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Teaching Mathematics and Computer Science

Didactical remarks on the changes in the requirements of the matriculation exam in Mathematics in Hungary

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Abstract. Students within the Hungarian education system typically take a matriculation exam to obtain a secondary education certificate, which also serves as a prerequisite for university admission. Public education is regulated at different levels. One of its most fundamental elements is the National Core Curriculum, the current version of which came into force in September 2020. It is crucial to adapt the requirements of the matriculation exam in mathematics to this and ensure transparent communication about the changes. Regarding this, there exists a sample paper that contains tasks that one can reasonably expect in the actual exam in the spring. Since I have been working as a private math tutor for almost a decade and have been preparing students for the matriculation exam since then, I intend to highlight the most outstanding features from a didactic point of view based on the analysis of this sample paper.

Key words and phrases: matriculation examination, matura, curriculum reforms, public education, secondary school mathematics.

MSC Subject Classification: 97A30, 97B10, 97B70, 97D60, 97U40.

Regulatory documents for education in Hungary

In public education in Hungary, a dual-pole curriculum management system has been in operation since 1989, preceded by a centralized approach. This means that both central and local decisions are made, and the curriculum regulation itself is implemented at three levels (Vágó & Vass, 2007), with one of its most essential components being the National Core Curriculum (NCC). This document is centrally developed, approved, and universally applies to everyone concerned.

It is published in the "Hungarian Gazette" (Magyar Közlöny), which is a periodical, official journal of Hungary. The NCC undergoes review and revision regularly; the versions released so far are from 1995, 2003, 2007, and 2012, and the current one came into force in 2020. It covers every grade and field of competence, outlining the key principles, goals, and developmental tasks. Its main function is to define a common base of knowledge and create equality and unity in public education. It does not deal with the guidance of daily pedagogical practice, as it falls within the scope of the Framework Curriculum, which, by compiling the general concept of the NCC, makes it locally applicable and has been part of our education system since 2000. (Lukács & Tompa, 2002)

The matriculation exam of Mathematics in Hungary

Students aged between 17 and 19 usually take a matriculation examination at the end of their secondary education, which has various names across the globe. We generally use the term 'matura' or 'érettségi' in Hungarian, just like in a great deal of other European countries centered around the former Austro-Hungarian Empire, but we also often refer to it as 'school-leaving examination' or simply 'final exam' (Csapodi, 2016). Passing it is a prerequisite for obtaining the Hungarian "maturity certificate" or 'érettségi bizonyítvány', which is mandatory for admission to universities or other institutions of tertiary education, and considered a crucial qualification in the job market in Hungary.

Hence, in the Hungarian Educational System, the matriculation examination has a dual purpose, serving as a closure of secondary school studies and, in case of further education, an entrance examination at the same time. It is centrally standardized, and the same requirements apply all over the country to ensure fairness and consistency. Mathematics is a compulsory subject, but candidates can choose the level of the exam. This two-level exam was first introduced in 2005, coinciding with the abolition of separate university entrance exams, and has been operating since then. The intermediate or standard level measures basic knowledge, while the higher or advanced level requires deeper analytic skills and covers topics that are excluded from the intermediate level. The exam does not necessarily have to be taken in Hungarian; candidates can freely choose its language.

The matura from Mathematics is primarily a written exam at the intermediate level. However, at the advanced level, students must take both a written and an oral exam. This oral component is particularly significant as it allows students to articulate and defend their knowledge, demonstrating a deeper understanding of the most important concepts learned during public education.

All official documents related to the matriculation exam can be found on the website of the Hungarian Educational Authority. This administrative body established by the government is in charge of coordinating public and tertiary education in many respects.[1] The new exam requirements, which are based on the National Core Curriculum 2020 and will be uniformly applicable to everyone from the exam period of spring 2024, can also be found here. This document contains detailed declarations of the expected competencies and describes the exams on both levels, but it is only available in Hungarian.

