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The Constructivist Principle of Learning by Being in Physics Teaching

By Mihail Calalb[*]

A detailed characteristic of teaching and learning approaches used within the new concept of Learning by Being (LBB) is given. The evolution of educational paradigms from Learning by Doing (LBD) and Learning by Understanding (LBU) toward LBB is analyzed. The basic idea of LBB is students' ownership on cognitive goals, or the assumption of learning objectives, in other words – intrinsic motivation of students. Along with LBB, the author proposes the term of guided self-scaffolding. Both terms tend to accentuate high level of student's intrinsic motivation. The article examines the school physics lab as an example of constructivist learning environment and analyzes several didactic approaches as inquiry-based learning, problem-based learning, project-based learning, case studies, and just in time teaching from constructivist point of view. The author enumerates the basic principles for the organization of school physics lab in a constructivist manner: provision of opportunities for students' own thinking, giving students a certain freedom degree in identifying solution through verbalization of the problem, necessity for teacher to know a priori concepts of students, students' effort as a mandatory condition to achieve students' interest. The concept of "big scientific ideas" is in the core of this organization. The author emphasizes that conceptual understanding in school physics lab, which is inseparable from learning by being, is achieved through the overlapping of several learning and teaching approaches which form the core of LBB concept.

Keywords: *constructivist pedagogy, educational paradigms, learning by being, ownership of cognitive goals, school physics lab*

Introduction

The results of recent researches show that wrong understanding of physics concepts remains high not only among school students but also among teachers, when up to 30% of them have naïve, non-scientific ideas about terms and notions with which they operate in class (Parinda Phanphech et al. 2019, Cahyadi 2007). This fact is not necessarily reflected in problem solving skills of the students or in the application of modern teaching methods. Thus, there is a discrepancy between understanding of notions and problem-solving skills of students (Bao and Koenig 2019). It means that we can have students accustomed to project-based or problem-based learning strategies, or to inquiry-based learning methods, but who do not have correct conceptual understanding of notions. This happens when excessive emphasis is placed on constructivist, active learning approaches, because conceptual understanding does not appear as a result of the repetitive

[*]Chair of Theoretical and Experimental Physics, Tiraspol State University in Chișinău, Republic of Moldova.

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practice of solving simple problems or carrying out laboratory work only following teacher's instructions. Thus, the so-called "active" learning, the false Brownian movement of students in the classroom, still does not ensure understanding (Calalb 2017).

In this article, we will start from the basic idea that there is no understanding without reflection, which in its turn, can be encouraged by creating in classroom the premises for conversation, discussion, and analysis (Von Glasersfeld 2001). As a result, the logic chain Conversation - Reflection - Understanding should be present in any physics lesson. Considering this, the Section I of this article analyzes the basic principles for embedding constructivist didactics into physics class.

As the formulation of teaching principles is not yet teaching, we will analyse the evolution of educational paradigms from well-known one of *Learning by Doing* to the recent concept proposed by the author – *Learning by Being*. This evolution reflects the main problem educational systems from various countries face. Namely, low motivation and interest showed by the majority of school students for learning (OECD 2017). In this way, the higher is students' involvement degree into class activities, the more successful is that strategy. More and more researchers and teachers realise that school does not belong to entertainment industry and student centered education hides actually the central role of the teacher. For example, the Section II of this article presents three-step ladder of paradigms. We analyse each paradigm from the perspective of student's role in the learning process and propose an integrated approach named *Learning by being*. In addition, based on the results of the *Visible Teaching Learning* (VTL) theory, the impact factors on academic achievement of students are analysed for the case of several constructivist strategies (Hattie 2009). In this context, in *Learning by being* we put the accent on student's *ownership of cognitive goals* or *assumption of cognitive goals.*

Section "Student's Role Within LBB", from the perspective of main principles of learning by being such as student's personal learning effort or metacognition, analyzes the student's place within several teaching approaches, which have a high impact factor proven by VTL. Section "Teacher's Role Within LBB" examines such approaches like: a) guided self-scaffolding; b) structuring of new information; c) recurrent application of previously learned knowledge; d) problem solving; and e) seeking help. All these approaches are inherent to Learning by being and strongly correlate with VTL principles. Along with the term of *learning by being*, the author also proposes for the first time the term of *guided self-scaffolding*. Both terms tend to accentuate high level of student's intrinsic motivation. Last section presents the main obtained results and draws several major conclusions from the perspective of the new approach of *Learning by being*.

