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Case Report

Towards an Experimental Verification of Vygotsky's Zone of Proximal Development: A Docimological Approach

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Abstract: We describe a group session specifically designed to experimentally verify the existence of a concept that is frequently used within the constructivist framework. This exercise involved a group of students $n = 40$. A randomly chosen half of the entire group responded to a questionnaire on arithmetical topics. This 'test' did not provide the respondents with any clue or help. The other half were asked to solve the same problem, but with the assistance of an informative heading printed on the question paper. In the subgroup that did receive help, a 'Zone of Proximal Development' process was observed in ten cases - i.e., an assisted learning process where the respondents took advantage of the problem-solving help.

Keywords: Zone of Proximal Development, Transfer of Knowledge, Problem Solving and Learning

1. Cognitive Particularities and Problem-Solving

The genesis of learned knowledge related to the solution of problems, especially when the learning procedure is carried out in collaboration with one or more schoolmates (under the assumption that at least one of the participants has previous knowledge), constitutes a pedagogical dynamic with strategic value. Several concepts often used in constructivism (a theory that seeks a materialistic explanation of learning by considering the individual and its social environment) are based on the solution of problems [17, 8, 9]. Two of these concepts are described here: cognitive transfer or T (the transfer of knowledge or skill used by a subject to solve a particular problem to the solution of another, related, more complex problem), and zone of proximal development or ZPD (when the capacity of an individual is insufficient to solve a problem independently, requiring direct or indirect guidance or assistance, through various means, of a facilitator or expert).

The expression 'cognitive particularity' is not part of the pedagogical vocabulary; for the purpose of this article, it refers to a learning situation of negligible or minimal dimension, related to a highly specific subject and associated with the solution of problem experienced by the subject without the occurrence of cognitive transfer in a clear process of ZPD, requiring the help of a facilitator or expert.

2. Zone of Proximal Development

The concept of zone of proximal development (ZPD), according to Vygotsky, who explains it in general terms in the context of other considerations, can be defined as:

The distance between the level of development, as determined by the subject's ability to solve a problem independently, and the level of potential development as determined through the solution of a problem under adult guidance or in collaboration with another, more capable schoolmate [17].

Rather than a fact or an identifiable cognitive phenomenon

(actually, Vygotsky associates other key elements of his theory with the concept of ZPD: mediation, cultural development, affectivity, imitation and influence of the teacher), ZPD is a process in which two proactive actors are involved: the learner and the one who contributes, using various means and mediations, to the occurrence of learning. The demonstration of this process is usually theoretical, i.e., it depends on incomplete evidence and speculative arguments, although there have been serious attempts to provide an empirical demonstration or to collect evidence by documenting experiences [14, 15, 11].

In itself, it is a practically unquestionable pedagogical axiom that has been extensively studied, although with significant gaps, especially regarding the scope of the collaboration, maturation, dimension or extent of the ZPD. Another gap is related to the appropriateness of the concept in the context of a general law of cultural development formulated by Vygotsky that includes biological, intellectual and social attributes of the human being, which leads to consider other learning situations besides adult-child interactions, such as child-child and adult-adult interactions [5, 3]. In all these cases, the participant on the left has greater command over the subject of learning compared to the participant on the right. In its original approach, Vygotsky did not have the opportunity to develop the full spectrum of applications of the concept and its many possible variations; thus, it is inappropriate to assume a dogmatic or strict attitude on this matter by adopting an absolute definition of the ZPD [16]. It is worth noting that the ZPD can now occur through the new technologies of communication and information, which in Vygotsky's time- who developed his ideas during the 1920s- were in an incipient stage of development or belonged to the realm of science fiction.

While there is substantial empirical evidence of its existence or occurrence, there is, until now, no formal experimental demonstration of the ZPD. An important obstacle is that educational events are highly permeated by subjectivity; they occur within each person and can hardly be generalized, particularly when dealing with clinical or special education cases. However, if subjectivity is reduced to a minimum, it could be possible to achieve a truly experimental approach [7].

To achieve this goal, it is necessary to use a pre-experimental design and to compare pre- and post-observations with the same group of participants [12]. A particularity of the ZPD is the personalization of the actors involved, the learner and the adviser or helper; there are no reports of this process wherein the latter is invisible, anonymous or implied, which is now common in electronic tutoring systems and distance education. In this regard, we will try to demonstrate the operability of the ZPD, experimentally promoted through an informative header that must be read and understood to solve a problem in an arithmetic test; in this case, the header represents the mediation or medium that is central to Vygotsky, and it also represents the participation of a competent facilitator -invisible in this case but implicit in the elaboration of the

questionnaire. The reported experiment was conducted with undergraduate students in the second year of a science degree.

