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ARTIGO ORIGINAL/ ORIGINAL ARTICLE

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Indagación y modelización matemática para descifrar un antiguo mensaje romano en Educación Secundaria

Inquiry and mathematical modelling to decode an ancient roman message in Secondary Education

RESUMEN

En este artículo se presenta el diseño de una situación de aprendizaje para promover la emergencia de evidencias del uso conjunto de los procesos de indagación y de modelización matemática. Esta situación de aprendizaje forma parte de una investigación más amplia y aún en proceso que tiene como objetivo general describir cómo los procesos de indagación y modelización matemática interaccionan y se enriquecen mutuamente, caracterizar las actividades de enseñanza y aprendizaje de las matemáticas que promueven el desarrollo de los procesos de indagación y modelización, y las competencias y habilidades ponen en uso los estudiantes al abordar tareas de este tipo. La situación de aprendizaje que se presenta no ha sido aún implementada, pero sirve de ejemplo de actividad matemática situada en un contexto interdisciplinar, cercano a los estudiantes y que supone un reto para ellos, promoviendo así un aprendizaje de las matemáticas de mayor significatividad.

Palabras clave: contexto arqueológico, indagación, modelización matemática, educación secundaria.

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ABSTRACT

Abstract: This article presents the design of a learning situation to promote the emergence of evidence of the joint use of the inquiry and mathematical modelling processes. This learning is part of a larger and still ongoing research project that aims to describe how the processes of inquiry and mathematical modelling interact and mutually enrich each other, to characterise the mathematics teaching and learning activities that promote the development of inquiry and mathematical modelling processes, and the competencies and skills students need to use when they deal with tasks of this kind. The learning situation presented here has not yet been implemented, but it serves as an example of a mathematical activity situated in an interdisciplinary context, close to the students and challenging for them, thus promoting more meaningful learning of mathematics.

Keywords: archaeological context, inquiry, mathematical modelling, secondary school education.

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INTRODUCTION

Didactic of mathematics tries to give responses to a double purpose: on one hand, it aims to describe the teaching and learning processes of a variety of mathematical contents and competencies with the will of understanding how these processes take place and which elements concern them; on the other hand, didactic of mathematics aims to provide mathematic teachers with tools for improving their practice and thus promote better learning of this subject (Font & Godino, 2011).

Among these efforts made by didactics of mathematics to improve the mathematics teaching and learning processes, there are studies focused on the importance of strengthening the use of problem-solving and inquiry (Maaß & Doorman, 2013; Rocard et al., 2007), as well as the work with mathematical modelling (Kaiser, 2020). Both inquiry and mathematical modelling are considered interesting and enriching processes to be developed in mathematics teaching practices.

However, and despite the air of resemblance (in terms of Wittgenstein, 2009) between some of the sub-processes conforming the processes of inquiry and mathematical modelling —which share non obvious characteristic common to them all, but show some similarities among some sub-processes without a unique pattern of resemblance—, the research on their properties and characteristics has been conducted separately until a couple of studies recently have been published (Falcó-Solsona et al., 2024; Sala Sebastià et al., 2021).