School Physics Lab as Constructivist Learning Environment

The need for constructivism in physics class is fully justified because it comes from the fight against students' boredom and their low motivation for sustained cognitive effort. This led to the replacement (mostly in science education research at this moment) of conventional teaching, which has formed absolutely all illustrious physicists, with a series of modern methods in which the student "reconstructs" existing knowledge and builds his/her own (scientific or less scientific) vision of the world. The good part here is the student's personal learning effort, which ultimately leads to the formation of sustainable lifelong learning skills – the school's goal in the era of technological and information boom. With a good organization of the lesson in constructivist style, when the student is in his/her zone of proximal development, the cognitive success is ensured (Anamezie 2018, Akanwa and Ovute 2014).

Let us start with several principles of constructivist didactics that we will take into account within school physics laboratories. First, create opportunities for students to manifest their own thinking. Do not start the lesson with the issuance of undeniable truths. Second, namely the students formulate the problem and it is their duty to identify the solution through conversation, when they verbalize the problem, the phenomenon, the notions, the quantities, and the possible relations between them. Third, in order to build correct conceptual understanding, it is mandatory to know what are the a priori representations and conceptions of the students. In addition, it is not a given that, after the lesson, the students will assume the teacher's conception. Fourth, along with subject knowledge, the teacher has an arsenal of teaching methods and techniques suitable to different situations, all aimed at awakening and forming the students' interest. Fifth, when evaluating student's work avoid giving such marks as "wrong" or "insufficient", if you know that the student has made an effort.

These principles can be easily followed within any constructivist teaching method. The only requirement is that students should be accustomed to them, because the sporadic, facade application of modern methods confuses students, having a negative impact on their academic achievement and conceptual understanding. In addition, before adopting a method, as in any conventional class, we will define the learning objectives in terms what the student should be able to do (explain, calculate, elaborate ... etc.). Further we will briefly characterize some methods that allow the implementation of constructivist approach within school physics lab.

a. *Inquiry-based learning* or reflexive learning, known as IBSE (inquiry-based science education). Recommended for beginning teachers. The organization of student – teacher interaction and the guidance of the research action of the students is the essence of IBSE. For example, in order to make students learn and understand as many notions as possible during a lesson, it is advisable to embed a peer instruction moment (Crouch and Mazur 2001).

b. *Problem-based learning*, PBL. An authentic, open-ended issue is debated within PBL class. PBL requires teachers who are experienced in organizing peer instruction, or in any other method of cooperative learning. Among all methods, PBL is most valuable because: i) PBL suits to the existent curriculum (while other methods require reconceptualization of the curriculum); ii) PBL forms students with sustainable lifelong learning skills; iii) The student's scientific conceptual understanding of the world is the result of the student's personal cognitive effort within PBL; and iv) PBL prepares students for cooperation and teamwork.

c. *Project-based learning* where students cooperate within teams, but each team member has his/her individual responsibility for the entire project, but learning objectives are mandatory for all students. As the project suits well with the concept of “big scientific ideas”, we have to restructure the curriculum into such ideas, so that a project corresponds to one big scientific idea (Harlen 2010). For example, within the 6^{th} grade physics course during the whole academic year the students will develop ten small projects, each project containing about three new notions:

- Mass, volume and density.
- Motion and rest.
- Force, weight, gravitational acceleration.
- Atoms and molecules.
- Gas, liquid and solid bodies.
- Temperature, thermal equilibrium.
- Thermal expansion/contraction.
- Nature of electricity, electrical charges.
- Conductors and insulators.
- Magnets, magnetic poles.

d. *Case studies* are less common in physics lessons because it is time consuming for teacher to prepare the necessary information, but 11^{th} and 12^{th} grades students could apply case studies, when they examine a problem in a global context. For example, in the 12^{th} grade physics course, the study of the external photoelectric effect can be done in the context of renewable energy or in the context of the analysis of the multiple applications of photoelectric emission.

e. *Just-in-time learning* suits to online teaching because it allows the distribution of tasks and the evaluation of individual responses of students. In its essence, the method *Just-in-time learning* is an online translation of frontal teaching method, when students have to keep up with the lesson and daily tasks. From teacher it requires flexibility and experience in order to adjust the delivery of the course according to the answers received from the students.

