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A Research Methodology on the Knowledge Construction Process in Linear Electrical Circuits Elaborated Based on the Piagetian Clinical Method

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This paper presents the research methods developed to investigate the knowledge construction process of students and how they understand the concept of internal resistance as represented by the everyday situation in which an electric shower causes the light of a light bulb to dim when turned on. The theoretical framework for this study is based on the Piagetian genetic epistemology and the linear circuit theory. The methodology was developed based on a qualitative approach, using the multiple-case study strategy. The semi-structured interviews were inspired by and adapted from the Piagetian clinical method in order to identify and analyze the students' explanations and associations regarding the theoretical model that explains the phenomenon. The goal is to make this paper available for teachers as a reference material and an encouragement to reflect about their own teaching practices so they can develop pedagogical actions to assist the students' learning process in vocational courses on Electricity, Electronics and similar areas in both secondary and higher education. The paper provides detailed information about the development and improvement of the data collection tool, includes answers from the subjects interviewed, reflects on the method's concerns and benefits to allow for the grasp of knowledge of other points of view, and, finally, discusses the possibilities of developing activities that are more interactive and forward-looking for the students.

Keywords: Genetic Epistemology; Technology Education; Clinical Method; Electrical Circuits.

Introduction

The expression "how do you not know this?", which is commonly used by teachers in the classroom to express their concerns about learning issues, is taken up in this paper to point out, with the same meaning, the authors' concern and interest on the difficulties of students in learning, which refers to the need of knowing the learning processes.

Precisely for this reason, the question of understanding was the central theme of the research that served as reference for this paper. The authors use the term understanding according to Piaget (1978, p. 179): "to understand is to isolate reason from things, whereas doing is only using them successfully".

The authors believe that the epistemological conception that leads to the planning and execution of actions related to teaching can influence the construction of knowledge and, therefore, understanding, favorably or negatively. Piaget (1975, p. 88) explains that externally reinforced learning, which occurs when the student is informed or allowed to observe the results of a reasoning, that he or she should have done, produces "little change in logical thinking or else an extraordinary momentary change without real understanding". The cognitive development expressed in logical thinking, according to the author, depends on the actions of the subject on the object, on its coordination of operations and reflective abstractions and on the awareness that allows it to explain the reasons for its successes and failures.

In this sense, the research, conducted on the learning of Linear Electrical Circuits Theory, sought to verify how the students of the third year of an Electronic Vocational Course integrated to High School construct and how they could (re)construct the concept that the voltage in the electric power grid is not constant, but also depends on the current demanded from the voltage source, considering the studies conducted by them during the first two years of the course.

From the point of view of Genetic Epistemology, which was the main theoretical reference of the paper, the authors intended to follow the reasoning of the students during the process of conceptual construction of the explanation of this phenomenon, aiming to identify how the subject constructed the notion of the existence of a relation between the electric quantities voltage and current in a battery. Their intention was to map the development of the conceptual understanding of the phenomenon of the internal resistance of the source, at the same time verifying the relations that the subjects established between the variations of brightness in a light bulb and the changes in the values of currents and voltages in the circuit.

To contextualize the physical phenomenon, the occurrence of the reduction of the brightness of a light bulb, a daily situation such as a shower that is connected in the same electric power grid as the light bulb was chosen as an example. The theoretical models that the subjects needed to elaborate a conceptual explanation about this phenomenon had already been studied during the 2nd year of their Vocational Course, as they are a reference in most of the disciplines of the curricular matrix of this course.

The research sought to identify and analyze the explanations and the relations

that the students established with the theoretical model that describes the phenomenon. Thus, in general, the authors wanted to verify how the cognitive processes of the subject were exhibit in the learning of linear electrical circuits.

The methodological design of the research, defined from the theoretical principles of Genetic Epistemology, was essential for the achievement of the proposed objectives. For this reason, and due to the importance of the contribution of this methodology to teacher training, this paper is dedicated to this theme.

Thus, the present paper proposes to describe the methodological process elaborated for that research, based on Genetic Epistemology and inspired by the Piagetian Clinical Method, with the objective of presenting to readers who are teachers the possibilities of using this material as a reference, reflection and stimulus for the investigation of their own practices, as well as for the elaboration of pedagogical actions that favor the development of learning in the context of technological courses of electricity, electronics or the like, both in High School and Higher Education.

In this sense, the authors consider it relevant to present some references to the results obtained with the use of such methodology, in order to show the potential of the Clinical Method as it was used, although the presentation of these results is not the objective of this paper.

Research Design

The research on the cognitive processes evidenced in the learning of linear electrical circuits was developed through a qualitative approach, in which the strategy was the multiple case studies (Yin, 2001) and semi-structured interviews (Delval, 2002), based on and adapted from the Piagetian Clinical Method.

The case study strategy was chosen as it would be adequate because it uses the logic of replication to do the data analysis, since, according to Yin (2001, p. 54), "empirical results can be considered even stronger if two or more cases support the same theory". Thus, the case study strategy does not use the logic of sampling and statistical analysis.

The choice of using the Clinical Method to perform the interviews with the participants, in turn, considered Delval's (2002, p. 70) explanation, when he emphasizes the universal, not the peculiar, in each subject and, then considers it as "an epistemic subject, a subject who produces knowledge". For Piaget, Battro (1978, p. 227) comments that while the psychological subject is centered on the conscious self, the epistemic subject is constituted from what is common to all subjects that are part of the same level of development, in that context. The author states that, for Piaget, those "are the most general coordinations of the whole system of actions that thus translate what is common to all subjects and therefore refers to the universal subject or epistemic subject rather than individual".

In this sense, the researcher followed the proposal of Delval, who argues that the Clinical Method is useful to examine the "general characteristics of the way of explaining or solving a problem" by the epistemic subject, as well as to "find the ways in which the

subject arrives at its explanations". For Delval (2002, p. 71), "the subject has a conception of the world, generally implicit, of which it itself is not aware, but it is what it uses to give its explanation" and, in this sense, the Clinical Method can help "to make this explanation conscious, to know how it is organized".

According to Piaget (1926, p. 10) in the Clinical Method the interviewer "when directing, lets himself be directed", placing each response within the subject's mental context, observing, posing problems, varying the conditions at play, testing and controlling each of the hypotheses according to the subject's reactions.