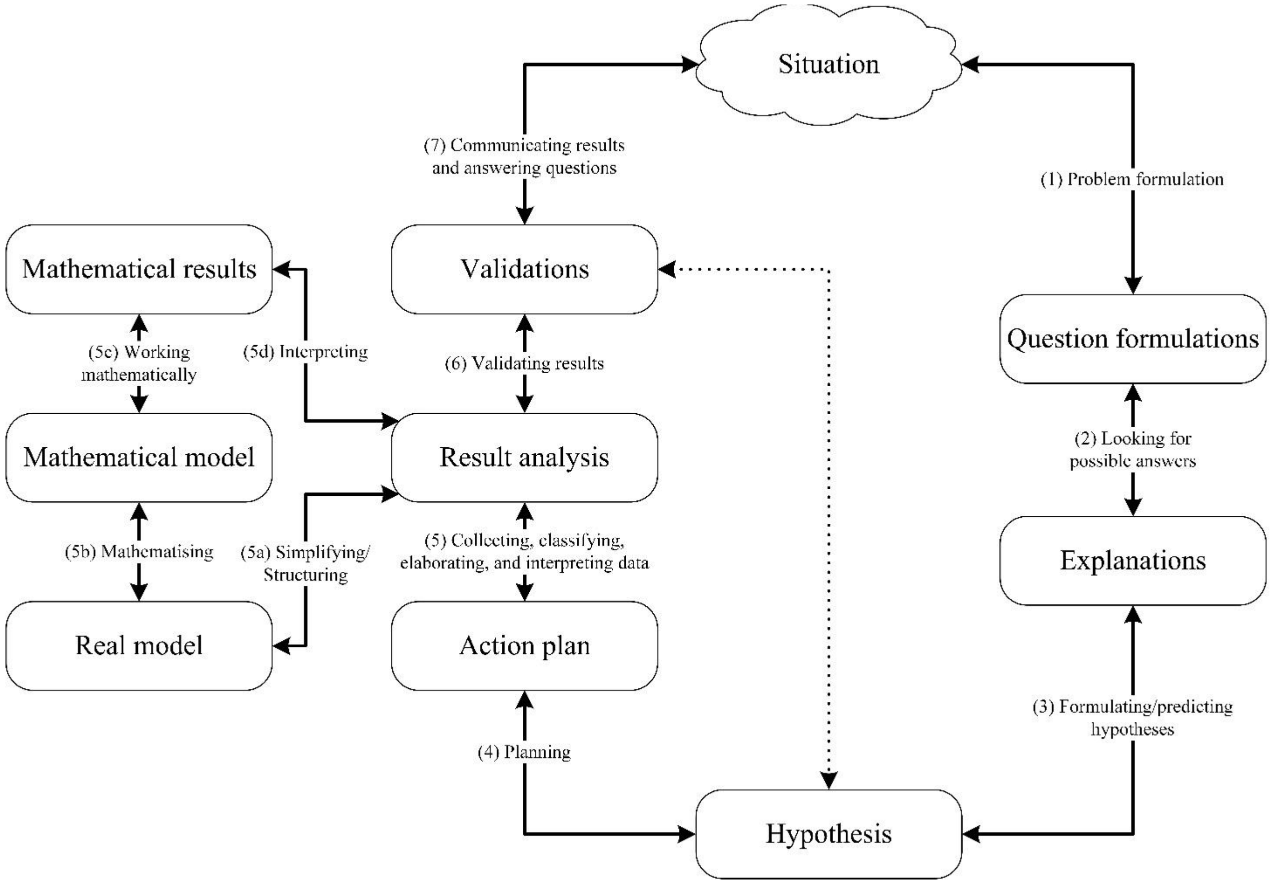
The research hereby presented, which is still being conducted, aims to develop the study carried out by Falcó-Solsona et al. (2024). This article proposed an integrative cycle for the processes of inquiry and mathematical modelling after having conducted a first approach to the connections between the two processes, connections that were observed throughout the evidence of the different sub-processes of inquiry and mathematical modelling arising from the implementation of a learning situation designed to promote both processes.

As it has been already said and we shall remark, the investigation corresponding to this paper is not yet finished since the hereby presented learning situation must be implemented; its objective is to check and verify the first proposal of an integrative cycle for inquiry and mathematical modelling presented by Falcó-Solsona et al. (2024) and observe more accurately the different competencies and skills that have to be used and developed by students to carry out each one of the sub-processes of the inquiry and mathematical modelling cycle. However, the authors have considered it interesting to present the learning situation designed for this research as it is a good example of a mathematical activity which could promote both inquiry and mathematical modelling, and connect mathematics with other knowledge in an interdisciplinary context.

THEORETICAL FRAMEWORK

As it has been said above, the research presented pretends to explore the relations and synergies between the processes of inquiry and mathematical modelling. Both processes have been widely studied before and there is plenty of literature describing them separately; but only recently some studies have dealt with the existing connections between the two processes, studying which kind of learning activities promote these connections to arise, which

Figure 1. Integrative cycle for inquiry and mathematical modelling processes.



Source: Falcó-Solsona et al. (2024).

sub-processes of inquiry and mathematical modelling appear together and under which conditions, and which are the learning processes developed by students when facing problems that require the use of both inquiry and mathematical modelling.

This research is based on the integrative cycle for inquiry and mathematical modelling processes by Falcó-Solsona et al. (2024) (see Figure 1), which offers a common path for the design and implementation of learning situations aiming to develop both inquiry and modelling.