We emphasize that the methods presented here are learning and not teaching ones. It does not imply that teacher does not remain the central figure in class. In the same time, teacher and students strictly share their distinctive parts of responsibility. It means that the learning objectives are not optional and the learning effort is mandatory, because without effort there is no ascent. That is why ludic education has a smaller impact factor on students’ academic achievement than conventional-frontal teaching (Hattie 2009).

In conclusion, although constructivist methods are different, there are some common moments: a) reflective learning in physics laboratory; b) enhanced (in comparison with conventional teaching) student-student communication (IBSE, peer instruction, PBL) and student-teacher communication (IBSE, scaffolding); and c) intuitive structuring of information. Thus, the distinctive features of school physics lab organized in a constructivist manner are:

- Unlike the common custom, in a constructivist class the teacher organizes laboratory at the beginning of new chapter because at this stage, the cognitive goals are formulated as a research problem and students better understand the notions and connections between new terms within their research projects.
- One laboratory corresponds to one research project and to one big scientific idea.
- In order to achieve deep conceptual understanding, students study no more than three physical concepts within one physics lab.
- First comes understanding of the notions and connections between them, then - formulas and problem solving. Avoid sterile formulas during the laboratory measurements. Juggling with simple formulas does not bring understanding of physical meaning.
- The students estimate and analyze the possible results before measurements. Estimating results develops both the understanding of physical meaning and the mathematical skills of students.
- The students discuss and debate the obtained results at group and class level. Without the moment of analysis and reflection, the laboratory work is useless.
- Laboratory ends with a homework task, which should look like a small challenge and not time consuming. Homework is mandatory, but in order to avoid frustration and maintain interest, it should be accessible to all students.

Thus, a successful organized physics laboratory in a constructivist style will necessarily access a series of intelligences (bodily - kinesthezic, spatial, logical - mathematical, linguistic, intra- and inter-personal), none of them being superior to the others (Aina 2018). For example, interpersonal intelligence is about communication, and communication, in its turn, ensures the mutual feedback. Without feedback the student only guess the teacher's objectives, and the teacher does not know the initial conceptions of the student, nor what the student understood from his/her discourse (Hattie 2009). It is about visible teaching and learning, VTL.

In order to structure the information in an intuitive way, there are several related approaches: reference signals, concept or cognitive maps, graphic organizers (Шаталов 1979, Iofciu et al. 2010, Placing 2006). These approaches allow students to have an overview on a body of knowledge, structure the knowledge, help them in understanding new notions, facilitate conceptual learning, and eliminate students' boredom and fatigue. In addition, as a way of learning, students may be involved in the creation of these intuitive teaching aids.

The Ladder of Educational Paradigms

There is no modern paradigm, which does not declare itself as a constructivist one. It is fashionable to put the accent on student's active role within teaching –

learning process. For example, let us examine the first step of the ladder of educational paradigms – one of the well–known strategy of Learning by doing, LBD, which tries to find solutions for more noticeable presence of students in class. A LBD approach is ludic education. According to the VTL theory, ludic education has an impact factor on students' academic achievement equal to 35% (Hattie 2009). Another LBD approach is problem-based learning with lower impact factor – 26%. If we relate to benchmark level of 40%, which corresponds to the case when an experienced teacher applies conventional frontal teaching during two years, these approaches have a negative impact factor, because doing is far away from understanding.

The next step on the ladder of educational paradigms is the one of Learning by understanding, LBU. The transition from the linear paradigm of doing to the one of understanding requires a higher degree of students' involvement. Thus, it is about understanding through involvement. Thus, LBU requires a more advanced level of communication. Good communication requires and atmosphere of empathy. A good example of LBU is IBSE, which has an impact factor two times higher than ludic education – 77% (Bao and Koenig 2019). Thereby the LBU approach has a double effect compared with LBD.