As mentioned before, the National Core Curriculum is one of Hungary's essential regulatory documents for public education. Its recent changes have led to different levels of transformation in the matriculation exam for each subject, involving a revision of the detailed exam requirements. In Mathematics, the most remarkable changes have occurred on the intermediate level, which also concerns most candidates, as only approximately 5-10% of the students opt for the advanced level each year. Therefore, we exclusively focus on the intermediate level in this paper. (Csapodi & Filler, 2017)

Unlike in other compulsory subjects, Mathematics has not undergone significant changes; only minor modifications have been made. In general, content that has been excluded from the intermediate level has been retained at the advanced level, with only a few exceptions. Additionally, new material from the curriculum has been introduced into the requirements at the intermediate level.

The structure of the exam

Complexity, in a mathematical sense, is one of the unique advantages of the Hungarian teaching traditions of Mathematics, which was established by Tamás Varga in the 1960s-70s. He distinguished five main topics, which were 'Thinking methods (sets, logic, combinatorics)', 'Arithmetic and algebra', 'Relations, functions, sequences', 'Geometry', and 'Probability, and statistics', but also intended to emphasize the coherence of different domains and the rich intersections between them (Gosztonyi, 2020). The requirements of the matriculation exam in Mathematics deal with almost the same areas. These are not sharply separate from each other either; to solve a problem, one must merge concepts of different

[1]For more information about the Hungarian Educational Authority, one can refer to https://www.oktatas.hu/projects_educationalauthority

ones and apply them simultaneously. Therefore, their given proportions serve only as guidelines.

The 5 topics, with their approximate proportion in brackets, are:

(1) Methods of mathematical reasoning (20%): operations on sets, mathematical logic, combinatorics, graphs.

(2) Number theory, Algebra (25%): arithmetic, divisibility, basics of algebra, i.e., powers, roots, concept of logarithm, algebraic fractions, use of formulas, percentages, equations, inequalities.

(3) Functions (15%): relations, different types of functions, arithmetic, and geometric sequences.

(4) Geometry (25%): geometrical calculations in 2D and 3D, trigonometry, coordinate geometry.

(5) Probability and Statistics (15%): descriptive statistics – data visualization included, classical probability.

It is also regulated centrally that 30-50% of the problems should be related to everyday life situations that require simple mathematical modeling techniques. Open-ended questions dominate the written examination, complemented by some closed tasks, mainly in the first part, exclusively on the intermediate level. On this level, in Hungarian, candidates have 180 minutes to complete the test, which is not divided equally between the two parts of which the exam paper consists, and the second part can only be distributed after the first one has been collected. To do so, students are allowed to use, i.e., a calculator, which cannot store and display textual information, and any edition and number of the so-called "4-digit Data Booklet", which is a print collection of the most important formulas and tables. The maximum number of points that can be achieved is 100.

The first part contains 12 short questions focusing on basic concepts, definitions, and simple computational skills. The emphasis in this section is mainly on the final answers. Only a few of the problems require detailed solutions and if one does, it is always clearly indicated by its instructions. Students have 45 or 57 minutes to complete it, depending on the language of the exam, and the maximum achievable points are 30.

The second part consists of 3 mandatory questions, each worth 9-14 points, followed by 3 problems, from which students are required to solve only 2, for 17 points separately. Each question has more sub-tasks, which can be solved independently. Here the reasoning used to obtain the answers is always a must, and most of the scores will be awarded for this. The maximum score is 70, and the time limit is 135 minutes, and 169 for the foreign language examination papers.

At the intermediate level, an oral exam occurs only if the candidate achieves at least 12 points on the written exam but remains below 25 points, the maximum achievable score being 50.

Analysis of the sample paper

One of the two purposes of this analysis is to provide a brief overview of the current status of the Hungarian matriculation exam for researchers who may not be familiar with the system, the other is to highlight the most important aspects of the changes from a didactic point of view. Additionally, I hope this article might also provide students and their teachers with a clearer understanding of the expectations they need to meet from now on.

