



## THE CHARACTERISTICS DIDACTIC GESTURES OF A STUDY AND RESEARCH PATH INVOLVING MATHEMATICS AND PHYSICS AT SECONDARY SCHOOL

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### Abstract:

This paper analyses the development of a Study and Research Path (SRP) involving mathematics and physics by means of the theoretical construct proposed by the Anthropological Theory of Didactics (ATD) called *dialectics*. The SRP was implemented in five secondary school math courses and 116 students participated in total. The data analysis was performed using qualitative techniques and constructing nominal variables and their modalities, which also allows the use of descriptive statistical techniques. In this work, absolute frequencies are analysed and some considerations are made - in the light of the theory - to interpret these results.

**Keywords:** study and research paths, dialectics, secondary school

### 1. Introduction

The Study and Research Paths (SRP) are didactic devices based on recovering the meaning and the reasons of the knowledge studied in the school, which consider that questions are essentials in the construction of knowledge (Chevallard, 2007, 2009). The Anthropological Theory of Didactics (ATD) defines *dialectics* as didactical gestures or actions which are essentials for the development of a SRP (Chevallard, 2013). The

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research related to how to teach through SRP is recent and there are (only) few works about the design, analysis and/or evaluation of SRP implemented at least once a time at some educational level (Parra & Otero, 2018). Researches analysing how the dialectics work in a SRP and if they appeared together, or if some of them occur more easily than others are scarce. The works of Parra & Otero (2017, 2018) and Salgado, Otero & Parra (2017) are pioneers on this topic. In such papers, didactic-mathematical indicators were generated for each dialectic based on the results obtained during the implementation of a SRP in secondary and university level.

In this paper, we study how dialectics work in secondary school, developing a SRP that involves mathematics and physics. The SRP was implemented five times in five different math courses at the argentine secondary school (Gazzola, 2018, Otero, Gazzola, Llanos & Arlego, 2016). An inductive categorization was made by means of qualitative data analysis techniques (Otero, Moreira & Greca, 2002) aroused (Lebart, Morineau, 1994). Thus, dialectics that function during the SRP are identified and the difficulties in developing such didactic actions in the classroom are evidenced by the low frequency of each one.

## 2. The SRP and the dialectics

The Study and Research Paths (SRP) involve the study and development of a strong question, called *generating* question that is indicated as *Q*. The answer to this kind of question is not trivial, nor it could be found directly by looking at books, surfing in the internet, etc., on the contrary, it is necessary to study different types of knowledge to elaborate a certain possible answer. In a SRP, the teacher is responsible for proposing *Q* and the entire classroom has to produce an answer. In order to do this, it is necessary to create an "environment" in which the necessary knowledge and the appropriate instruments are available, called didactic medium *M*. Once *Q* has been proposed, other relatively simple questions arise, called *derivating questions*. The answers to those questions that can be found in the institution, for example a book, the notes of previous years, etc are called 'already made answers' because they are related to knowledge that has been acquired before, perhaps in a different context from the one posed by *Q*. For this reason, the "already made answers" must now be questioned, readapted, or restudied in relation to *Q*. This process requires gestures or instructional actions that are infrequent\_(uncommon) in the traditional teaching paradigm and such process is referred to as dialectics in the ATD framework.

### 2.1. Dialectics of a REI

The term dialectic refers to two poles of opposing action within the studying process which are not dual, on the other hand: one action calls the other and vice versa. So far, nine dialectics are defined (Chevallard, 2013):

- . D1- *Dialectic of the study and the research*, also called of *the questions and the answers*: it refers to asking questions and elaborating answers continuously, that is, to study and research the knowledge that might be appropriate to answer *Q*. The

research extends to a broad context while the study focuses on specific knowledge.