Further, the third step in the evolution of educational paradigms is *Learning by being,* LBB, when the student not only knows the learning objectives, but also assumes them. Thus, LBB is about the *ownership of cognitive goals*. LBB has several distinctive components such as: independent research with an impact factor on students' academic achievement equal to 83%, knowledge of success criteria – 113%, revealing similarities and patterns – 132%. Since LBB integrates these highly efficient strategies (two – three times higher than conventional teaching), due to the synergy effect the impact factor for *learning by being* is much higher than the given numbers. Thus, simultaneous or parallel application of such didactical strategies, all of them being based on deep intrinsic motivation, would give strong cumulative effect.

Student's Role within LBB

In this section, we will examine the requirements for what students should be able to do in order to apply efficiently LBB approach.

Knowledge of Learning Objectives and Assumption of Learning

According to VTL this strategy has an impact factor on academic achievement of students equal to 113% (see Table 1). It is a common thing that each class starts with clear definition of the learning objectives: what students need to know, understand, and be able to do. However, we have to emphasize that in LBB each student must not only know the learning objectives, but also assume them. In order to achieve this highest level of intrinsic motivation, the learning objectives must be challenging and exciting for students, according to their current level of knowledge. Thus, the teacher should act at the edge of their zone of proximal development.

Here we recall well-known didactical principle of learning with effort, because only the effort develops, and any ascension requires effort. For a better assimilation of cognitive goals of the lesson, we can group the learning objectives according to the concept of big scientific ideas. Thus, in order to obtain a more advanced involvement degree of students, we may prepare a series of questions such as: a) What do you think should follow after previous subject? b) What will be the aims of today's lesson? c) What do we already know and would it help us to reach today's goals? d) What should we do in order to achieve our goals?(Killian 2014). As we can see from the structure of these questions, we actually prepare students for inquiry-based learning. Such type of learning will be a successful one if the impulse for research comes intrinsically from students.

Table 1. Key Features of Several High-Impact Teaching Approaches Used Within LBB

Teaching approach	**Didactical principle**	**Didactical tools or means**	**Impact factor**
Assumption of learning objectives	Learning effort	• Structuring of learning goals • Inquiry-based learning	113%
Active Involvement	Practice	• Series of practical tasks with different complexity degrees	77%
Knowledge of understanding degree	Scientific character of teaching	• Offline digital evaluation system • Peer instruction	129%
Structuring new material	Intuitiveness of teaching	• Support signals • Interactive white board	114%
Fostering metacognition	Consciousness of learning	• Analysis of learning strategies • Self-assessment	61%

Active Involvement

When the teacher comes with a new subject, the first question of students is "What use is it?" In order to remove this refractory attitude, the teacher should prepare series of practical examples that directly give an explicit answer. Active involvement suits to another well-known didactical principle of practice and training. It contributes to a deeper understanding especially when it has a permanent recurrent character. For this purpose, the practical examples and the tasks proposed later to the students will be of a certain degree of complexity, so that the students can break them down into stages. Thus, we not only say and show, but also challenge the students for a creative fulfilment of tasks. In addition, we could say that the teacher may apply within each lesson the rules for a good presentation. For example: firstly we tell the students what we are going to talk about; then we present the content by underlining the main moments; then we invite the students to draw conclusions; finally the students analyse if and how the objectives of the lesson were achieved.

Knowledge of Understanding Degree

Feedback is the essence of *visible teaching and learning*. In order to be useful, it has to be mutual and simultaneous. For this purpose, the teacher divides the lesson into several sequences, so that a sequence will answer a question related to a new notion. We examine a new notion only if the previous one is understood. An offline digital assessment system will ensure the participation of all students in this ad-hoc formative evaluation, i.e., the total inclusion of students in questioning. This strategy of sequential teaching corresponds to an important didactical principle that the student must leave the classroom with the learned lesson, which means – with the scientific understanding of new concepts and inclusion of these notions in his/her active vocabulary. A good example in this sense could be peer instruction strategy (Crouch and Mazur 2001).

Anchoring New Material into the Student's Conscious and Subconscious

LBB is more concerned with deep understanding than superficial knowledge. Only "unforgettable" knowledge has a visible impact on a student's personality and lifelong learning skills. Storing a certain amount of information is impossible without structuring, which could be in the form of diagrams, tables, maps, etc. generically called landmarks, support signals, or cognitive maps (Шаталов 1979, Iofciu et al. 2010, Placing 2006). This approach corresponds to the didactic principle of intuitiveness. For example, logical connections between new concepts or terms can be easily presented nowadays using interactive whiteboard tools. The diagrams built by the teacher will contain only landmarks (expressions, symbols, images, video files), which will help to form logical connections and anchor new matter in the student's conscious and subconscious. Research shows that it does not matter who drew the support signals – the teacher or the student (Lavery 2010). However, it is advisable to involve students in the development of cognitive maps. See, for example, the experience of the e-Twinning program (Istrate et al. 2018).