According to this approach, the cycle starts from a realistic and authentic problem situation which is *problematised* by students. Once the problem is stated and the questions related have been formulated, the students try to *look for possible answers* that provide them with preliminary explanations (such explanations are not supposed to solve the problem stated, but they are a first approach to the problem situation and thus help the students to get a better understanding of the problem; this first approach provided by preliminary explanations allow students to *formulate their hypotheses*, that they shall try to validate or reject during their investigation towards the problem solution. These first steps through the cycle are necessary for students to get a better understanding of the problem situation.

Then, once they have their formulated hypotheses to work with, students *plan the actions* that they must perform to get the solution. They then *collect and classify data* considered relevant for finding the problem solution, *elaborating and interpreting these data* in terms of the problem situation. Having done so, an analysis of these data can be conducted.

Mathematical modelling skills come into play at this point if the data needed for solving the problem situation are mathematisable. If this condition is fulfilled, students can *simplify and structure* the problem situation to construct a real model; this real model, as well as the data obtained in previous steps of the cycle, can be then *mathematised* and thus transformed into a mathematical model to work with. By *working mathematically* with the mathematical model, students obtain mathematical results; these mathematical results can be abstractly considered and are therefore suitable for a mathematical analysis that will polish the analysis obtained merely by working with data.

Once analysed in light of mathematics, the mathematical result needs to be *interpreted* in terms of the context of the problem situation, obtaining a more accurate result than the one obtained by only interpreting data. However, if there are no such mathematizable data related to the problem situation, the work conducted with the available data shall provide a result analysis referring to the data, with no possible abstraction to be made, and the inquiry cycle shall go on.

Having mathematizable data or not, students need to *validate their results* once they have got them to make sure these results are the sought answer to the stated problem situation. Finally, students *communicate their results and answer the questions* that their presentation might raise.

According to Falcó-Solsona et al. (2024), students also could directly validate their hypotheses if the data they have allows them to do so and they could also skip the intermediate sub-processes if the validation shows a hypothesis to be true and fulfilling the demand of the problem situation. Moreover, students can go through the different sub-processes onwards and backward, revisiting the steps that they have already made or skipping some sub-processes.

METHODOLOGY

The emergence of evidence of the use of the different sub-processes of inquiry and mathematical modelling will be observed throughout the implementation of a learning situation designed for this purpose. This implementation will be carried out during the school year 2024-25 with 90 students in the first year of secondary education (12-13 years old) in a school in Badalona (Catalunya, Spain). The location of the school is important for the design of the learning situation since the problem stated is deeply related to it.

Thus, it is important to remark that the school in which the learning situation will be implemented is located beside the Badalona Museum. This museum, located in front of the schoolyard, on the sidewalk in front of Via Augusta Street, is known for containing the ruins of the ancient Roman city of *Baetulo*. Everyone in Badalona knows that beneath the main building of the museum, one can visit sections of the *cardo minor* and the *cardo maximus*, a small section of the *decumanus*, as well as the building of the baths and numerous insulae that once contained shops; the students of the school have previously visited the museum, since it is common for primary education schools to visit it, and have been previously involved in a learning situation that stated authentic and realistic research in collaboration with the museum (see Falcó-Solsona et al., 2024).

Therefore, the students of the school are aware that the ancient Baetulo extended beneath the Museum and partially beneath what is now the playground. Additionally, this playground is largely below the street level, since there is a severe slope in the streets Temple and Pare Claret, both parallel and surrounding the schoolyard, and the street Via Augusta, which separates the school from the museum, is at the pot of this slope.

Therefore, the schoolyard is necessarily below ground level, which becomes plain from Via Augusta Street, located at the top of the slope of Temple and Pare Claret streets and which is much higher than the schoolyard, about three or four metres. Hence, it is easy to deduce that the Roman remains beneath the museum are not at a great depth relative to this schoolyard.

Figure 2. Location of the schoolyard and the Museum.

Source: Google Maps (adapted by the authors).

Furthermore, during the 2022-2023 school year, the wall surrounding the schoolyard was renovated, and the works were perfectly visible from the schoolyard as well as from the street. This fact was taken in advantage by the authors to prepare the learning situation used in Falcó-Solsona et al. (2024), which consisted in telling the students that a broken pieces of ceramic had been discovered at the wall foundations during the renewal works; such a discovery was not real, but it was completely plausible and was considered to be real by the students.