- . D2- *Dialectic of media-milieu*: the information systems (mass media) will be introduced into the milieu M after being tested, while the answers to the asked questions are developed. In a SRP the teacher is not a privileged information system; any student can incorporate into M any knowledge found in any media.
- . D3- *Dialectic of the individual and the collective*: the magnitude of question Q requires distributing individual responsibilities and assigning tasks which will then be put into the consideration of the group during the process leading to a possible collective answer. These actions -characteristics of any research team- are "alien" in the traditional teaching paradigm.
- . D4- *Dialectic of the skydiver and the truffles*: this name is metaphorical and was used by the French historian Emmanuel Le Roy Ladurie in reference to the historians. Ladurie classified them as a skydiver or truffles seekers. The first ones perform an exploration in large areas of territory that are seen "from above" and the second ones search for buried treasures: the "truffles". On the one hand you take distance from the problem and explore the terrain from the outside, but on the other hand, you should inspect it very closely until you find the solution. In a studying process, both actions are necessary: inspect large areas of knowledge until distinguishing the "gold nugget", which will serve to answer to a problem.
- . D5- *Dialectic of subject and out-of-subject*: the searching for answers can – sometimes- require "get out" of the subject specifically related to the question, or even go beyond the discipline to study other knowledge and later return to the subject that motivated the withdrawal.
- . D6- *Dialectic of black boxes and clear boxes*: it is necessary to determine which are the relevant knowledge are and how much to study about them to answer a Q. That is, to determine which knowledge deserves to be deepened, clarified, analysed and/or to remain at an appropriate "grey level".
- . D7- *Dialectic of reading and writing*: it is about analysing, developing, interpreting and rewriting the useful part of the knowledge found in relation to the problem.
- . D8- *Dialectics of the analysis-synthesis, praxeological and didactic*: any analysis of the knowledge involved in a problem generates questions related to its communication (didactics). Where does this knowledge come from? How is it used in this institution? All of which leads to questions about the knowing itself.
- . D9- *Dialectic of the dissemination and the reception*: it refers to the communication and justification of the answer elaborated by the study community. The communication explains the answers obtained and calls for questioning and acceptance or not of the rest of the community. It is an epistemic dissemination that can be oral or written in which there is a justification for each response elaborated, each knowledge used or each path travelled in the construction of an answer.

### 3. Material and Methods

The SRP was implemented five times in five math courses at three different secondary schools (in characteristics and context) in Tandil city, Argentina. In total, N = 116 students between 16 and 18 years old participated. The lessons were carried out by the same researcher-teacher and the research team. Participant and non-participant observation was performed and all the students' written protocols of all classes were compiled. The teacher wrote notes down at the end of each meeting.

The SRP is developed from the question *Q: Why did the Movediza Stone (MS) fall down in Tandil?* and it seeks to develop a valid response from the scientific point of view. Thus, the question originates a path that involves the combined study of Mathematical and Physical knowledge (Gazzola, 2018; Gazzola, Otero & Llanos, 2018; Otero, Llanos & Arlego, 2017; Otero et al., 2016). The Movediza Stone (MS) was a balancing rock located in the city of Tandil, Argentina. It was on the edge of a hill and its weight was about 248 tons. In 1912, the stone fell for no apparent reason and for over a hundred years this event generated all kinds of conjectures to explain it. In this study, we try to explain the movement of the MS and the possible cause of its fall from the Mechanical Resonance phenomenon. Therefore, it is necessary to study knowledge related to oscillatory movement (oscillators, types of oscillations: free, dampened and driven, oscillator energy, etc.) and useful mathematics to describe these movements such as harmonic functions.

The data analysis was performed using qualitative techniques (Otero, Moreira & Greca, 2002) and an inductive categorization is carried out, creating nominal variables and their modalities arise (Lebart, Morineau, 1994). The variables correspond to each dialectic and the modalities refer to the different ways in which the dialectic is identified in the written protocols of the students. The obtained results are presented in the next section.

### 4. Description of variables, modalities and results

The data obtained allow us to identify seven dialectics. Table 1 summarizes the variables (dialectics) and the modalities of each of them. The column to the left indicates the absolute frequencies of each modality.