Fostering Metacognition

Metacognition assumes that the students: a) analyze what strategies they will use in order to accomplish the task; b) argue why they have selected a certain strategy; c) estimate the possible result; d) analyze the obtained result; e) decide if it is necessary to change the strategy for carrying out the task. Thus, awareness and understanding by students themselves of their way of thinking in the case of learning is more than applying a learning strategy, taken from the teacher. In this way, the metacognition is equivalent to the didactical principle of consciousness of learning and closely relates to the assumption of learning objectives by the students (Kirschner et al. 2006). Like in sport when the athlete not only knows what the coach wants from him/her, but also assumes these tasks as his/her own goals and he/she has all physical, technical, tactical and emotional means to achieve the goal set initially by the coach.

Teacher's Role within LBB

Just as there is no efficient teaching without active involvement of the student, in the same way there is no successful learning without teacher guidance. Thus, the student – teacher interaction acts as a harmonic oscillator, with features determined by those of its constituents. Considering this, we examine in this section the role of the teacher in a series of learning approaches used within LBB. The impact factors of these learning approaches on students' academic achievement and the related didactical tools are given in the Table 2.

Table 2. Key Features of Several High-Impact Learning Approaches used within LBB

Learning approach	**Didactical principle**	**Didactical tools or means**	**Impact factor**
Guided self-scaffolding	Learning through effort	• IBSE • Problem – based learning	75%
Structuring of information	Consciousness	• Highlighting • Revealing the logical links	85%
Recurrent use of previous knowledge	Consistency and systemic character of learning	• Retrieval • Integration • Practice	93%
Problem solving	Active character of learning	• Analysis • Formulation of patterns	92%
Help seeking	Commitment	• Offering and asking feedback	72%

Guided Self-Scaffolding

The student's mind is far to be *tabula rasa*. Students already understand the world – in their own way, often having naive or quasi – scientific representations. In this context, we have to remind that the task of the school system is to form citizens with scientific understanding of the world. Any learning act has several stages: a) understanding; b) sublimation to the essence; c) coding; d) transferring the knowledge into the category of deep one. Without the last two stages, knowledge remains into the phase of the superficial one, volatizing rapidly and having no noticeable impact on personality development. Research shows that students had better encode new information when they connected it with their previously existing knowledge and understanding (Killian 2019). In this sense, for the effective application of this strategy based on previous knowledge, the teacher will teach the students to ask themselves the following questions about how and what they learned: a) Did it *confirm* what I already knew? b) Did it *complete* what I already knew? c) Did it *cancel* what I think I knew? d) Did it *challenge* me for deeper research? Thus, it is about activating a scheme through which new knowledge is connected with previous one. Learning with this scheme can be easily performed even in primary classes, when pupils are taught to summarize the text they read. In fact, this process lays the foundations for the formation of critical and analytical thinking, which will facilitate learning through research in middle school and in high school. In addition, this set of simple questions contributes not only to the student's understanding and assumption of cognitive objectives, but also to the formulation of their own learning objectives. Thus, the student knows which learning vector he is going to and is able to anticipate what he will learn in the near future. In this sense, we could say that the strategy of basing on previous knowledge facilitates the anticipation by the students of their future learning finalities, because the students are aware about their learning and fully assume the learning process. This is why the reliance on previous knowledge has such a big impact – 92% on the student's academic success. If in the international literature there is a talk about the scaffolding process (in the context of inquiry-based learning), then here we could introduce the term of *self-scaffolding*, which would emphasize the student's personal effort in inquiry-based learning.