This new learning situation will be in fact carried out with students who have participated in the implementation of the learning situation shown by Falcó-Solsona et al. (2024) and are therefore aware of the context.

For introducing this new learning situation, the students will be told that, after the success of their first collaboration with the museum, they have once more asked for their help: the museum archaeologists found a papyrus beneath the schoolyard wall foundations, a bit deeper than the archaeological remains with which the students worked in the problem-situation stated in Falcó-Solsona et al. (2024); it seems to be old and not well preserved, appearing to be very brittle. Thus, they will not bring it to the school.

However, this papyrus contains a text that is not Latin, as would be expected, and does not fit any language that they know. The papyrus contains, in capital letters, the following:

P. VHVYHF PNRFNE T. SNOVB, FNVYGRZ.

CBFG IVPGBENVFN ABFGENGF VA TNYYV, GRZCIF RFG HG YRVTBNAVBVF ABFGENGF CEB SBEGRVHAGVHR RGU SVQVYNGVNGR CERZVHRZF. VGNDHRG GVOV VZCREB HG IRGREANF YRTHAVF XIII VA HEOR ONRGHYB PBAFGHVNGHENFG.

ONRGHYB VA CEBIVAPVNP GNEENNABAFFV FGHGF RFG, VA BEVRAGR VFCANZVNR, CEBCR PVIVGNIVR ONEPVABARF. ERVTB VA IVARVFV QVIRF RFG, ERF DHRN QVIRGVNGVF RG CEBFCREGVNGVA ERTBVARN NGGYVYG.

PHENOVF HG IRGREANF GNEFNF VQBARNF NQ PBYRAQHZR RG QBZBF PBAHPEHRAQNRF NPCVNNG. GNEANF CEBCR SYHZRA ORFBF RFFR QBORAG, DHBQ NNDHZ RG PBARVBHAGNAPR HZ NYV

VFEBTVBAF CENORFG. SNC HG VAFHGEANZGNR NG NYVN FHOFVQVNF NQ PBYBAVHZ VAFGHZVRAGNZQN UNORNAG.
HG YRTNFGHF ZRNF, NHPEBHGNEVZRAG CYNZNA NQ UBP ZNQNGHZR RKRRHERAQHZ UNORF. AVUVYBZVAF, PHCVB HG QR CEBTENFFH PBYBAVNRF RG QR DHVHODHZPR QVSVGHEGNFVNF BEVHAGEHZ ZR PERGVBERZ SNVPNF. SVRQRF GHL RG RKCREVANGVNA VA UNP ER ZVUV ABGN FNGVA.
PHEN HG INYRNF.
FPEVCGHZ YHGRYVRN, VQVFHF QRPOZHOORF, NABB PBAFHYNHGF P. PYNHQVH NAQ Z. FREIVYVV.

The objective that will be proposed to the students is to discover what this papyrus is. Since some of them have learnt some notions of cryptography in an optional class and the students are going to work in collaborative groups, it is expected that some of them will be able to decode the message. This message has been coded by the researchers by using Caesar's cipher with a right shift of 13, meaning that each letter has been translated 13 positions in the alphabet to the right, i.e., any A has been transformed into an N, and B has been transformed into a P, and so on.

By decoding it, we can find the following message, written in Latin:

