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Understanding English Language Learners' Needs in Mathematics Education

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Abstract

This study investigated the current understanding of English-language learners (ELLs) mathematics education and tried to formulate a coherent picture of this process. The paper is divided into three major parts: (a) the conceptual understanding of the relationship between mathematics learning and cognitive processes, and resulting implications for ELLs, (b) the role of language structures in teaching and learning mathematics and implications for ELLs, and (c) a discussion of proposed teaching and learning strategies for ELLs. Directions for research and holistic conclusions are also provided.

Keywords: English-language learners, mathematics education, code switching, and cognitive load theory

1. Introduction

The need to understand challenges confronting English-language learners (ELLs) when studying mathematics is certainly not new, but despite the sustained efforts of the scientific community for the last three decades or more, it still represents an issue in mathematics education today. Cuevas (1984) pointed out that "an inadequate grasp of the language of instruction is a major source of underachievement in schools" (p. 134), often resulting in underperformance of ELLs compared to English Primary students (EPs) in classroom and in standardized testing. In addition, Cuevas cited the landmark Supreme Court case of Lau v. Nichols (1974) and concluded that "students who do not understand English are effectively foreclosed from any meaningful education" (Cuevas, 1984, p. 134).

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Further, learning mathematics is a complex school activity that involves acquiring new vocabulary, manipulating new symbols and concepts in a specific context, developing new thinking and reasoning skills, and communicating the results and the steps of the deductive processes to the outside world. Some authors would even consider that "the language of mathematics can be as challenging as a foreign language" (Freeman & Crawford, 2008, p. 11). For the case of English-language learners, the difficulties associated with learning a specific mathematical vocabulary are amplified by an incomplete knowledge of English.

Moreover, the need to understand and improve upon the challenges facing ELLs is increasing. According to the National Center for Education Statistics (2012), between 1980 and 2009, the number of school-age children (ages 5-17) who spoke a language other than English in the US schools increased from 4.7 to 11.2 million, or from 10% to 21% of the population in this age group. In 2009, 5% (or 2.7 million) of children 5 to17 years spoke English with difficulty, and 73% of those who spoke English with difficulty spoke Spanish. Concerning differences by age, 7% of children 5 to 9 years, 4% of children 10 to 13 years, and 4% of children 4 to 17 years spoke a non-English language at home and spoke English with difficulty (National Center for Education Statistics, 2012). The ELL market is projected to grow at a rate of 10 % per year for the next decade, at which time ELLs are expected to represent up to 25% of the total U.S. K-12 student population - one in every four students. Ragan (2008) estimates that by 2030 the number of ELLs enrolled in American schools will be about 40% of the entire school population.

The situation becomes even more complicated if we try to differentiate among English proficiency levels of ELLs. According to Moschkovich (1999), a Latino student who is a recent arrival in the US and who missed 3 years of school in his country has different instructional needs than a Latino student who was born in the US and followed a regular school schedule. The same author also noticed that significant differences exist among the ELLs in terms of background, socio-economic status, and motivation for learning.

In an attempt to improve the level of mathematics education for all students, the National Council of Teachers of Mathematics (NCTM) published a comprehensive set of guidelines for teaching and learning mathematics at each grade level (NCTM, 2000).

The central part of the Standards is represented by the following educational principles: (1) focus on equity and excellence for all students; (2) necessity of developing a coherent curriculum; (3) need to present students with teaching and learning experiences that build on students' existing knowledge base; (4) careful assessment; and (5) seamless technology implementation.

Every state has interpreted and implemented independently the NCTM's recommendations, and in many cases contradictions and discrepancies exist. However, it is important to note that the overall result of these efforts did not lead to the expected improvement in ELL mathematics performance: "Nationwide, 82% of Hispanic fourth-grade students are bellow proficient in mathematics (56% of whom are bellow basic), increasing to 88% of Hispanic eight-grade students (50% of whom are below basic)" (Freeman, 2008, p.11).

The root causes behind the achievement gap between ELL and EP students are complex, and different authors have tried to understand various aspects of ELLs' mathematics education experience. The plethora of articles published in the field span different research directions and methods, from case studies to investigations of the psychological process involved in learning of mathematics and the role of English language structures used in the learning process. As a result of these investigations, different principles and teaching methodologies have been proposed and implemented.