**Table 1:** variables, modalities and absolute frequencies

Variables	Modalities		Frec.
D1 Questions and Answers	D1.1	No searches	11
	D1.2	Searching and studying of answers	85
	D1.3	Formulation of new questions	20
D2 Media-Milieu	D2.1	No D2	66
	D2.2	Questioning of results obtained or answers proposed by the teacher	38
	D2.3	Studying and questioning of other answers, different from those of the teacher	12

<b>D3</b> Individual and Collective	<b>D3.1</b>	No D3	83
	<b>D3.2</b>	Individual and group answers are differentiated	33
<b>D5</b> Subject and out-of-subject	<b>D5.1</b>	No D5	19
	<b>D5.2</b>	Leaving and returning to the different knowledge "without motives"	84
	<b>D5.3</b>	Leaving and returning to the different knowledge "motivated" for the initial problem	13
<b>D6</b> Black boxes and clear boxes	<b>D6.1</b>	No D6	74
	<b>D6.2</b>	Identification of relevant and functional knowledge to Q	15
	<b>D6.3</b>	Determining what and how much to study of a knowledge	27
<b>D7</b> Lecture and Written	<b>D7.1</b>	No D7	49
	<b>D7.2</b>	Compilation of partial answers	54
	<b>D7.3</b>	Reading, Interpreting and rewriting	13
<b>D9</b> Dissemination and Reception	<b>D9.1</b>	No dissemination	68
	<b>D9.2</b>	Narrative dissemination	33
	<b>D9.3</b>	Epistemic dissemination	15

### **D1 – Dialectic of the questions and the answers**

We identify this dialectic in students who ask questions and elaborate answers to all the questions studied. It presents three modalities:

**D1.1 - No searches:** students do not search for answers in the information systems, nor the formulation of new questions.

**D1.2 - Searching and studying of answers:** students search the information systems (newspaper clippings, books, teacher texts, internet, etc.) and they study the knowledge that are useful to elaborate the answers to the different questions. For instance, we identify study actions around: characteristics of the MS and conjectures of its fall down, oscillations (harmonic, damped and driven), trigonometric angles and ratios, harmonic functions, mechanical energy and mechanical resonance.

**D1.3 - Formulation of new questions:** In addition to seeking and studying information, students ask new questions and seek answers. We identify mainly: (a) Questions and studies related to mathematical and/or physical knowledge, (b) questions and studies related to the linking of knowledge with the Movediza Stone, (c) questions and studies related to the Movediza Stone.

### **D2 - Dialectic of media-milieu**

We identify this dialectic in students who question any results obtained or proposed by some information system. It presents three modalities:

**D2.1 - No D2:** Students do not test the elements of the M. They do not question about the validity of the answers found or those proposed by the teacher. They simply accept them as valid and use them.

**D2.2** - *Questioning of results obtained or answers proposed by the teacher*: students question the answers obtained or those proposed by the teacher to determine its relevance and analyse its validity. This also generates the need for new information. For instance:

- Students ask questions in terms of “why?” or “how?” i.e.: Why is not the Movediza Stone a free oscillator? Why is the amplitude function analysed? How do we prove that the Stone fell fall down by mechanical resonance phenomenon? etc.
- Students who use different resources and tools to justify and validate an answer.

**D2.3** - *Studying and questioning of other answers, different from those of the teacher*: In addition to the above-mentioned, students incorporate an answer or knowledge into M, which they are obtained from some mass media (other than the teacher) to be analysed and studied.

### **D3 - Dialectic of the individual and the collective**

We identify this dialectic when the students differentiate the answers that they elaborate individually from those that they elaborate in groups. It has two modalities:

**D3.1** - *No D3*: students cannot distinguish between the answers obtained from the individual study from those obtained from the collective study.

**D3.2** - *Individual and group answers are differentiated*: students can differentiate individual answers from group answers.

### **D5 - Dialectic of subject and out-of-subject**

The answer to Q demands to “leave” the initial problem and “enter” into the study of mathematical and/or physical knowledge, and then returning to it. The modalities are:

**D5.1** - *No D5*: students are able to leave the subject' but it cannot be identified the subsequent `returning of the subject'. They study mathematics and physics but they do not use them for the construction of the answers. For instance:

- The students go to physics to study oscillations.
- The students go to math to study trigonometric functions.
- In the same discipline, the students go to study other knowledge. For instance, in mathematics students go to study angles in the plane and trigonometric ratios, or in physics they go to study the concept of mechanical energy.

