions - Limit of sequences / functions	- Characteristics of living things and levels of organisation - Bioelements and bio-molecules - Research project.	
II.Drug-free life time	- Logarithmic and exponential equations. - Arithmetic calculations - Graphical representation of sequences/functions	- Health and illness - Immune system - Research project	- Computational strategies (GeoGebra)
III.Drug introduction	- Percentages - Arithmetic calculations - Algebraic expressions - Graphical representation of sequences / functions	- Health and illness - Immune system - Research project	- Medical research - Medical treatments
IV. Survival	- Arithmetic calculations	- Characteristics of living	

Block	Mathematics content	Science content	Technology content
		things and levels of organisation - Bioelements and bio-molecules - Research project	

3. Results

Students show a good resolution of the numerical calculations that appear during the problem and a good approach to percentages. Both mathematical notions were already acquired in previous years. In addition, they correctly pose and solve logarithmic equations (Figure 1). In all three cases, these are tasks that require the acquisition of different processes and skills, but not a particular reflection on the problem posed.

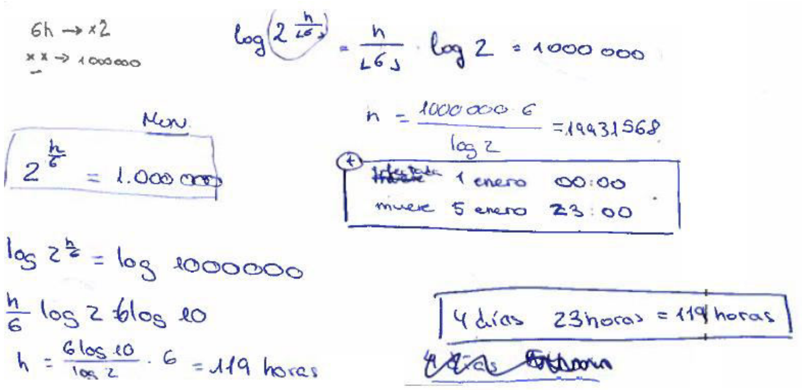

Figure 1. Approach and resolution of logarithmic equations.

Despite being part of a multitude of tasks that pupils of this age have to solve at school, algebraic expressions are not tackled with the rigour they require. Moreover, a great number of difficulties are detected in their interpretation; for example, some pupils incorporate the same number of bacteria in each step of growth and add them to the previous ones, instead of doubling the number of bacteria in each step of growth, e.g., 2x+h instead of 2^h (Figure 2).

Figure 2. Some proposed algebraic expressions.

The greatest difficulties arose when dealing with the notion of limits and, above all, in the graphical representation and interpretation of the results reached in each of the questions posed. Regarding the graphical representation, the students had the opportunity to use the educational software GeoGebra. However, they decided to use paper and pencil instead (Figure 3).

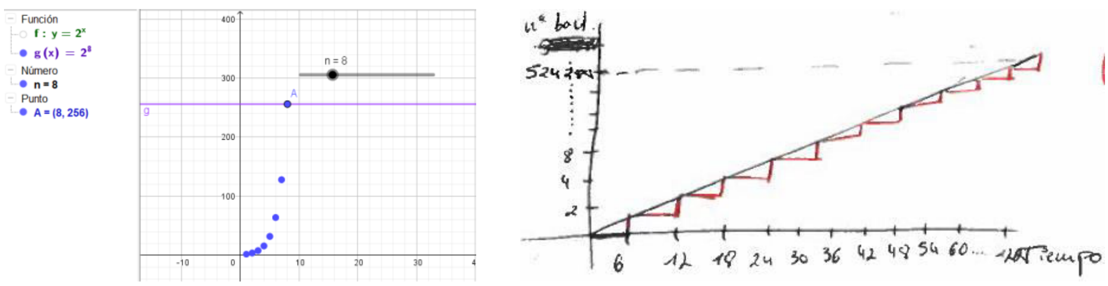

Figure 3. Expected graphical representation and example of function proposed by a student.

The students barely alluded to the concepts associated with Science (Biology), even though they were implied in the context of the problem. They only used the word bacteria to determine the units of the numerical quantities.

4. Conclusions

After carrying out this case study, we can affirm that the students involved in the task were not able to apply what they learn in the classroom to a specific situation that demands reasoning instead of a previously established procedure. This happened regardless of the growing attention of the Spanish curriculum [4] to the development of different scientific practices associated with Science and Mathematics.

Although this proposal was not intended to assess specific knowledge of Mathematics and Science, we were able to observe some obstacles in the integration of these subjects. Among these obstacles, we highlight those related to the graphic representation and interpretation of the results achieved, and the absence of the specific vocabulary of Science that provided context to the problem. Moreover, despite the suggestion to use GeoGebra, the students declined this option and preferred to carry out traditional graphical representations.

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