The objective of this study is to investigate the current understanding of the ELL mathematics education and to try to formulate a coherent picture of this process. I also attempt to summarize some of the proposed solutions for increasing ELLs' mathematical understanding and participation. The paper is divided into three major parts: (a) the conceptual understanding of the relationship between mathematics learning and cognitive processes and resulting implications for ELLs (Gutstein, 1997; Campbell et al., 2007), (b) the role of language structures in teaching and learning mathematics and implications for ELLs (Adler, 1998; Campbell, 2007; Cuevas, 1984; Freeman & Crawford, 2008; Garrison, 1997; Moschkovich, 2002, 2005), and (c) a discussion of proposed mathematics teaching and learning strategies for ELLs (Adler, 1998; Enyedy et al., 2008; Freeman & Crawford, 2008; Morales, 2003; Moschkovich, 1999,2005; Parvanehnezhad & Clarkson, 2008; Riordain & O'Donoghue, 2009).

1.1 Understanding the relationship between mathematics learning and cognitive processes and resulting implication for ELLs

The activity of learning and knowledge formation are complicated psychological processes that have been actively studied in cognitive psychology in the last three decades.

The manner in which new information is added to the already existing knowledge is of crucial importance for understanding the process of mathematics learning in school. The new information becomes knowledge if it can be connected in a logical manner to the information already stored in brain.

At the elementary level, the process of learning mathematics can be seen as made up of two fundamental blocks: a) learning new concepts (or definitions), and b) establishing new connections (proofs, relationships, theorems) between concepts. Mathematics knowledge cannot be understood or committed to the long-term memory in isolated pieces; new concepts must be related to the existing ones in a logical manner, and based on a set of rules. In the case of ELLs, it is expected that an additional level of complexity will exist - that of translating the new information from English to the native language prior to forming connections to existing knowledge. The existing knowledge can be both formal and informal, and using it as a basis for further scientific accumulation is one of NCTM standards recommendations. Additionally, Gutstein et al. (1997) suggest that, "evidence confirms that helping teachers build on children's informal knowledge in mathematics classroom helps children use their intellect well, make meaning out of mathematical situations, learn mathematics with understanding, and connect their informal knowledge to school mathematics" (p.711). Thus, it is important for ELLs to learn new concepts, translate them to the native language, and form connections between these new concepts and their already existent set of informal mathematics knowledge.

Forging connections between mathematical concepts presented in the classroom and informal knowledge of students highlights one of the potential pitfalls for ELLs. For example, Campbell et al. (2007) presented the case of an EL pre-service elementary school teacher who had difficulties in solving a mathematics problem formulated as a baseball problem. The authors concluded that the teacher, in fact, possessed the necessary mathematics skills for solving the problem, but she did not possess the informal knowledge about the baseball game, knowledge taken for granted by the problem's authors. This particular example illustrates the complexity of the ELL situation; even if the students understand the English words, they might not always have a clear representation of their meaning in particular contexts.

Campbell et al. (2007) also point out another issue related to instruction that relies heavily on the existing student knowledge: the limited amount of memory available for storing new information. Assuming that the teacher is aware of the limitations in informal knowledge of ELLs and that she is willing to compensate for it with additional explanations, these students will have to memorize an additional amount of information compared to their English-speaking peers. By introducing this extraneous linguistic information, not necessarily connected to the mathematical concept under investigation, ELLs might run the risk of not being able to properly absorb the critical information.

Under these circumstances, it is imperative that the teacher finds a "common ground" of informal knowledge for all students before attempting to build on preexisting understandings.

The issue of extraneous linguistic information overload is present not only in the teaching process, but also in the current standardized testing process. The authors note that, “there is prima facie evidence that test writers are not linguistically or culturally aware of the difficulties that particular wording and phrasing is word problems cause students, especially those taking the tests in second or additional language” (Campbell et al., 2007, p. 13).