**D5.2** - *Leaving and returning to the different knowledge “without motives”*: students perform ‘leaving’ and ‘entering’ to mathematics and physics but without motives, i.e. without considering question Q. We identify the following:

- The students who use results obtained in one discipline to advance in the study of the other.
- The students used the knowledge, built techniques or results obtained in a discipline to advance in the study of that discipline itself.

**D5.3** - *Leaving and returning to the different knowledge “motivated” by the initial problem*: students reinterpret knowledge based on the real system, that is, there are “leaving and entering” motivated by question Q. They continually consider mathematical and physical knowledge to analyse the phenomenon of MS. For instance:

- They study the spring model and look for analogies between the movement of this system and the MS.
- They study the sine and cosine functions and relate to the movement of a spring and to the MS.
- They re-interpret the position graphs of the damped and driven oscillations to exemplify the movement of the MS as a function of time.

### **D6 - Dialectic of black boxes and clear boxes**

We identify this dialectic in students who determine which knowledge is relevant and deserves to be studied, clarified, analysed, etc., to elaborate an answer to Q or its derivating questions. In addition, in students who use only what is strictly necessary, that is, they study knowledge in an appropriate grey level. It presents three modalities:

**D6.1 - No D6:** students do not identify which knowledge is relevant to elaborate the answer to Q or its derivating questions. They only study the knowledge proposed by the teacher.

**D6.2 - Identification of relevant and functional knowledge to Q:** students decide which knowledge are necessary to answer Q, or -of everything studied- they only take into consideration what is useful to them. For instance, they set that it is necessary to study oscillations to understand the movement and the fall of the MS, or the harmonic functions are the relevant knowledge to describe mathematically the simple harmonic movement.

**D6.3 - Determining what and how much to study of a knowledge:** In addition to the above-mentioned, students determine the scope of the study, they decide the 'grey level'. Also, when there is partial or 'incomplete' study of certain knowledge only the necessary is studied. For instance:

- The sine and cosine trigonometric functions are studied but the tangent is set aside.
- Kinetic and potential energy is studied considering the equation as a function of time.
- The equilibrium conditions are studied considering a supported triangle that turns on one of its vertices.

### **D7 - Dialectic of the reading and the writing**

We identify this dialectic if the students analyse, interpret and rewrite the answers found without making a textual copy, but by developing the ideas that they want to construct. They generate summaries, synthesis notes, notes, etc. The modalities are:

**D7.1 - No D7:** We do not find indicators about student's readings in different media and later pieces of writing. They do not collect the relevant information available in documents related to MS, math and physics books, internet, etc.

**D7.2 - Compilation of partial answers:** the students do the following actions: they underline or highlight what they consider important from the searches, they rewrite in their folders the data that they consider useful for the elaboration of the answers. Also they write summaries or synthesis of the texts, they take notes from the board, from

another group of students or from the teacher and they rewrite in their folders the information obtained from the use of some software such as GeoGebra, Mathematic or spreadsheets.

**D7.3 - Reading, interpreting and rewriting:** the students interpret the information they collected from their readings and rewrite it, without a textual copy, and they also consider the initial problem. For instance, they search for information about the characteristics of the MS and create graphs and scheme, they search for information about the mechanical resonance phenomenon and they relate it with the MS, and/or they prepare a synthesis of their own work which involves reading, reinterpreting and rewriting the knowledge studied.

### **D9 - Dialectic of the dissemination and the reception**

We identify this dialectic from the written synthesis instances. It has three modalities:

**D9.1 - No Dissemination:** the students do not prepare written synthesis to communicate the answers.

**D9.2 - Narrative dissemination:** the students communicate their answers in the form of a 'story' without referring to the knowledge studied, or why and how they used them to construct the answers.

**D9.3 - Epistemic dissemination:** the students communicate their answers based on knowledge. They use the mathematics and physics to validate, disseminate and defend their answers. These syntheses may include formulas, graphs, drawings and schemes that represent the relationships between different knowledge.