One of the most noticeable changes regarding the sample examination paper (Mathematics Sample Paper at Intermediate Level) could be its new separation. It is essential to note that this will not be present in the matriculation exam in May 2024. The first part will still consist of 12 short tasks, typically requiring only the result, and the second part will follow without any modifications in its format.

Therefore, there will be three mandatory problems up to Task 15, and out of the last three, candidates still need to solve merely two of their choices, indicating in the designated area the number of the problem not to be assessed. If the selection is not made, or not explicitly evident from the student's work, the task that is not to be assessed will automatically be the last one in the examination paper.

Although the test's structure differs from the standard, there is no reason to assume that these modifications, such as the absence of the blank rectangles for the answers in the first part, will show up in the written exam itself either.

Didactical remarks on the first part

The first three tasks belong to set theory, graphs, and combinatorics and show complete consistency with the former problems from the past years, since there have been no significant changes in the requirements in these topics, except for the inclusion of the practical application of the degree sum formula of graphs, and the inclusion-exclusion principle to determine the number of elements in the union of two or three finite sets. The latter could play a significant role in a new type of task, where a triple Venn diagram, for instance, cannot be filled in full directly from the text, and one should determine the sum of the cardinalities of the intersections of any two sets.

One noticeable aspect of the combinatorial task is that it deals with the squad selection for the Hungarian team preparing for the 2021 UEFA European Football Championship, aiming to make the question more exciting. Although the situation itself is not realistic, only plausible, tasks dressed up in this manner can still capture students' attention and provoke sympathy. (Ambrus, n.d.)

PROBLEM. *The base-*10 *(decimal) form of a number is* 2021*. Write up this number in base-*8 *(octal) form.*

This task is brand new. While in the past, at the intermediate level, we solely required transitions between the binary and decimal numeral systems, almost exclusively in foreign language tests, the new curriculum now expects knowledge of the conversion between the decimal system and any base-n numeral system, where $2 \leq n \leq 9$, $n \in \mathbb{N}$, and equips students with a deeper understanding of how numeral systems work.

Numeral systems today play a crucial role primarily in informatics and computer science, where the binary, octal, and hexadecimal number systems are mainly used. The fact that the octal number system appears in the sample problem set could, of course, be a coincidence, but the number 2021 might have been used deliberately, since the sample exam paper was published in that year.

PROBLEM. *The second term of a geometric sequence is* 2*, and the fourth term is* 4*. Determine the sixth term of this sequence. Explain your answer!*

The type of problem that inquiries about the n-th term of a geometric or arithmetic sequence can also be familiar from the previous years. Although the formula for the general term still seems evitable due to the small indices, my teaching experiences show that students prefer substituting values into the formula instead of using the stepwise approach.

PROBLEM. *Graph the function* $f : x \mapsto |2x - 4|$ *on the interval* $[1; 4]$.

Students are required to graph a function defined on a closed interval in the above task. While the absolute value function, among many others, has been elevated to the advanced level, taking a function's absolute value has shown up, expanding the range of the necessary function transformations. Correspondingly, an arbitrary quadratic, the $\sqrt{x}$, the $\frac{1}{x}$, or an exponential function can be considered.

Problem. *Give the lower and upper quartiles of the sample:* 1, 1, 2, 2, 3, 3, 3, 5.