3. Experimental Approach

3.1. Hypothesis

Hypothesis: the experimental verification of the occurrence of a zone of proximal development process requires that the ability shown by the study subjects in the autonomous resolution of a problem exceeds what can be attributed to cognitive transfer alone.

3.2. Subjects and Procedure

Two subgroups of undergraduate science students were asked to participate in a carefully designed didactic situation that encouraged a committed participation of the subjects in the experimental exercise. The first group (n=40) had the help of an informative header (prefixed to the description of the problem they were asked to solve), while the second group (n=40) had no such help. For both groups, the problem to solve was the sum of a three-term polynomial (serial addition or subtraction). Both groups of students had to previously answer another problem, included in the same questionnaire and consisting of the sum of a two-term polynomial; this previous problem acted as target or control for the two treatments. The group session, which included the two treatments, was conducted simultaneously and in the same place; neither the applicators nor the students were informed about the nature of the experiment in which they participated. The students were warned that all information collected would be used for a report by the school.

3.3. Questionnaire

It consist of an arithmetic test with twelve questions: ten are contextual questions and two were designed for experimental observation. The contextual questions included basic operations (addition, subtraction, multiplication and division), exponents and square roots, valuing fractions, decimals, and mental arithmetic [10, 13].

4. Design of the Problems

Let P be a basic problem (it can about a wide range of knowledge and daily life situations) for which no guidance or assistance is provided to the student. P' is a problem related to P (relatively more difficult) for which the student is given guidance or help. T is the coincidence of correct answers for P and P' per participant; for the purposes of this demonstration, T represents, hypothetically, the cognitive transfer from P to P' performed by each subject. The above elements allow us to formulate an integrating equation, so that: $ZPD \approx P' - T$. To better understand this equation, consider that T represents, in large measure, the cognitive base of each subject, and ZPD represents the short-term learning performed by the subject in solving a problem (P') with the mediation of the facilitator. We avoided the use of the equal sign (=), and used instead the

approximation sign (≈) due to epistemological prudence and our own convictions (we believe false positive and false negative comments are inevitable). We acknowledge that the results of this kind of experiments cannot be exact; however, carefully made observations can lead to significantly valid conclusions.

To select an appropriate problem (to facilitate the experimental observation, the chosen problem should be of high difficulty), we considered the case, already reported, of the identification of the terms in a sum of polynomials (which is explained in the informative header of P'), which is widely documented as very difficult problem in school mathematics [1]. The results of the experiment confirm that this math problem does have a high difficulty, even in higher education. The problems described below are part of a questionnaire that includes more questions.

These are the problems that were are examined in this study:

P) Execute the following operation (1):

$$2 + 3 \times 4 = ? \qquad (1)$$

This sum of two terms (the concept is explained in the header of the second problem) can in rare cases be solved by a hunch or intuition of the student, even when the terms are not properly recognized, especially when the sum is done mechanically from right to left, i.e., starting by solving 4 x 3 and thoughtlessly adding 2.

Other non-related questions are introduced between both problems. The second problem is introduced by the header mentioned above, asking the participants to read it with the utmost care before providing an answer. This header is included only in the experimental treatment; in the control group, the problem is introduced in the same way as P.

P') In the case of serial operations or polynomials, the calculations and independent values, which are called terms, are separated by addition or subtraction. Pay attention and carefully execute the following operation (2):

$$3.2 + 4.4 \times 2 + 8 = ? \qquad (2)$$

This sum of three terms (containing decimal numbers, which in some cases may increase the difficulty) makes it difficult to answer correctly by hunch or intuition if the terms are not properly identified.

The correct answers (R) are: P= 14 and P'= 20; the calculations must be done without the use of a calculator. Generalizing the solution of the two problems, we have, in the case of P, $A + (B \times C) = R$, and in the case of P', $A + (B \times C) + D = R$. The parentheses are an unnecessary mathematical indication. Although they are widely used in elementary mathematics texts as an aid to readers, here they are included for explanatory purposes.

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Applying these problems to the two subgroups (control and experimental) of forty college students each, we obtained the results shown in Figure 1.