The key to a correct understanding of the cognitive processes involved in teaching and learning mathematics is the association between cognitive load theory and the reflective abstraction processes. Cognitive load theory is centered on the attributes of memory, either long- or short-term, while reflective abstraction represents the process of active reenactment of the learned concepts (i.e., re-thinking of the problem and committing the remodeled structures to the long-term memory). The link between these two approaches is represented by memory, and we cannot understand the process of mathematics learning by analyzing them separately. As Campbell et al. explains:

> Without attention to issues of working memory, students are doomed to suffer inefficient and unproductive problem-solving techniques… Also, unless students have a stimulus to abstract by reflecting on the operations used in the solution of a problem, they risk never seeing a more inclusive picture (Campbell, 2007, p. 15).

In their proposed framework for integrating students' culture and language in the teaching process, the authors suggest that “reflection on culture, language and socially-situated prior experiences, in addition to reflection on mathematical content and students’ cognitive processes and understandings, be incorporated into models of mathematics teaching” (Campbell et al., 2007, p. 16). The teaching process should be continuously reevaluated and comprise multiple cycles of planning and instruction implementation. This framework is considered to be especially beneficial for the ELLs: in the case when the teacher and the students are coming from different cultures, establishing a common ground requires continuous analysis and lesson planning.

Thus, the authors propose a framework for teacher education courses with four components: “ (a) academic content; (b) mathematical and cognitive processes; (c) mathematical and contextual language; and (d) cultural/life experiences” (p. 20). Academic content brings to attention the mathematical knowledge of the student – the richer this basis, the more the students will be capable of processing and analyzing new information.

The second component, mathematical and cognitive processes is concerned with identification and development of the cognitive processing skills needed for learning mathematics. Cognitive and metacognitive skills can be taught especially by using thoughtful examples, but also by questioning, planning, or drawing conclusions. The goal of the instruction, in the view of the authors, "becomes one of enabling students to take control over their own learning through the practice and development of increasingly complex processes modeled by the teacher in activities and demonstrations, and in texts and materials" (p. 22). In the case when students have difficulties in transferring strategies learned in one problem to another problem, the preferred method is the reduction of the goal specificity. According to this strategy, cognitive load is reduced because students are directed towards understanding the situation presented in the problem instead of focusing on the goal required by the problem.

The third component of the proposed framework is represented by the relationship between mathematics and contextual language. In essence, the researchers are concerned with the degree in which the language used in problems' statement corresponds to the level of the English language of the ELLs. One suggestion was for the teachers to enhance the role of the natural language in instruction because it helps students mediate among mental processes, symbolic expressions, and logical organization, as well as "finding counterexamples and in developing arguments of validity" (Campbell, 2007, p. 23).

The fourth component, cultural/life experiences, is essentially concerned with the informal knowledge base that a student needs to possess in order to understand the mathematical concepts. Since many of the ELLs are coming from a different cultural background, their informal knowledge basis cannot be taken for granted. In the above example, not knowing details about the baseball game can prove a real impediment in understanding or applying simple mathematical rules.

1.2 The role of language structures in teaching and learning mathematics and implications for ELLs

In the process of transmitting the new information to the students, the major vehicle is represented by spoken and written language. A model for the role of the first and second language in mathematical activity is presented by Cuevas (1984) in the form of a complex diagram that shows that language is situated at the intersection among concepts, mathematical notations, diagrams, and inspiration.

The language is involved in all major activities of the learning process: representation, definition, creation, discussion, instruction, description, and verbalization. The author cites previous research in emphasizing that, "researchers have found high positive correlations (.40 to .86) between mathematics achievement and reading ability… In addition, there appears to be a direct relationship across various school subjects between instruction in the student's native language and high achievement in the subject" (p. 138). Starting from this established relationship between mathematics learning and language ability, the early recommendations for ELLs were that emphasis should be placed on vocabulary and comprehensive skills (Moschkovich, 2002).