One of the most significant changes has occurred in the field of statistics, in line with our 21st-century data-driven society. Quartiles have been introduced in addition to the former measures, such as central tendencies, including the mean, mode, and median, and measures of variability or dispersion, e.g., standard deviation and range, that were used to describe a data set. In contrast, the weighted arithmetic mean and the mean absolute deviation (MAD) have been excluded. The short task particularly requires the calculation of quartiles from a sample containing 8 data points. There is a general lack of consensus in determining quartiles, so values obtained by spreadsheet software, e.g., MS Excel, or different calculators may differ from what is taught in school. Although the difference is irrelevant for large datasets, it is crucial to compute them according to the curriculum. First, one must arrange the data in ascending order, which was already given in this example. Then, in the case of an even number of elements, taking the median of each sub-population divided by the median, and in the case of an odd number of elements, doing the same after omitting the median itself. Additionally, it is still being determined whether quartiles will be included among the statistical measures, like the mean and standard deviation, for which calculators can be used without further mathematical justification.

It should be noted that although the task mentions a sample, students are not expected to be able to distinguish the population from the sample.

Problem. *The cosine of an acute angle is* 0.6*. What is the cosine of its supplementary angle?*

It is essential to draw attention to the fact that although the general definition of trigonometric functions, the concept of negative angles, and trigonometric equations have also been elevated to the advanced level, at the intermediate level, the calculation of angles from the given value of their trigonometric functions by a calculator is still expected. Furthermore, students are also supposed to be able to deal with obtuse angles given their supplementary angles' sine or cosine value.

This may be particularly relevant to the law of sines. However, it is uncommon in the matriculation exam to have two triangles, acute and obtuse, that satisfy the given conditions. Finally, degrees have become the only way to measure angles at the intermediate level, and radians have moved to the advanced level.

Another noteworthy change has occurred in the topic of coordinate geometry, which also caused many difficulties for students in the past (Csapodi & Koncz, 2016). There is no longer a need to determine the trisection of a segment or the centroid of a triangle. The equation $y = mx + b$ (and $x = c$) of a straight line has remained the only form that is required henceforth, meaning that determining the equation of a line passing through two given points can be expected, as it is needed in the sample examination paper. The two points can be arbitrary and do not necessarily have to be on any axes.

In addition to the exclusive knowledge of the above form, a line's slope (grade) and the relationship of the slopes of parallel and perpendicular lines can also be assessed. Even though normal vectors and direction vectors are no longer required, in my experience, they are still taught in many classes.

The equation of a circle can only be required with its center and radius, or possibly with the length of its diameter or with the two endpoints of the diameter. Retrieving them from a quadratic equation is no longer an expectation. Determining the intersection of a circle and a line or the equation of the tangent drawn to a circle is no longer necessary either.

The 12th Problem is, not surprisingly, probability calculation. The array of knowledge related to this topic has significantly expanded. From now on, one must know the following: elementary event, sum, and product of events, the complement of a given event, as well as mutually exclusive and independent events. Broadening this topic is well-founded if we desire to bring school material closer to the real world.

Although the problem requested the calculation of the probability of the joint occurrence of independent events, it can also be solved using the classical combinatorial model. The answer key provides both approaches. However, it may not be evident from students' work if they were aware that the relationship

$$P(A \cdot B) = P(A) \cdot P(B)$$

holds exclusively for independent events.

Didactical remarks on the second part

Usually, Task 13 involves some equation, inequality, or system of equations. This is no different in the sample problem set, where a simple exponential equation appears for 5 points in part a). It may catch someone's eye in the answer key that only providing the exact solution $x = \frac{4}{3}$ is acceptable, and no point is awarded for a rounded value. This is a bit unusual because earlier, the following viewpoint applied: 'If the text of the problem does not instruct the candidate to round their solution in a particular way, any solution rounded reasonably and correctly is acceptable even if it is different from the one given in the answer key.' It also needs to be clarified whether the solution's justification can still be replaced by checking the equation's domain and referring to equivalent transformations. Evaluation is already a subtle component of the matriculation exam in Hungary; therefore, substituting the obtained result into the original equation is suggested in every case to check the solution.

Task 13 b) highlights the domain of the equation. Although drawing attention to it in this manner is undoubtedly beneficial for the candidates while still assessing their understanding of the concept, this hint should fade away as students get used to it.