For Delval, the interest of the research should not be centered on the individual, but on how he can solve the problem, which is often not explicit, as well as on the reasons the subject presents to explain how he understands such a situation. In this sense, the researcher "should avoid directly transferring his or her own way of thinking to the subjects he or she is studying. In short, he or she has to find coherence in the conducts and explanations given by the subjects" (Delval, 2002, p. 71). According to this author, this represents one of the difficulties in using the Clinical Method.

According to the author, one of the ways to adequately address this issue is to produce the phenomenon in front of the subject, to ask him to explain it, and to provoke other situations that may call into question these explanations, or to present counter-arguments, which are explanations with different points of view about the problem (some are correct and others distorted in relation to the scientific explanation), presented as if they had been said by another interviewee. Therefore, the researcher needs to have a knowledge compatible with the object of study and with the application of the Clinical Method, since it will have to establish new hypotheses or reformulate the previous ones about the reasons of the explanation given by the subject, as well as to produce changes in the questions or in the experimental situation, to try to extract information about the way the subject constructs his reasoning.

Delval (2002) seeks to highlight the importance of the design of the experiment and the interview with the questions and counter-arguments, which should be presented by the interviewer avoiding to suggest, direct or induce the respondent's answers. This is another difficulty in using the Clinical Method, as sometimes it is necessary to retrieve some previous response from the subject or to reconsider a previous decision.

These issues require a lot of attention and flexibility from the interviewer, as well as knowledge about the subject and the ability to formulate the right questions in a timely manner and in the most appropriate way possible, in order to test the subject's internal coherence between what he does and what says, aiming at solving the problem presented to him. There is space for flexibility and freedom regarding interventions at any time during the interview. According to the author, there are different possibilities of intervention, which he defines as elements that serve as support to stimulate the subjects' responses.

In the research that served as the basis for this paper, different types of intervention were used to stimulate the subjects' responses, which characterize the

research instrument, such as: the stories told to the subjects, which involved presenting them the daily situation of the reduction of brightness of the bathroom light bulb when the shower was switched on, and whether they could predict what would happen and how they would explain the phenomenon; a task in which the subjects elaborated an experiment to simulate the phenomenon under study while they were questioned by the interviewer; the questions addressed to the subjects during the experiment and the counter-arguments, which presented explanations with other points of view. The circuit drawings and calculations, both made by the subjects themselves, were also used as support elements, which served as a reference both for the elaboration of new questions and counter-arguments and for the analysis of interview results.

Delval (2002, p. 98) warns that questions should not be distanced from the focus of the problem and suggests that they be guided by the hypotheses and objectives of the research. The author also recommends that a "core set of questions that relate to the fundamental aspects of our research should be elaborated, and therefore, should be made to all subjects", so that a comparison can be made between the responses.

On the other hand, this necessary and inherent flexibility of the Clinical Method entails a variety of responses that complicates the data analysis procedure, since, according to Delval (2002, p. 162), "there are no general procedures for doing it , and each new research means a different form of analysis that we will have to invent". Thus, the author suggests establishing categories of analysis to identify what is recognized as similar and what is perceived as different based on the aims and hypotheses initially defined.

Delval (2002, p.168) exemplifies that one way of proceeding to this analysis is to contrast the subjects' explanations with the concepts established by the science in question. This confrontation is necessary to be able to identify a conceptual hierarchy in the answers since the construction of knowledge presupposes the initial use of notions, preconceptions and partial generalizations that can be overcome by the reflection on their own actions and the results of their experiences. When making an evolutionary study, the researcher should presuppose that the main references by which the progress of the subjects should be verified should be the conceptions generally accepted by this science, which the author denominates as disciplinary conceptions.

Thus, this procedure of analysis can result in the establishment of levels, which, according to Delval (2002, p. 232), present a hierarchy and a sequence, established not only by "better explanatory principles, of another type or of a different level", but also by the possibility of relating the explanations between themselves.

Research participants

The research was conducted with third year students of a Vocational Course of Electronics integrated to the High School, that were not students of the researchers, in a school of the Metropolitan Region of Porto Alegre – RS. To do so, at the beginning of the school year in 2013, an Authorization Form for Conducting the Research was signed

with the Direction of the School.

The participants were invited through a presentation of the project in the classroom for the students of this respective period of school. During this presentation, all students were informed that their participation should be spontaneous and that they were free to withdraw from the research at any moment, without any encumbrance and they would be assured the right to have their identity safeguarded.

Thus, students aged between 16–19 years were interviewed. Those who agreed to participate signed the Consent Form, with the written authorization of their parents (for minors).

Initially, a pilot study was conducted to test different versions of the data collection instrument and the interview script. The data collection with the final version was performed in May 2014, with ten subjects who then developed and operated an experiment that simulated the problem of reducing the brightness of the light bulb when the shower was switched on. The subjects were observed by the researcher, who argued and intervened, based on the Piagetian Clinical Method, during the execution of the activity.

The development of the instrument

The aim of the data collection instrument used in the interviews was to direct the research so that it was possible to discover how the cognitive processes are manifested during the construction of students' knowledge about linear electrical circuits, regarding specifically the phenomenon of the reduction of the brightness of a light bulb at the moment that an electric shower of the same electric power grid is turned on.

In order to obtain richer, more accurate, reliable and results aligned with the research objectives, it was necessary to submit the initially designed data collection instrument to several tests and reviews, in which changes, inclusions and withdrawals of stages were made, aiming at making it more interactive and prospective.

The first version of the instrument was quite simple, since it consisted only of measuring the voltage of a set of batteries, alternately connecting two different types of light bulbs to verify, through questioning, how the subject explained the voltage variation of the source and how it related this voltage variation to the current required by the type of light bulb attached to that source. At this initial moment, the authors had not yet thought of including the shower situation as a way of exemplifying this phenomenon. Thus, this first version started with the voltage measurement of a battery pack or a battery, attaching to it a 6V and 40mA light bulb and then turning it off and turning on a 6V and 250mA light bulb. What was expected was that the subject would realize that, when the high current light bulb was switched on, the battery voltage would decrease. Then he would be asked to explain the reasons for this phenomenon to see how he understood it. It was observed that in some situations, the subject could not provide an explanation and thus could not proceed with the interview, since the interviewer could not change the conditions of the experiment or create new situations that could favor a

change in the point of view of the subject and, consequently, produce new reflections.