C. IULIUS CAESAR G. FABIO, SALUTEM. POST VICTORIAS NOSTRAS IN GALLIA, TEMPUS EST UT LEGIONARIOS NOSTROS PRO FORTITUDINE ET FIDELITATE PREMIEMUS. ITAQUE TIBI IMPERO UT VETERANI LEGIONIS XIII IN URBE BAETULO CONSTITUANTUR. BAETULO IN PROVINCIA TARRACONENSI SITUS EST, IN ORIENTE HISPANIAE, PROPE CIVITATEM BARCINONEM. REGIO IN VINEIS DIVES EST, RES QUAE DIVITIAS ET PROSPERITATEM REGIONE ATTULIT. CURABIS UT VETERANI TERRAS IDONEAS AD COLENDUM ET DOMOS CONSTRUENDAS ACCIPIANT. TERRAE PROPE FLUMEN BESOS ESSE DEBENT, QUOD AQUAM ET CONIUNCTIONEM CUM ALIIS REGIONIBUS PRAEBET. FAC UT INSTRUMENTA ET ALIA SUBSIDIA AD COLONIAM INSTITUENDAM HABEANT. UT LEGATUS MEUS, AUCTORITATEM PLENAM AD HOC MANDATUM EXEQUENDUM HABES. NIHILOMINUS, CUPIO UT DE PROGRESSU COLONIAE ET DE QUIBUSCUMQUE DIFFICULTATIBUS ORIUNTUR ME CERTIOREM FACIAS. FIDES TUA ET EXPERIENTIA IN HAC RE MIHI NOTA SUNT. CURA UT VALEAS. SCRIPTUM LUTETIAE, IDIBUS DECEMBRIBUS, ANNO CONSULATUS C. CLAUDII ET M. SERVILII.

Which may be translated as follows:

Julius Gaius Caesar to Gaius Fabius, greetings.

After our victories in Gaul, the time has come to reward our legionaries for their courage and loyalty. Therefore, I order you to establish a settlement of veterans from the Thirteenth Legion in the city of Baetulo.
Baetulo is in the province of Tarraconensis, on the eastern coast of Hispania, near the city of Barcino. It is an area rich in vineyards, a resource that has brought wealth and prosperity to the region.
You must ensure that the veterans receive suitable lands for cultivation and the construction of their homes. The lands should be near the river *Besos*, which provides water and connects with other areas. Also, make sure they have the necessary tools and resources to establish themselves properly.
As my legate, you have full authority to execute this order. However, I want you to inform me

> about the progress of the settlement and any problems that may arise. I trust in your capability and experience to carry out this task.
> Take care.
> Written in Lutetia, on the Ides of December, in the year of the consuls Gaius Claudius and Marcus Servilius.

This message is not real, but as happens with the learning situation designed for the research conducted by Falcó-Solsona et al. (2024), it might be real: the papyrus is supposed to have been found beneath the ceramic remains used for a previous learning situation, which the students know to be Roman; Julius Caesar fought in the Gallic wars with the Thirteenth Legion and Gaius Fabius was his legate in the province of Tarraconensis during the war, as Caesar himself explains in his book *Commentarii de Bello Gallico* (Cèsar, 1928); Baetulo and its area was indeed rich in vineyard (Comas i Solà, 1991; Ferreras, 2015); Caesar usually rewarded his war veterans by giving them land to establish in the provinces, according to the Roman historian Suentonius (Suetonio, 2008); the Roman consuls of the year 51 B. C., when the Gallic wars were near to the end, were Gaius Claudis and Marcus Servilius according to Titus Livius (Livi, 2015); moreover, Suetonius also explains how Caesar used the cipher that bears his name:

> If he had anything confidential to say, he wrote it in cipher, that is, by so changing the order of the letters of the alphabet, that not a word could be made out. If anyone wishes to decipher these, and get at their meaning, he must substitute the fourth letter of the alphabet, namely D, for A, and so with the others. (Suetonio, 2008)

The only aspect of the context that is not historically plausible is the fact that the codification used for the learning situation includes the letters J, U and W, which were not included into the alphabet until the Middle Ages; therefore, Caesar could not have used these letters but, even so, the authors have included them in our message. This has been done to avoid a problem-situation too difficult to be solved, since the students that will carry out the implementation do not know that the Latin alphabet has evolved since the Roman period.

The learning situation will be implemented in a group of 90 students in first year of secondary education (12-13 years old) who have previously carried out the learning situation used by Falcó-Solsona et al. (2024), and they thus know the context of the discovery. They will work in groups of three students to discover what the found papyrus says, among them, some students will have learnt some notions of cryptography such as Caesar's cipher and the importance of the statistical frequency with which each letter appears in a language and how this knowledge can be used for decoding messages. How these students approach the problem is something to take into account when observing the implementation, since their approach can be compared to the approaches made by those students with no previous notions of cryptography.