However, today the research community agrees that a successful result for ELLs in mathematics learning can only happen if the process is seen in a holistic way (rather than solely a remedial focus on vocabulary and comprehension). In a study published in 2002, Moschkovich investigated three perspective of the role of the language on the learning process: "acquiring vocabulary, constructing meanings and participating in discourses" (Moschkovich , 2002, p. 191). Each of these perspectives is based on a gradually larger encompassing concept. Acquiring vocabulary was founded on the concept of lexicon - the student must learn the correct meaning of the mathematical words and symbols. Constructing meanings was founded on the concept of mathematics register (Halliday, 1978) and was understood by Moschkovich as "a language variety associated with a particular situation of use" (Moschkovich, 2002, p. 194). The concept of register was contrasted to the concept of lexicon from the perspective of non-verbal and contextual inclusions. For example, a *quarter* was seen as 25 cents in a particular money problem or as one fourth of a whole in common situations. ELL participation in mathematical discourses was situated on both these practices (acquiring vocabulary and constructing meanings). The concept of *discourse* represents more than words (lexicon) and meanings (registers), because it refers also to models of action, thinking, reasoning, and communicating, such that, "mathematical Discourse practices can be understood in general as talking and acting in the ways that mathematically competent people talk and act" (Moschkovich, 2002, p. 199). While vocabulary and registry are in general stable, mathematical discourse, as a situated-sociocultural perspective, depends on a variety of factors. The author suggests that by shifting the focus of instruction from simple vocabulary and registry learning to a mathematical discourse, teachers can help ELLs to focus on mathematics learning.

Issues of vocabulary and registry are also considered by Campbell et al. (2007). In terms of vocabulary, the authors note that in many cases, ELLs' language proficiency might be one to three levels below that of their mathematics proficiency. Even in the case when the language and the mathematics levels are compatible, the teachers still should pay close attention to the registry. The meaning of words in the natural language might be completely different in mathematics language. For example, words like *table* or *division* are used differently in natural language than in mathematics language (Campbell et al, 2007)..

Moreover, Adler (1998) argues that "even within a mathematical register, meanings shift" (p. 28). The example analyzed by the author is the word *most*, which in early mathematics learning is argued to be associated with the term *more* or equivalently with the expression *greater than*. But in some specific cases, for example when used in the construct *at most*, the same word has exactly the opposite meaning and becomes the negation of *greater than*.

While Moschkovich built the concept on learning mathematical vocabulary in an inclusive manner (from vocabulary to registry to the role of mathematical discourse), other authors considered a leveled approach to mathematics instruction for ELLs. In a study published in 1997, Garrison presented four equally important perspectives in learning mathematics: (a) mathematics as problem solving, (b) mathematics as communication, (c) mathematics as reasoning, and (d) mathematical connections. In this approach, the NCTM standards emphasizing language development for ELLs are in agreement with the current teaching strategies in bilingual education. The author suggests that the complexity of the language in a lesson can be reduced by using a combination of strategies such as: "providing a rich context environment, using manipulatives, preteaching vocabulary, and allowing students to work in cooperative groups" (Garrison, 1997, p. 136). Among these techniques, providing a rich context environment is argued to be most helpful for ELLs to infer the meaning of unfamiliar words. Moreover, the author suggests that groups of related words can be taught through mathematics.

The idea of teaching English language through mathematics was also explored by Campbell et al. (2007). For example, a good deal of research had been dedicated to exploring and implementing Cummins' assumption that an ELL who masters the mathematical concepts in his/her own language would then be able to use them for English learning. However, Campbell and colleagues warn that "one of the limitations of a language-content approach to lesson and material analysis is that the language analysis tends to be at the surface level" (Campbell, 2007, p. 19) and that ELLs are best served if the main focus of the lesson is on mathematical content.

Similarly, Freeman and Crawford (2008) argue that, "a distinction between social language (basic interpersonal communication) and cognitive academic language is essential to understanding why teachers need to take a special approach toward the teaching of mathematics to ELLs" (Freeman & Crawford, 2008, p. 12). The study points out that the use of a simplified language in mathematics classes showed positive results, but the authors warn against a simplification of the mathematical concepts that must be taught. They also argue that mathematics teaching must be also associated with vocabulary building.

1.3 Discussion of proposed mathematics teaching and learning strategies for ELLs

The presented analysis of the role played by the cognitive processes and language structures in mathematics learning gives a glimpse of the complexity of the problem and of the difficulties faced by ELLs. It is therefore disheartening, but unsurprising that, as Garrison (1997) points out, "Hispanics, a group with many emergent English speakers, have not excelled in mathematics and are significantly underrepresented in all scientific and engineering careers" (p.132). The need for a workable solution has resulted in different authors suggesting different methodologies in order to alleviate the problem. In this section, several key strategies are outlined.