With the intention of solving this dilemma, a second version was developed, introducing in a second stage of the interview the concept of "drawing" as a projective element (Delval, 2002; Gouveia, 2007). In this second stage, the subject was then asked to produce an electrical diagram of the circuit he had assembled. With the use of this technique, the authors intended to present other elements to the subject that would help him elaborate his explanations. Thus, more information about the conceptions, the understanding and the use of the conceptual schemas of the subject would be obtained, which, according to Piaget (1990, p. 310), are "general and abstract schemas at once one single pace, that is, which take the form of classes or relationships". As an example of a conceptual schema, in the context of technical and technological education, one can highlight the conceptual schema of the Ohm's Law (V= I. R), which relates the voltage (V) to the current (I) in a given electrical resistance (R), referring, in this case, according to the Theory of Linear Electrical Circuits, to a specific class of conductors subjected to a determined range of voltage in which the electric resistance is constant.

Thus, when using this technique, it was found that, even when making the circuits drawings, some subjects still could not find the explanation for the phenomenon of the voltage reduction in the battery, presenting standardized and elusive answers, for example: "it is because the practice is different from the theory", without, however, being able to explain the reasons behind his argument.

It was then considered that it would be important to place the subject before an empirical situation that would produce an intellectual conflict and to awaken his attention to the need to recognize that there should be a scientific explanation for the problem of reducing battery voltage. To do so, in the third version of the interview, the authors decided that the voltage of the source would not vary with the exchange of the light bulbs, when replacing the batteries by a source of regulated voltage, which is an equipment designed to maintain the tension constant independently of what is connected to it, simulating an ideal voltage source. Thus, the intention was to enable the subject to verify that the voltage variation could be related to the characteristics of the source. Thus, this observation of voltage variation and invariance was called "voltage observable", in the same way that Battro (1978, p. 173) states that "the observable is far from constructing a single sensitive data, which is passively recorded: it is the result, observed without presupposing an experimental action on the real". The authors believed, therefore, they would be able to investigate how the subject articulated his conceptual schemas on the Linear Electrical Circuits to explain this intellectual conflict between his voltage observables: voltage variation in the battery, in the first stage, and voltage invariance in the regulated source, in the third stage.

However, when the interviews were conducted, it was verified that the difficulty remained in finding explanations for the phenomenon, and that the diversity of situations the subjects encountered, in itself, did not influence much the development of new points of view, the consideration of possibilities and the construction of hypotheses.

We then considered the hypotheses that (i) the conceptual schemas of linear electrical circuits were not sufficiently consolidated to the point of hindering their use in new problems, or (ii) they were the mechanisms of relations that did not allow for the possibility of using the conceptual schemas built to solve new situations. In any case, the authors recognized the need to present situations in which the subjects could revisit their conceptual schemas seeking to establish relationships in which it was also possible for the interviewer to identify the existence or not of these gaps.

In this context, a fourth stage was created in the interview that consisted in requesting the subject to connect the two light bulbs in series and in parallel. Thus, it was intended to verify the consolidation of the conceptual schemas of the TCEL while researching how the subject established relations between these conceptual schemas and the notion of internal resistance in the battery, which corresponds to the resistance connected in series with the battery. However, this activity was not very productive for the establishment of these relations and for developing new possibilities, and also it made the experiment longer and more complex, diverting the focus from the interview to solving problems on series-parallel circuits.

In order to allow the identification of the subjects' ways of thinking, as well as to verify the conceptual development, fifth version was developed in which the interview was stratified into three levels, with increasing degrees of difficulty: i) an experimental level, in which the subject would set up the circuits, take measurements, and make hypotheses; ii) a representational level, in which the subject would elaborate the electrical circuit diagram and explain its operation; iii) a conceptual level in which the subject should use the concepts of Linear Electrical Circuits Theory (TCEL) to deduce relations and to develop generalizable models. However, during the course of the interviews, this stratification was still much more related to the conceptual knowledge than to the process of its construction, as opposed to what the authors wanted to research. Therefore, this stratification was removed, returning to the previous interview model. In this version, it was also necessary to add a fifth stage, which consisted of asking the subjects if it would be possible to determine the values of the light bulbs resistances and, if so, how this could be done. The authors considered that this stage could favor the subject, from the observable "resistance of the light bulbs", to establish relations between the experiment with the use of light bulbs and the theoretical circuit with the use of resistors.

An interesting fact in this fifth version was that, despite the failure of this stratification, this way of organizing the results already conceived a hypothesis, even if the authors were still unaware, about the possibility of the existence of what Garcia and Piaget (1987, p. 197) similarly called as "the psychogenesis of physical knowledge", that is, a psychogenesis of the construction of that knowledge.

According to Garcia and Piaget (1987, p. 73), psychogenesis presupposes cognitive constructions that are not linearly built, but proceed from reconstructions and rearrangements of contents from previous lower levels through the integration of subsequent knowledge, level by level, leading to "new constructions, by extension of the

contents and enrichment of the structures" of thought.

As an example, Garcia and Piaget (1987, p. 193) present the mechanism of psychogenesis in the evolution of theories, which is described from the assumption that a certain T^i theory originates from certain O^i observables obtained from the experience level, in given domain D^i, through a process of empirical abstraction. When establishing this theory T^i establishes, also by abstraction, a distinction of this set of observables in relation to others of the same domain. This promotes an expansion of its field of action due to the establishment of new relations. These new relations, in turn, may facilitate the identification of new O^j observables in another Domain D^j, thus enabling the transition from this lower level theory T^i to a theory of a next higher and extended level, T^j, and so on.

Another attempt to present to the subjects situations that could help them in the establishment of relations and hypotheses was made in the sixth version of the interview, when a sixth stage was added to the data collection instrument, which consisted of the sealed box experiment. This experiment consisted of an airtight container containing a hidden electrical component that belonged to the knowledge domain of these subjects. Thus, identification of this component would only be possible by first measuring the observable "voltage" and "current" in two wires connected to it, which extended from the inside to the outside of the box. Then, from the establishment of these relations, the subject could deduce, without seeing, what would be the component that was inside the sealed box. If the subject was successful, the authors sought to ascertain if the subject could use the same conceptual schemas with which he deduced the component of the sealed box to, by transposition or analogy of relations, deduce the phenomenon of internal resistance of the battery.

Few subjects could identify the component and, in addition, many did not seem to understand the relation of the experiment of the sealed box with the experiment of reduction of the voltage in the battery. However, nothing can be said about the existence or not of benefits derived from the use of this experiment in the construction of conceptual schemas or the establishment of relations by subjects that demonstrated progress in the conceptualization of the phenomenon of internal resistance of the battery as that this was not the aim of the research.