We applied to these data the following equation: ZPD ≈ P' - T. In the case of the control group, ZPD = 10-10 = 0, while for the experimental group, ZPD = 19-9 = 10, indicating that ten students did took advantage -experimentally induced ZPD process- of the assistance provided (found in the header of P') and that, without it, they would not have been able to solve the problem, which was confirmed by the results obtained by each student in P. Three participants in the experimental group, who provided a correct answer for P did not understand the header and erred in P', either due to confusion or inadvertent mistake (maybe for other reasons).
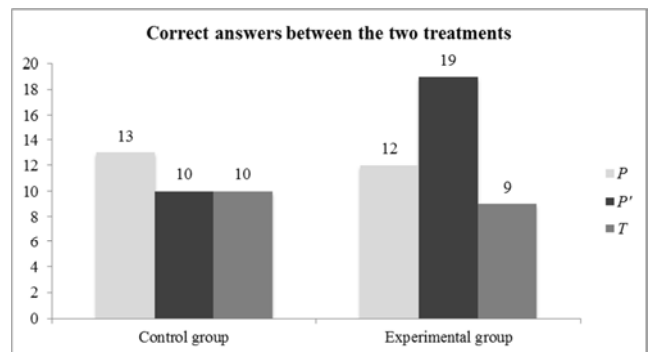

Figure 1. *Correct answers to the problems and coincidence in both between the two treatments. Source: Original data obtained for this report.*

In the control group, P is slightly less difficult than P', which is reflected in that ZPD = 10-10 = 0. In both groups, P makes it easier to provide a correct answer, which is not the case of P'. In the comparison between both groups of students, the ZPD indicator favors the treatment where P' is preceded by an informative header (10-0 = 10). This difference reaches a statistical certainty of 99.9% according to a two-tailed t-test (non-parametric) with 40 + 40-2 = 78 degrees of freedom. Thus, the significance value is 0.002 (probability of non-occurrence of the observation), which is remarkable, particularly considering the sample size (n = 40); this significance value decisively rules out the null hypothesis (which presupposed no difference) and allows us to accept the working or experimental hypothesis (which presupposed a significant difference).

In the contextual mathematical questionnaire (containing ten questions), the control subgroup obtained an average rating of 9.2, while the experimental subgroup obtained 9.0, a statistically insignificant difference that supports the homogeneity of the examined numeracy skills of the students divided randomly into two subgroups.

6. Originality and Contribution of the Study

We obtained an experimental confirmation of a process similar to the zone of proximal development (ZPD) in the context of a test (in this case on mathematics, although the subject may include various aspects of daily life) that was applied to normal subjects who enjoy an advantageous

educational situation (they are college students), which is rare in the empirical study of this concept. Studies of the ZPD usually refer to clinical cases of people receiving special education, arts students (where personalized instruction is common) or subjects attending elementary school; in contrast, this research was carried out with subjects enjoying optimal conditions, which contributes to its originality. We found that the ZPD is an intellectual process that does not operate in isolation or independently, but in combination with other cognitive processes (such as autoregulation and meta-cognition, which in this report were only tangentially touched). Our study demonstrated that the ZPD is directly associated with cognitive transfer, which was possible to represent with the following equation: ZPD ≈ P' - T. This constitutes an original contribution, since it involves a demonstrable mathematical approach, even if the observations correspond to one case. Regarding the type of exercise, other authors have used similar examples [6]. Moreover, the whole exercise can become a regular experimental practice in schools -it can include other subjects, such as language or even games, shedding light on the relationships of the ZPD with other pedagogical concepts- to allow a more scientific study, under direct observation of facts, of the teaching-learning process. In this regard, a docimological evaluation, based mainly on the application of tests or equivalent evaluations [2] could be appropriate for an international academic committee to experimentally verify the occurrence off the ZPD and establish it as a cognitive law, which would be consistent with the approach of Vygotsky, the "genetic laws" related to the cultural development of children and, in general, of anyone who learns something new.

7. Conclusions

The experiment meets the criteria to be recognized as such in the field of social sciences [4]: randomness in the distribution of treatments, double-blind design, homogeneity in the psychomotor condition of the subjects, spatio-temporal coincidence in all stages, and repeatability and generalizability of the observations. These are aspects that are open to debate. However, the study of the ZPD (or cognitive processes similar to it) will continue to be highly subjective, since it is difficult to establish scientific criteria about how to study it. For this, it will be necessary to design experiments in the fields of exact, natural, and social sciences, as well as in the arts and Humanities, that allow us to establish objective criteria to determine the occurrence of the ZPD and thus state more clearly its pedagogical applications.

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