Freeman and Crawford (2008) proposed a methodology which focuses on a small set of sheltered instruction key strategies, and their paper presents a Web-based supplemental curriculum designed around these strategies, called Help with English Language Proficiency (HELP). Some of the key points the study suggests are an increased comprehensibility of mathematical presentation, a focus on vocabulary and a scaffolding approach in presenting new facts, as well as an increased student-to-student interaction, and a closer connectivity between mathematics and the existing students' experience.

From the Moschkovich (2005) perspective, one frequent phenomenon among the bilingual mathematics students is represented by *code switching*. *Code switching* occurs when bilingual students switch languages when performing arithmetic computations, thereby reducing the time necessary for calculation. It has also been well-documented that bilingual students need more time to retrieve the same information in the second language (English) when compared with the native speakers. Based on these observations, the author suggested that instructors should allow students, whenever possible, to choose the preferred language for carrying out arithmetic computations. Furthermore, a delayed response from a bilingual student should not be considered as evidence for a low degree of preparation or mathematical proficiency, but rather as potential evidence that the student is not engaging in *code switching* and is attempting to solve problems in the non-native language.

Interestingly, the same study provides evidence that bilingual students may have developed specific skill sets to offset the difficulty of performing tasks in their non-native languages. For example, they have better selective attention, allowing them to ignore misleading clues. They also are more practiced and thus more proficient at translation skills, such that the children "use high level sophisticated translation skills between two languages" (Moschkovich, 2005, p.128). Mathematics educators should take these skill sets into account.

A similar view of *code switching* is shared by Adler (1998). The author constructed her article as a challenge to the misconception that the reason for successes or failures in school mathematics should be only looked for in the minds and abilities of the learners or teachers. The dilemma of *code switching* is analyzed from the teachers' perspective. On one hand, teachers feel that explaining the mathematical concepts in the native language of the ELLs might help them to better understand the material. On the other hand, since all the official testing as well as the future mathematical applications are written in English, the students will have to re-learn the same concepts in this language. In acknowledging the multiple benefits of the *code switching*, the author suggests that it "is not a matter of whether or not to code-switch, nor whether or not to model mathematical language, but rather when, how and for what purposes" (Adler, 1998, p. 30).

The idea of *code switching* is also discussed by Parvanehnezhad and Clarkson (2008), who discovered that the context in which this happens is related to the type and difficulty of the problems presented to the students. While the authors found no relationship between the difficulty of the problem and the frequency of the *code switching* for open-ended problems, it was demonstrated that in the case of word problems, students would increase the number of times when they would switch to the first language as the difficulty of the problem is increased. The authors consider that a possible explanation for this behavior is that the students would prefer to perform the numerical computations in their first language. The same authors were also able to confirm that students who were proficient in both their maternal language and English were also more proficient in mathematics.

In a separate study, Riordain and O'Donoghue (2009) reached a similar conclusion: Irish students who were most proficient in both Irish (Gaeilge) and English were also most proficient in math. This finding offers support for the Thresholds Hypothesis elaborated by Cummins (1976). This hypothesis predicts that a bilingual student must reach a threshold level of proficiency in both languages in order to a) avoid cognitive deficits and b) make efficient use of both languages for learning new concepts and solving mathematical problems. In other words, *code switching* is an efficient use of ELLs' language skills and should be encouraged.

The same study determined that English proficiency and mathematics performance were significantly correlated ($p < 0.05$) and the degree of correlation increased with the students' age/grade level.

Similarly, Morales et al. (2003) argue that teaching is more than a simple linguistic communication between teachers and students. Instead, they argue for use of a multimodal teaching strategy. The rationale behind this suggestion is the manner in which the new information is transformed into knowledge. From the complexity of signs used by the teachers during explanations, the students are continuously reshaping and adapting the information to fit into their existing knowledge matrix. The authors explain that, "the richer the complex of signs, the more resources the students can select and use to make new meanings" (Morales et al., 2003 p. 134). The authors present the case of a fifth-grade bilingual student who solves a geometrical problem by continuously constructing meanings while moving between written text, spoken text, geometrical figures, and his hand-held calculator (mathematical symbols). Based on these observations, the authors recommend that teachers use multiple communication channels in order to improve the ELLs' mathematical understanding.