This context reinforced the hypothesis that an insufficient consolidation of the TCEL conceptual schemas justified the subjects' difficulty in explaining the phenomenon of the reduction of the voltage in the battery. It was decided, therefore, to add a seventh stage in which the subjects were questioned about the concepts of TCEL, both at the beginning and at the end of the interview. The aim was to verify the consolidation of these conceptual schemas before and after the experiment. However, during the course of this seventh version of the interview, it was verified that these questions were not producing the expected contributions, as the interview ended up being very directed, resembling the verification tests of knowledge traditionally used in schools. This procedure also shifted the focus of the interview, generating a very large demand for time. Moreover,

this form of questioning did not ensure that the information thus obtained could prove, irrefutably, that the subject understood the concepts, because the subject could only be repeating concepts that were memorized.

In the eighth version, the stage in which the subjects were evaluated about the concepts of the TCEL was withdrawn, but the hypothesis about the insufficiency in the consolidation of TCEL concepts remained strong, which caused discomfort and uneasiness in the researchers. Another concern that the researchers faced was that the interview developed so far was very directive, inhibiting the spontaneous actions of the subjects. This concern is relevant, since it is precisely this type of action that can bring more reliable information about the mental functioning of the interviewees. One should therefore try to avoid directing the subject's reasoning, an obstacle that could be dealt with if the person were placed before a routine and familiar situation that presented a problem in which, until then, he had not thought of. In this context, the participant would be required to use his or her internal thinking structures and conceptual schemas to formulate answers that could help explain the phenomenon. During this process, the authors thought it would be possible to question the subject and follow the evolution of his thinking. In this context, when reading a question presented at ENEM in 2014 (Globo, s/d), which asked the respondent to identify the relationship between voltage and resistance (from the length and cross-sectional area of the wire) in an electric shower resistor, the researchers had the idea of including an eighth stage consisting of a day-to-day situation in which, when an electric shower was switched on, there was a reduction in the brightness of a bathroom light bulb.

So the question that started the interview was if he had already observed what happens during the moment an electric shower is turned on. If the subject could not explain the phenomenon of reducing the brightness of the light bulb with the use of the appropriate scientific model, one should be asked to connect the lamps in the battery one at a time, to observe what happened in each case, and then measure the voltages. If the subject still did not present the adequate explanation, the sealed box experiment could be used.

For those cases where there was still no success with the use of the sealed box, the authors tried to present other points of view to the subjects in order to promote a cognitive conflict with their current conceptions. Therefore, it would be possible for them to revert to their conceptual schemas for their solution, and the researcher could identify the courses they followed, as well as verify how the subject articulated his reasoning. This was how the ninth stage was developed, which consisted in presenting the subjects with different explanations about the phenomenon, as if they had been formulated by other students. These responses served as counterarguments and consisted of true explanations or purposely distorted explanations – that is, those which in a superficial view seem to make sense, but if analyzed in greater detail, seem to contain subtly disguised untruths, much similar to sophistry or fallacies.

Although this paper is not primarily intended to present results, some will be

transcribed below to elucidate the potential of the method in this particular research. As an example of a situation where the counterargument was used, the following transcript will displayed:

> Researcher: A colleague of yours said that the battery, like the electric power grid in his house, works as if they were capacitors, that is, they store power. Then when you plug the light bulb, they get discharged. What do you think about that?
>
> Interviewee: *I think you can compare them because when the capacitor is... No, no... I do not think it could be the case because the battery current will always be still. So the battery will always provide power... It will not get discharged...*

In cases where the subjects presented the adequate scientific explanation, their answers were challenged with the use of this or other techniques described below, in order to verify the consolidation of these conceptual schemas. Another procedure used with the same objective was to request the subject to prove their arguments, explaining them through an electric circuit design (second stage); calculating the value of the internal resistance of the battery (tenth stage); and by simulating the reduction of the brightness of a lamp attached to a battery by placing a regulated source in the place of the battery (eleventh stage).

In this context, the researcher could follow the course of the subject's reasoning, questioning him as he progressed, after setting up the circuit to simulate the battery-light bulb-shower situation:

> Researcher: What happened?
>
> Interviewee: *It decreased, I could see it... very little.*
>
> Researcher: Is that what happens in your house?
>
> Interviewee: *Yeah, the same. With the shower off and on.*
>
> Researcher: So would it be possible to state that this experiment simulates the situation of the shower or not?
>
> Interviewee: *Yes.*
>
> Researcher: Why do you think the brightness of the light bulb has decreased?
>
> Interviewee: *In parallel, if I'm not mistaken, the voltage is the same... It may have changed because the current was split or because the internal resistance of the light bulb influenced it.*
>
> Researcher: What do you mean?
>
> Interviewee: *What decreased the intensity of the light might be the current, which has decreased...*

By following the reasoning of the subject, the researcher could then identify situations that showed previous conceptions, cognitive conflicts, elaboration of hypotheses, awareness and, consequently, the reconstruction of conceptual schemas that could lead him to new levels of understanding, thus enabling the development of the conceptual understanding of the phenomenon of internal resistance of the battery.

As an example of the identification of a previous conception about the phenomenon in question, the following dialogue is presented:

Researcher: What happened?

Interviewee: *The brightness of the light bulb has decreased.*

Researcher: Why has the brightness of the light bulb decreased?

Interviewee: *I think that... The shower uses a lot of electric power, hence if it needs to pull much more electric current and it can end up pulling some of the other equipment*.

With regard to cognitive conflict and the use of drawing to enhance the contradiction, the following passage can be used as an example:

Researcher: You said that when you put the shower resistor here, that current in the light bulb splits, right?

Interviewee: *Yes.*

Researcher: But here in the picture you showed me it did not split, right?

Interviewee: *Yes.*

Researcher: But if it did not split, how did the brightness of the light bulb decrease?

Interviewee: ...[pause]... *Now I got lost too*.

And then the subject set up the circuit again.

In the following transcript, one can see an example of how the interview helped in the development of hypotheses to try to solve the problem and in the interviewee testing them by himself: "What would you measure in there? *I wanted to see if there was any resistance... If there was a voltage loss on the way until it got there...*".

Likewise, this technique also facilitated the identification of awareness-raising with the consequent construction of new conceptual schemas, as seen in the following excerpts from an interview:

Researcher: So why was the brightness of the light bulb reduced?

Interviewee: *Maybe it's because the power supply does not provide these 750mA,* [...]

Researcher: Do you have any way to prove it?

Interviewee: *Maybe if I measured the voltage...*

Researcher: And which value do you think you would get?