Structuring of Information

It is another approach that is going to be learnt, which fully requests student's effort and involvement. The process involves the introduction by the students themselves of the titles, subtitles, bulleted lists, underlining, etc. In addition, here we could add the analysis of information coming from different sources. This is what good students do at university when they prepare for exams, but for school students, at least in middle school, it is a little bit unusual. Thus, structuring of information relates with the formation of analytical and critical thinking skills. For this reason, the permanent application in the classroom of this strategy of information structuring has a significant impact of 85% on academic success (see Table 2). We have to note that structuring is a mandatory step before understanding and memorization (Van der Graaf et al. 2019). The procedure of structuring information is similar in some extent to diagonal reading, useful in the case of a large amount of information, when the reader is forced to separate the necessary from useless. Thus, we consider if the student is get used with permanent structuring of new information, he/she is immunized against surrounding informational buzz, which has a deviant action on the motivation to learn, because it induces a false impression of knowing the subject.

Recurrent Application of Previously Learned Knowledge

Here we talk about information retrieval by applying it to understanding and studying a new situation; in other words, the practical application at a deeper level. The benefits are multiple. For example: a) learning new material in a practical way that involves the formation of sustainable knowledge about things, phenomena, and procedures; b) passing the previous knowledge from the category of operative memory into deep understanding, which also implies a certain degree of mastery in the application of research skills. We have to emphasize that this strategy is one of learning (not of teaching) where the student uses his/her research skills, formed during previous grades. This strategy is not about practice or repetition when the goal is to "strengthen the material", but it is about the student's conquest of a new fortress of knowledge with the same available weapons (skills). Therefore, recurrent application is a learning strategy that integrates previous knowledge into future ones. It is effective when students do not use textbooks or course notes, when they are alone with their skills and knowledge. It means that new knowledge is built on a stable foundation.

Problem Solving

Problem solving is an approach which has 92% impact on the students' academic success. In order to solve a problem the student must be able to:

- Understand the problem (this is proved if the student can reformulate the problem, emphasize the essential and detach auxiliary details).
- Create a plan for solving the problem (by arguing a strategy and choosing it from a number of possibilities).
- Solve the problem by following the outlined plan.
- Analyze the obtained solutions, relating them to the initial statement and data.
- Formulate a pattern or procedure for solving such type of problems.

All these verbs refer only to student. The teacher is the facilitator, site manager. We have to underline that namely permanent application, starting from primary school or even kindergarten, forms problem-solving skills, and prepares students for wide application of inquiry in middle and high school. The above-enumerated steps of this strategy require a certain degree of automatism, which can be achieved by practicing in a learning environment that promotes learning, such as, for example, the general atmosphere of empathy in the classroom, which leaves room for personal effort.

Seeking Help

Seeking help is a learning approach, which proves that the student has already taken over the learning objectives proposed by teacher and is oriented toward achieving them. It also reminds us that communication skills are a part of lifelong learning skills (Calalb 2018). Diminishing student – teacher communication factor, as seemingly unimportant compared to the immediate learning objectives, decreases the rate of academic success. Moreover, if the student seeks help it denotes that he/ she already is engaged in the lesson and there is no longer the question of demotivation, low interest or commitment to personal effort. The student who seeks help both from colleagues and from teacher is a recoverable one because he/she already is in the process of independent learning. Based on this reason, seeking help from the student part has almost double impact compared with the case of frontal teaching by an experienced teacher (72% versus 40%), which confirms once again that the most important thing in the classroom is the student's personal effort. Indeed, research shows that content knowledge level of the teacher does not have such a high impact on the students' success – about 17-19%.

Conclusions

Conceptual understanding in physics school lab is achieved through several constructivist approaches: inquiry-based learning, problem- and project-based learning, case studies or just-in-time teaching. The concept of big scientific ideas is in the base of most of these approaches. The concept of *Learning by being* is developed and is demonstrated that LBB develops and enriches the ones of *Learning by understanding* and *Learning by doing* with the student's attitude, intrinsic motivation and ownership of cognitive goals. In this sense, *Learning by being* goes beyond metacognition. According to the LBB approach, for a successful learning process we should target the assumption of learning objectives by students. Within LBB, as in *Learning by understanding*, the tools of feedback and practice are highly requested, because feedback-based strategies, such as knowledge by the teacher of understanding degree and assumption by the students of cognitive goals, have high impact on students' academic achievement. Parallel use or the overlapping of several teaching and learning techniques gives a synergistic effect. Learning by being is achieved in the frame of an environment that encourages learning effort through the atmosphere of empathy.

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