Moschkovich (1999) addresses the problem of mathematical learning by Latino population from the perspective of mathematical discourse. According the NCTM standards, the emphasis in mathematics class should depart from the traditional "silent and individual activities … to more verbal and social ones" (p. 6). This new emphasis placed on students' mathematical discourse is expected to modify the way in which teachers approach instruction. However, for ELLs, this recommendation is seen as a double-edge sword. On one hand, it will provide them with more opportunities to participate in meaningful discussion and consequently improve their language skills. On the other hand, there is a higher risk that they will be assessed as being deficient in the mathematical field. The author also points out that "a student's overall proficiency in one language does not necessarily reflect proficiency in mathematical discourse in that language" (p. 8) and suggests that the Latino students will benefit from Spanish translations. In the case in which the students have already learned mathematical concepts in Spanish, the bilingual translation will help make the transition much easier. For those who do not know the material, translation can help also to increase the Spanish proficiency.

The author suggests four ideas that can help Latino mathematical instruction: "(1) honor the diversity of Latino students' experiences, (2) know the students and their experiences, (3) avoid deficit models, and (4) provide opportunities for mathematical discussions" (p. 9). Given the large diversity of Latino students, it is expected that they will have different backgrounds and informal knowledge.

As was also suggested by Campbell et al. (2007), finding a common background for all the class participants (including teachers) can prove to be vital for the success of the instruction.

In the context of multilingual classrooms, one way to establish a common ground for all participants is represented by *revoicing* (Enyedy et al. 2008). Traditionally this procedure has been seen as a way of enhancing the class participation in mathematical discussions. However, in addition to this, the authors also find that *revoicing* plays a positive role in other class functions. *Revoicing* can be important in the case when ELLs do not have the linguistic abilities necessary for an effective participation into the mathematical discourse; the teacher can help make their ideas heard by the rest of the group and thus allow them to be perceived as competent members of the mathematics learning community. The authors introduce the concept of *revoicing to position* in recognition of the fact that one of the functions of *revoicing* consists in positioning the speaker's ideas in relation to a) the general mathematical context, b) other people ideas, and c) the particular task at hand.

2. Conclusion

The literature surveyed in this essay leads to the conclusion that a solution to improve the ELL mathematics performances cannot be found if we do not approach this problem from a holistic perspective. In analyzing the cognitive processes, different authors (Gutstein, 1997; Campbell et al., 2007) revealed the role of informal knowledge for mathematics understanding and the role of reflective abstraction processes in knowledge transformation and memorization.

Despite these encouraging results, the field of cognitive psychology still must seek to answer some important questions: (a) Which are the factors that motivate ELLs to engage in the effort of actively transforming their mathematical knowledge? (b) What is the most efficient way of transmitting the new knowledge to ELLs (e.g., visually, by written or spoken methods, diagrammatically)? (c) How much emphasis should be on the previous informal knowledge and how much on the formal previous knowledge? The effort to teach and understand mathematics should equally be made by both teachers and students. Yet, much of the success of learning depends on the student's willingness to spend time in studying. The language barrier can many times act as a deterrent from this commitment, especially in the case of students with a poor vocabulary.

The mathematical curriculum needs to offer ways to alleviate this problem by simplifying the vocabulary (Freeman & Crawford, 2008) and combining complementary ways for information transmission (Morales, 2003).

Understanding the way in which the language structures can assist teaching mathematics to ELLs (Addler 1998; Moschkovich, 2002) is imperative and the research needs to focus in this direction. One of the NCTM recommendations is to engage the student to participate in the mathematical discourse, but much still needs to be done to understand the transformation process from the simple vocabulary to mathematical expertise. The words in a language are just a fast way of communicating meanings. Moreover, the communication is efficient if both the sender and the receiver agree in advance upon their meaning, or the message will be distorted. ELLs, who do not have the benefit of learning these meanings in a natural way, must perform a cumbersome translation into their first language. A word with multiple meanings in English will be associated with a set of different words in the students' maternal language, and this can work as a deterrent against registry formation and discursive practices.

The suggestions made by various authors are centered on the idea of finding multiple ways for knowledge transmission and a careful evaluation of the students' informal knowledge base. The role of the teachers, as mediators among possibly multiple cultures in the same class becomes extremely complex, and in many cases they are not bound to success if the research and the society do not offer them all the assistance they need.

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