Interviewee: *The voltage of the source.*

Researcher: Are you sure?

Interviewee: *No, because it is... Let me measure it before to see if it will make a difference.* [The subject measures the voltage in the battery itself, without the devices attached to it] *It's 5,6V...* [Then he decides to measure the voltage on the battery with the light bulb and the resistance of the shower connected to it] *It's 4,46V* [This new observable enables the awareness of the internal resistance of the battery]. *Oh, that would have to represent another part of the circuit...there would be a resistance inside... there is a resistance at the source...*

Another change in this eighth version was to request that the subjects anticipate the results that could be obtained with each new execution, stage or variation of the experiment. With this, first of all, the researchers intended the subject to direct his reasoning to search for explanations, accessing his conceptual schemas. It is only after making their reflections, inferences and anticipations that the subject should act in the experiment to verify the results obtained and to verify the observables, confronting them with their points of view, their previous conceptions and their conceptual schemas.

Finally, the interview was more interactive and prospective and less directive, mainly due to the inclusion of stage 8, which we consider as a decisive milestone in the process of construction of this data collection instrument.

In this context, the ninth version of the interview was developed, in which the first stage (measuring the voltage in the two light bulbs) was removed and the fourth stage (placement of the two light bulbs in series and parallel), with all the others remaining part of the eighth version, and including two further stages. The twelfth stage, which was used at the beginning of the interview, replacing the first stage, consisted in questioning the subject about the possibility of simulating the phenomenon of the reduction of the brightness of the light bulb using some of the electrical components placed at its disposal. For this procedure, a 12Ω by 5W resistor was used to simulate the shower resistor, a 6V and 250mA lamp to simulate the bathroom light bulb, and a set of four small 1,5V batteries connected in series, which totaled a voltage of 6V, to simulate the electric power grid. The phenomenon could then be simulated by connecting the light bulb in the batteries to it so that it could be lit and then connecting the resistor in parallel with the lamp so that this action would produce a reduction in light bulb brightness.

In order to verify the stability of the response of the subject and the consolidation of his conceptual schema of the internal resistance of the battery, the ninth version was included in the thirteenth stage, which consisted of a question about what would happen if the small batteries were replaced by large batteries. Thus, if the subject had really understood the phenomenon, his response should also indicate the existence of the internal resistance in the large batteries, and, he could go further, stating that the resistance of these batteries is smaller since their current capacity is greater.

In the tenth version, there was a need to review the organization and systematization of procedures. First, at the beginning of the interview, the fourteenth stage was included, which consisted of an informative moment, when the ethical and methodological questions about: the purpose of the interview, which was to obtain general data and not to evaluating the subject or promoting learning; the absence of the teacher-student relationship; the position of the interviewer as if it were someone who was not understanding what happened in that situation and who would then be provoking the interviewee so that the interviewee would scientifically explain to him in detail the reasons for the occurrence of that phenomenon; the guarantee of confidentiality and the preservation of the confidentiality of identity; the prerogative of the subject to withdraw or to be absent from the research at any time, without need of justification and without prejudice of any type.

From the operational point of view, the researchers have taken some precautions with the procedures, such as: to question the contradictions more in order to facilitate the identification of their genesis; to use counterarguments when the subjects did not respond to avoid situations in which they had no way out; to question, in all situations, the reason that led the subjects to give this or that answer; to carefully ask questions as to not propose answers or indicate possible ways or solutions.

Finally, the eleventh version was developed, in which the fifteenth stage was inserted, which consisted of a written problem, an alternative for those subjects who could not elaborate the explanation for the phenomenon. This problem called for an explanation of how to calculate the voltages and currents in a circuit similar to the one that modeled the phenomenon, even with the same values, but without this similarity being informed. Thus, it was expected that the subject would identify the analogy between the written problem and the experimental battery-light bulb-shower situation and then proceed to hypothesize the existence of an internal resistance in the battery.

Another change in this version was introduced by the sixteenth stage in which the subject was asked to evaluate the interview and its performance, explaining why he did not find the solution or how he got the answer. In addition, the subject was asked to report if he remembered having studied this theory in class and described how he organized to study at home. These requests were inserted with the objective of obtaining information that could possibly complement or elucidate some question or, still, produce new reflections.

In each of the versions, a mean of five subjects were interviewed to verify the potential of the instrument for the acquisition of data that could contribute to the research objective, namely: to investigate the process of students' knowledge construction on the topic Linear Electrical Circuits. Therefore, it was necessary to elaborate some questions that addressed certain aspects of this process, especially those that refer to the subjects' attitudes, actions and mental operations, since they highlight and explain their way of thinking. Piaget defines *action* as any observable conduct that "aims at an objective from the point of view of the subject that is considered" (Battro, 1978, p. 18). *Operation* would

be, for him, "an action internalized and made reversible by its coordination with other actions internalized in an overall structure that includes certain laws of totality" (Battro, 1978, p. 173).

Thus, questions were developed to verify the achievement of three objectives: to verify observable characteristics in the subjects; identify individual characteristics when building knowledge; and, to determine characteristics of a psychogenesis.

The questions that sought to verify observable characteristics in the subjects were: i) how does the subject act (passive, unleashed or spontaneous attitude) in seeking explanations for the phenomenon?; ii) how does the subject structure his reasoning to explain the phenomenon?; iii) how does the subject explain the relationship between his actions and the results?; iv) what prior knowledge does it come from?; v) what knowledge seems to be missing or not yet consolidated?

The questions that sought to identify individual characteristics when constructing knowledge were: i) how does the subject explain the relationship between his operations and the results? ii) in what moments of the interview is it possible to detect awareness?; iii) how to verify the types of relationship (between the parts and the whole, on the totalities) that the subject establishes; iv) how to investigate the formation of hypotheses?; v) how to identify the type of observed observables (objects, actions or operations)?; vi) what course did the subject follow?; vii) how did the subject become aware of the relationship between voltage and current in the battery, which is explained by the theoretical model of the internal resistance of the battery?

The questions that sought to ascertain characteristics of a psychogenesis were: i) what news does the subject present in relation to what was expected?; ii) what are the characteristics common to all subjects in this trajectory?; iii) what each individual presents in particular in relation to others, or what differentiates one subject from the other in this course?; iv) how can one identify the construction of knowledge or understanding about the phenomenon of reducing the brightness of the light bulb at the moment when an electric shower is connected in the same electric power grid?

After this exhaustive verification, the researchers considered that the eleventh version of the interview would be able to provide the necessary answers to reach the desired results with the research, and then the process of elaborating the data collection instrument was closed and the data collection started.