## **5. Discussion**

The SRP allows to identify seven of the nine dialectics which do not work in the same way since some occur more frequently than others. Among the most frequent dialectics, the first is the *dialectic of the questions and the answers* (D2), identified in 105 students. Most of them do searches and studies (D1.2). This result could be related to the characteristics of the SRP which requires researching in mathematics and physics and studying knowledge of both disciplines to answer the questions asked during the study. However, only a few students ask and propose new questions (D1.3), which shows that this is a difficult gesture to carry out.

Then, the *dialectic of the subject and out-of-subject* (D5) is identified in 97 students. The study of a strong question "forces" not to limit itself to a single discipline and in this case, mathematical and physical knowledge must be considered together. Even so, the leaving and returning to the different knowledge "without motives" (D5.2) is more frequent which means that the "leave and entry" are mainly between the mathematics and the physics and the initial problem is left aside. Very few students analyse such knowledge in relation to PM (D5.3), making it difficult to deconstruct and reconstruct the knowledge adapted to the problem studied.

Third, the *dialectic of reading and writing* (D7) is identified in 67 students. This result could be related to the various searches that the students carry out and also to the



fact that the teacher collects the written protocols daily which required students to document their work, analyse the information and decide what to rewrite and how. The results reveal that students mostly collect partial answers (D7.2) and that only few of them read, interpret and rewrite (D7.3) the answers found. On the other hand, we observe that these pieces of writing are mostly narratives and this is not what it is expected (in theory) in a math class. However, reading and writing practices are alien to traditional teaching in any discipline, therefore, making this gesture (even in an incipient way) is a highlight.

Among the less frequent dialectics is the *dialectic of media-milieu* (D2), only identified in 50 students. Of these, 38 students question the relevance and validity of the answers (D2.2) while the rest incorporate other answers different from those of the teacher (D2.3). This could be because the students are accustomed to the teacher deciding what and how to study in the classes, while they "accept" the elements that enter the M without questioning them or putting them to the test. So, here the teacher had to intervene more than desirable to advance in the study, building the didactic medium M much more than expected in a SRP. In any case, it is auspicious to notice that some students were able to partially "break" unilateralism in the construction of M and this is auspicious.

The *dialectic of the dissemination and the reception* (D9) is identified in 48 students and more than half of them do so in a narrative way (D9.2) because knowledge is only described not used to justify the constructed answers. Only a few students do an epistemic dissemination (D9.3) based on such knowledge. However, this dialectic involves communicating knowledge, an action that implies an important modification in the school culture because it is very difficult to achieve and requires a long process. Therefore, we highlight the habit of communicating the answers acquired in the SRP even though it has not been in the most appropriate way for the ATD.

The *dialectic of black boxes and clear boxes* (D6) is identified in 42 students. The low frequency of this dialectic could also be due to dominant monumentalism because the teacher is the one who usually decides which knowledge is relevant and how much to study about it. Among the students who carry out the dialectic, a minority only remains at the level of determining which knowledge is relevant and useful to elaborate the answers (D6.2) while the rest, in addition, decides how much to study them (D6.3). The *dialectic of the individual and the collective* (D3) is the least frequent, only is identified in 33 students (D3.1). Traditionally, students are accustomed to work individually or in small groups carrying out the same activities. Current education does not conceive the elaboration of a collective answer agreed upon in and by the class, and the distribution of individual tasks and responsibilities that contribute to its reconstruction. Thus, we consider auspicious that this gesture is possible to modify it partially.

Finally, the *dialectics of the skydiver and the truffles* (D4) and the *dialectics of the analysis-synthesis, praxeological and didactic* (D8) cannot be identified in the students' written productions.

## 6. Conclusion

This paper has revealed the difficulties and certain conditions for the operation of the dialectics of a SRP in secondary school. The changes demanded by teaching through SRP are substantial and require a long and continuous process. The implementation of SRP in classrooms governed by the traditional or monumental paradigm causes adaptive changes in the device's own characteristics. In spite of the difficulties, the students carry out, although in an incipient way, some gestures of the SRP and of the teaching by inquiry.

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