During the implementation of the learning situation, the first author will play a double role as researcher and as support teacher, staying along the different class sessions needed to properly implement the learning situation. He will also make a direct observation of the implementation and write down notes about this observation; he will photograph and video record the work performed by the students during the sessions, transcribing their interactions (discussions, reasonings, deductions) for further analysis; and he will collect the productions of the students, such as their work diaries (where the students will write down their discoveries and describe their attempts to solve the problem) and the final report of the different working groups (consisting in a summary of the research conducted by that group and their conclusions).

Once the first author has collected the data, we will perform a thematic analysis, following an adaptation of the thematic analysis methodology proposed by Braun & Clarke (2006) (see Table 1).

Table 1. Phases of thematic analysis.

Phase	Process
1	Familiarizing with your data.
2	Generating initial codes.
3	Searching for themes.
4	Reviewing themes.
5	Defining and naming themes.
6	Producing the report.

Source: Braun & Clarke (2006).

It must be noted that not all the phases of the thematic analysis in Table 1 will be carried out since a direct application of this method would not fit the purposes of the authors. Thus, Phase 3 will not be performed, since we will already know the themes that will appear: those are the different sub-processes of the inquiry and mathematical modelling cycle (see Figure 1); there is similarly no need to conduct Phase 5, since the themes that the authors want to observe along the implementation of the learning situation are known by them, and thus need no defining and naming phase.

To perform the analysis, firstly we will transcribe the video-recorded data, read the diary of sessions (with the notes taken by the first author), and review the students' productions (Phase 1 in Table 1). We will then assign the codes to the data collected from each one of the students working groups participating in the implementation of the learning situation; these initial codes are the following, corresponding to the different sub-processes of the inquiry and mathematical modelling cycle:

Table 2. Codes used for thematic analysis.

Code	Inquiry and mathematical modelling sub-process
[1]	Problem formulation.
[2]	Looking for possible answers.
[3]	Formulating hypotheses.
[4]	Planning.
[5]	Collecting, classifying, elaborating and interpreting data.
[5a]	Simplifying/structuring.
[5b]	Mathematizing.
[5c]	Working mathematically.
[5d]	Interpreting.

[6]	Validating results.
[7]	Communicating results and answering questions.

Source: Authors.

In this phase, the first author will propose a first codification for the collected data and this codification will be triangled with the other two researchers until we reach a consensus higher than 90%. After doing so, the authors will compare the frequency of the codes assigned to the data collected, observing how the data fit each theme and, thus, the integrative inquiry and mathematical modelling cycle in Figure 1. By doing so, the whole integrative cycle will be reviewed and checked, and the authors will finally produce the report describing how the data collected from the implementation fit the integrative inquiry and mathematical modelling cycle.

EXPECTED RESULTS

Once the learning situation has been implemented and the researchers have conducted the analysis described above, the main expected result is that the collected data fit the proposed integrative cycle for inquiry and mathematical modelling (see Figure 1). The integrative cycle has been proposed based on the many evidence collected before the implementation of this learning situation, and thus we expect it to adapt to the new data. This new data is expected to certify what previous research conducted by the authors has pointed out in relation to the synergies and connections between inquiry and mathematical modelling.

The authors also expect to gather enough data related to the students' performance and their needs to carry out each step of the cycle so that the skills and competencies developed and strengthened at each sub-process can be properly described. That is an objective of the research that has been not yet achieved with the first approach to the integrative cycle for inquiry and mathematical modelling since the focus of the research has been on the description of the integrative cycle until now, but it is the next objective which needs to be dealt with to describe the inquiry and mathematical modelling competence in detail and in a way that can be useful for mathematic teachers.

FINALS CONSIDERATIONS

Despite being ongoing research, the authors strongly believe in its relevance, since it may supply mathematic teachers with a power tool to propose contextualized and rich real authentic problem-situations; the learning situation presented in this paper is an example of this.

As the research moves forward, we will get a deeper understanding of the relations and synergies between inquiry and mathematical modelling, describing each one of the competencies developed by the integrative process and providing rubrics for teacher to evaluate the performance of students in relation to them. These tools will enhance mathematic teacher's practice by providing them with a guideline of which kind of activities promote the work with inquiry and mathematical modelling, relating mathematics learning to the students' context and to other knowledge fields, and increasing the student's commitment to the problem-situations that deal with.

This learning situation hereby presented is, thus, a first example conforming this guideline for mathematic teachers to design rich mathematical activities promoting both inquiry and mathematical modelling.

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