An important process, which occurred concurrently with the development of the data collection instrument, was the elaboration of a guiding script that aimed to organize the interviews so that the questions addressed similar aspects in all of them. Thus, during the initial stages of the interviews, a questionnaire with 14 questions was developed. However, when using this script in the interviews, a difficulty was verified due to the need to read the written questions, which led to the development of a flowchart that presented the possible courses of action for the interviewer. However, this flowchart was not very efficient either because of the diversity of the trajectories and the explanations of each subject, besides the difficulty of predicting all possible combinations.

Inspired by the concepts of concept map and block diagram, each of the instrument's activities were placed into one block and then group all blocks that had an affinity regarding function or objective. This design was called the Partial Block Diagram of Experimental Situations (Figure 1), which greatly aided the interviews, facilitating the choice of the procedure that best suited each stage.

Briefly, the final version of the data collection instrument was initially an informative stage, in which procedures, norms and ethical care were explained to the subject. Then, the problem was presented verbally, through an everyday event: the reduction of the brightness of the light bulb at the moment a shower is connected in the same electricity grid. The subjects were then asked about the reasons for the reduction of the brightness of the light bulb and about the possibility of simulating the phenomenon through a laboratory experiment.

After that, the researchers presented the counterarguments. If the subjects had presented clarifications, the objective was to test the consistency of their answers. If the subjects had not presented explanations, the counterarguments aimed to provide hypotheses and perspectives of solution to enable the subject to think about the problem. Theoretical problems could also be presented with the same objectives, involving similar situations, but not equal ones.

The next stages contained other activities related to this phenomenon, in which the subjects were asked to make predictions and give explanations. The propositions that followed were intended to test the subjects 'arguments based on questioning and counterarguments, conflicting the subjects' points of view in order to verify the consolidation of their conceptual schemas.

To substantiate his claims, the subject was asked to make an explanatory drawing, which used the regulated source to simulate the effect of the internal resistance of the battery; which would explain what would happen if larger batteries were used (with higher current capacity and consequently less internal resistance); and to calculate the internal resistance of the battery. All these activities sought to verify the consolidation of conceptual schemas and the evidenced hierarchy of thought and, thus, to map the construction of knowledge about the proposed theme.

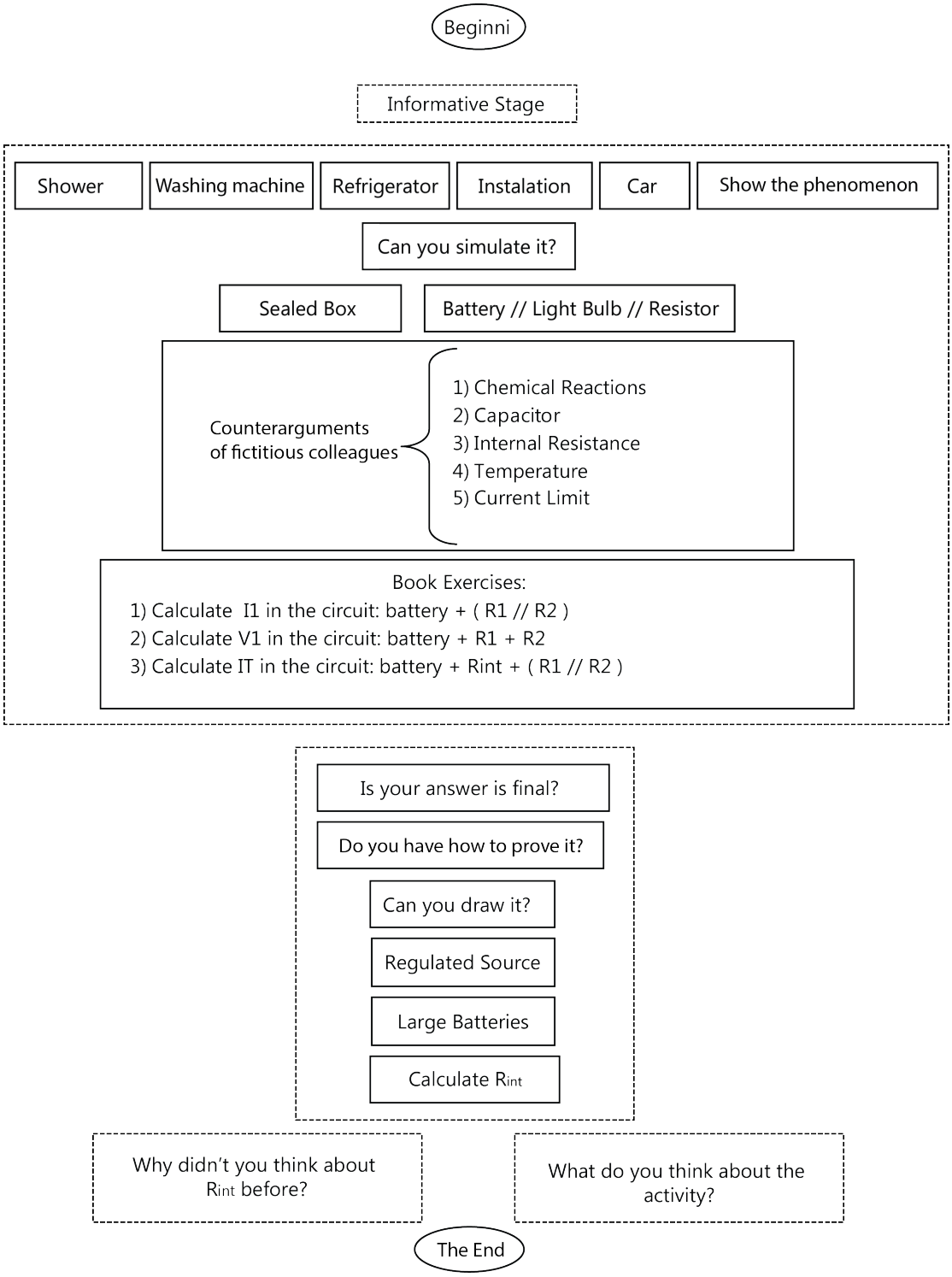

Figure 1. Diagram of Partial Blocks of Experimental Situations

The prototype of the experiment is presented in figures 2, 3 e 4.

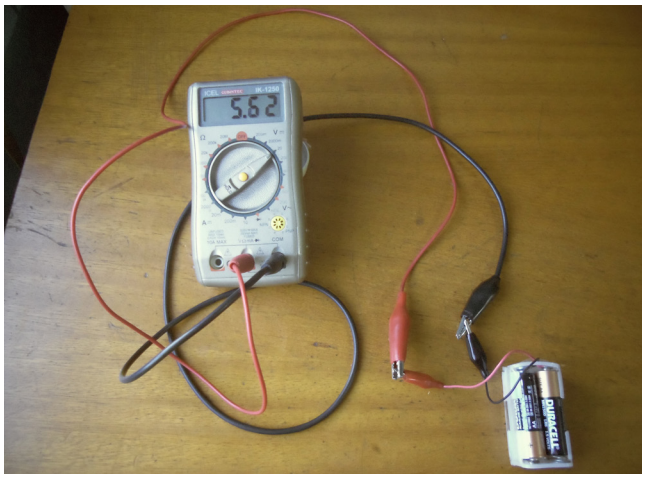

Figure 2. Final version of the experiment with batteries only

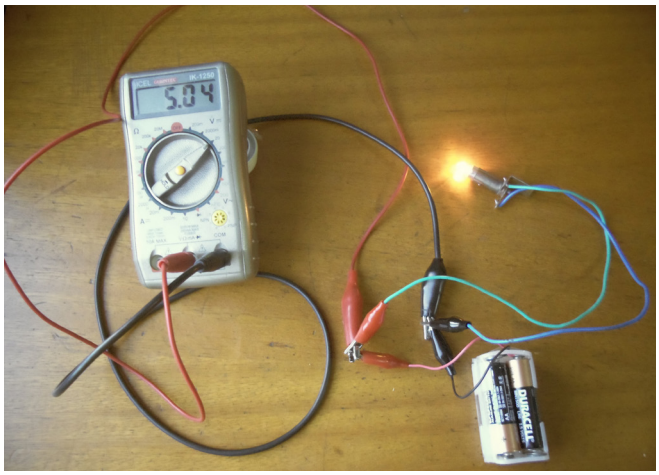

Figure 3. Final version of the experiment with batteries and light bulb

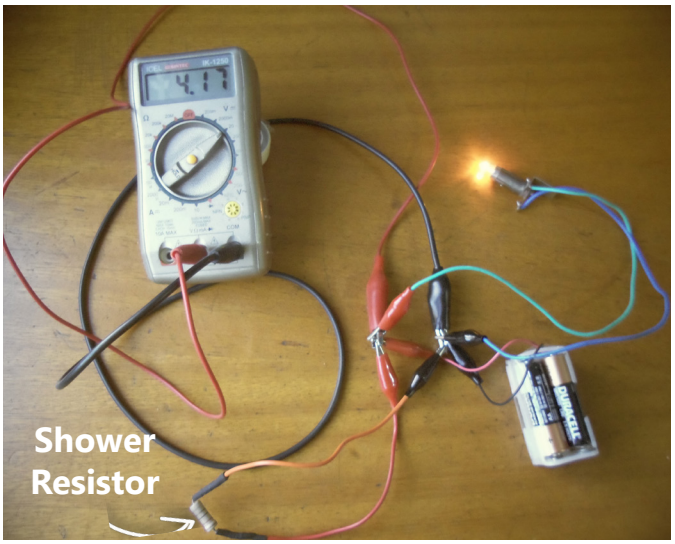

Figure 4. Final version of the experiment with batteries, light bulb and shower resistor

Finally, at the end of the activity, a self-reflection was proposed, which consisted in questioning the subject about the reasons for not immediately presenting the answer, and asking his opinion about the interview and the methodology of the research.

Results and reflections on the use of the methodology

An important aspect of the use of this theoretical and methodological articulation refers to the development of the interviewer's own learning process, evidenced in each new elaborated version of the instrument of data collection and its use in interviews. This methodology made it possible for the interviewer to reflect on his or her own thinking and then to become aware of transformations with breakthroughs in their own process of conceptualization and understanding, establishing relationships between the studied concepts of Genetic Epistemology and the data observed through the situations and interviews with students about the research topic.

The interviewer's awareness process started from the moment he had to resort to his conceptual schemes on Linear Electrical Circuits Theory and Genetic Epistemology to elaborate the preliminary hypotheses that served as a reference for the construction of the first version of the data collection instrument. Subsequently, this version was submitted to empirical tests, in which subjects were interviewed and observed observables. After these tests, the interviewer evaluated the results obtained and the instrument itself, based again on its conceptual schemes, making the necessary adjustments so that the instrument could bring information that is more in line with the research objectives. After making the changes, the instrument was submitted to new test interviews and new adjustments. This process was repeated in each new stage in which the interviewer verified the need for adjustments or improvements in the interview.

Another process began at each moment in which the interviewer verified that the conceptual schemas did not support the elaboration of new experimental situations that could bring results that contributed to the research. This other process involved, firstly, studies on theoretical references not yet addressed at the beginning of the research and, secondly, attempts to establish relationships between the new observables identified in those studies and possible experimental situations that could be provided by the instrument. Thirdly, if the impasse or doubt still remained, the instrument was submitted to the research group's appreciation and considerations, as well as at the end of the elaboration of each new version.

This process was identified, for example, when the interviewer found himself in a dilemma about how he could create an experimental situation that required the interviewee to construct the concept of internal resistance at the source or the power supply network, such as a way to solve the problem. Even after several empirical attempts and after accessing their conceptual schemas obtained from theoretical references, the solution seemed not to be possible. A solution perspective emerged by resorting to a press ENEM issue that asked the applicant to identify the relationship between the voltage, power, resistance, wire length, and straight section area of the wire in an electric

shower. This issue, which dealt with a day-to-day situation, triggered, by analogy, the reminder that the connection of an electric shower can cause a reduction in the voltage of the electric power grid, and, consequently, decrease the brightness of a light bulb, due to factors associated with the internal resistance of this power supply network. The authors argue that this was a determining moment for the research because, from this awareness and the inclusion of the everyday situation of the light bulb brightness decreasing when the shower is connected in the same energy grid as a reference for the questions, the research has become more interactive and prospective. In addition, the interviewer reached a new level of knowledge and, consequently, a more prospective position in the interview.

In short, what was identified during the elaboration of the data collection instrument is the initiation of mental processes of questioning, searching, reflections and organization of thought through a delicate movement of intellectual decentralization, which sought to articulate the observables present in the interviews with the concepts of the theoretical framework. This decentralization resembles the one presented by Piaget (1977, p. 198).

The aforementioned author considers that the thought about a material action produces an interiorization of this one. Thus, the subject's thought will move to a region bordering between his conceptual schemas and the action itself on the material object. Based on this movement, Piaget argues that knowledge comes neither from the subject nor from the object, but from the interaction between the two. Still in this section, the author states that the subject reacts in relation to the object in accordance with an objective and, therefore, apprehends the result assimilating the object to a schema.

Therefore, the authors argue that the interviewer's process of self-reflection of was supported by continuous movements of interiorization and exteriorization – and, so to speak, decentralization – of his thought. In this sense, it is possible to establish a correspondence between this process of the researcher and the one described by Piaget (1977), as long as one considers the reflection on the subject's own actions and operations of thought and the observables of the interview as the object. Thus, the authors suggest that it is possible to recognize an interviewer's learning, in a way that is analogous to that presented by the subjects interviewed in the research.

The process of developing the data collection instrument, by articulating experimental situations with elements of the theoretical references, both regarding the concepts of Genetic Epistemology and the Clinical Method and with regard to Linear Electrical Circuits Theory, brings important contributions for new research and for teaching.

The way the questionings, the counterarguments and the shower situation were presented in the interview made it possible to find structures of thought and conceptions at various levels of evolution, from those still very incipient, evidenced by rather rudimentary explanations and deformed in regard to the scientific concepts, such as the one that justifies that "the brightness decreased because the current was divided

between the light bulb and the shower" to structures of thought and more developed conceptions, which present more elaborated answers such as the one that explains that "*the variation in brightness is due to the variation of the voltage of the source and not to the variation of the current as I previously said. It is just that, with the variation of the voltage of the source, the current will also vary...*".

The description of the development process of this data collection instrument – alongside the examples of answers obtained through it and presented in this paper – allows the recommendation of its use by teachers as a reference for the elaboration of activities, experiments and evaluations in the study of the theme of research aimed at learning, in the classroom. This suggestion is supported by the fact that implied learning was identified in the changes observed in the answers during each interview. This finding agrees with Bovet, Inhelder and Sinclair (1977, p. 257), who argue that "it is possible, through appropriate exercises [and questions], to reduce the intervals that normally separate successive steps from the development of studied notions".

In general, exercises, practical activities and laboratory experiments are widely used as didactic instruments, mainly in courses that aim to train professionals to perform specific tasks, such as in vocational courses in Electronics and Electrical Engineering, the object of this research.

Taking this into account, it was possible to verify that the research points out alternatives to possible pedagogical actions to favor the development of the researched conceptions and a theoretical methodological course for research on learning other conceptions of interest for vocational and technological education. It is considered necessary to emphasize that this paper does not intend to prescribe methodologies, teaching techniques or specific scripts. It is argued that the imposition of very rigid and embedded didactic models or methods of discourse disregards the epistemological positions of teachers and/or their conceptions of empirical origin that have long been ingrained, without necessarily affecting them through reflection and the need for coordination with a new perspective. Thus, the novelty could produce reactions of rejection or deformed assimilations contrary to the idea of knowledge construction advocated in this paper. The purpose of the explanation of the research methodology is to stimulate the investigation of the teachers' practice, contemplating specific questions of the subjects with which they work, either as contents, or as stages of conceptualization.

The position taken from the research presented in this paper is that the activities planning can be done in correspondence with the type of knowledge to be studied, with the learning level of each student and with the learning context, using the constructivist referential as epistemological foundation and also considering that the result of this planning must be constantly subordinated to empirical validations. This position agrees with Macedo (2010, p. 53), when he reports that it is difficult to "determine all the circumstances of a didactic action" and also warns us about the "unique character of teaching practice" and about "quality and wealth" of the relationship between teacher and student (Macedo, 2010, p. 55).

It is also important to remember that the results obtained with exercises, laboratory experiments, surveys and evaluations, often used as references for didactic actions, are only initial information about subjects' knowledge, collected at a specific time. Such information is conditioned by factors such as resource limitations, activity focus, student predisposition, type of knowledge, form and context in which the activity was performed, among others. Therefore, the importance of integrating objectives, processes and knowledge on the learning of specific knowledge in an inquiry developed by the teacher himself.

The search for answers to the questions presented based on the Clinical Method requires an act of decentralization of the subject, which is endogenous. Therefore, there is no guarantee that the use of this method can trigger the decentration and consequent promotion of the understanding of the phenomenon, although it is possible to show other points of view to the subjects, as previously reported. It must be taken into account, in the elaboration of activities that aim at learning, that these processes are produced according to the interests of the subjects, through hierarchical and sequential levels, similarly to a psychogenesis of understanding, as in the phenomenon of the reduction of the light bulb brightness used in this research. The authors suggest, then, that the elaboration of these activities take into account the interests of the students and that they begin from the level of understanding in which they are in the moment, evolving, then, to higher levels, in which the thought is more complex.

The results obtained in researches inspired by the Clinical Method should not be considered in an absolute sense, but taken as a starting point for new inquiries with an interactive and prospective approach, aiming at promoting the student's approach to the object of study and instigating him to build new knowledge through the search for answers to problem-situations.

This finding is in line with Delval's (2010, p. 127) proposal that it is necessary to situate the student "in the face of problems and urge him to seek answers for himself", since students "move forward when we present intriguing problems, and we help them find explanations" (Delval, 2010, p. 128). In the same line, one may remember Piaget (1998, p. 180) arguing that it is desirable for the student to become "an active experimenter who seeks and finds solutions, through countless attempts, perhaps, but through his own intellectual means". One can also include the contribution of Ballard and Hodgson-Drysdale (2011, p. 4), which point to the importance of students sharing results through written explanations, promoting the exchange of arguments and counterarguments and, thus, decentralizing point of views.

In order to follow the course of individual development of each student, the learning assessment must change its focus, which is traditionally directed towards the final result. It is considered necessary to place it on partial results, conflicts, evidence and awareness. This change in the learning assessment seems to be very significant, to the point of it requiring a new view of the teacher about the learning processes, which should take into account the students' points of view, their initial knowledge, their

interests, their learning courses and their difficulties, among others.

Therefore, the authors believed that the understanding of the functioning of the mechanisms of knowledge construction by teachers can be constituted from a process of psychopedagogical training. It is clear that the difficulties in achieving a more student-centered teaching conception are not being overlooked, but the authors believe that, from what has been reported, all those involved with learning, whether researchers, teachers or students, can be active protagonists of their own learning and the development of their understanding.

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