Problem 14 measures more advanced statistical knowledge. It involves interpreting a box plot, also called the box-and-whisker plot or the box-and-whisker diagram. It is an entirely new component, just like determining the truth value of the related statements. A box plot is a standardized way of displaying the dataset based on the five-number summary: the minimum, the maximum, the sample median, and the first (or lower) and third (or upper) quartiles, and commonly used since its introduction in 1969 in real world's statistical and data analysis. The next level of statistics would be selecting the most suitable type of diagram for representing the given data and justifying this choice. While this requirement is already in the curriculum, compared to the statistical knowledge examined so far, this step would be too significant to make for now. Therefore, it is appropriate that only the correct interpretation of the statistical measures be assessed, which already goes beyond the former depth of this topic when we exclusively asked about their computation. Emphasizing their meaning can bring students closer to understanding the reasons behind teaching mathematics and its connection to real life. Recognizing and correcting graphic manipulations in diagrams deserve special mention; their practical utility is unquestionable. However, this skill is only included in the curriculum and has yet to appear among the sample problems.

Henceforth, proving simple statements and theorems becomes requisite at the intermediate level. This includes exponential identities, but only for concrete bases and positive integer exponents, formulas for the sum of the first n terms of arithmetic and geometric sequences, the theorems related to the point of intersection of the perpendicular bisectors of a triangle (called circumcenter) and the three angle bisectors (called incenter), the Pythagorean theorem, the formula for the number of diagonals of an n-sided polygon, the sum of interior and exterior angles, Thales' theorem, also known as the intercept theorem, and the law of sines. However, these proofs of statements and theorems will only be part of the oral exam for the present.

Although the statements to be proven in the written exam are more of the type 'Justify your answer by calculation' or 'Demonstrate by calculation', rather than providing a deductive proof, the previously intentionally omitted term 'Prove' can also appear hereafter. Despite the word choice, it still means only approving by calculations or verification with logical reasoning. The statement itself can come from a wide range of areas of mathematics, including, for example, geometry, number theory, or even graph theory.

The term 'prove' appears in Question 15. At first glance, it might seem more severe. However, it is important to remember that it is just a matter of demonstrating understanding through calculations and logical reasoning. If students are not aware of what is exactly expected from them as accomplished proof, they might overthink its depth and, therefore, not attempt to solve the problem at all. That is why it is crucial to make the above considerations clear for every interested party.

The shifting of the expected value from the advanced level to the intermediate level is another improvement in the curriculum. Task 16 contains details of a fictional lottery offering tickets with different prizes at a selling price of 300 HUF, and the question is the expected value of the profit per ticket from the company's side. The information that profit for the company should be calculated as the difference between the selling price of tickets considered as revenue and the prizes the company must pay after winning tickets as cost is included in the text for enhanced comprehension. One approach is converting the frequencies of each type of winning ticket into probabilities, then using these as weights to compute the weighted average of the different amounts that can be earned, and the other takes the given frequencies from the table without any modification and divides by the total number of tickets at the end of the calculation. The fact that tasks related to savings, investments, and loans, along with their risks, are becoming considered in both the curriculum and assessment can be attributed to improving financial education. In addition to compound interest, determining annuity and installment will also gain fundamental importance. Previous years' advanced-level problem sets can be an adequate resource for practicing tasks involving these two new elements. We talk about annuity when we regularly increase a starting value by the same amount in equal intervals, for example, putting a fixed amount annually in a savings account every year, where an annual compound interest applies to the ever-growing amount. In the case of installments, we repay the borrowed amount at equal intervals and in equal portions, gradually reducing the outstanding loan balance and accumulating compound interest over time.

In Hungary, students heading to tertiary education or the job market must have adequate financial literacy, and these tasks play a key role in their development.

However, the evaluation and appropriate scoring of these tasks need a more thorough consideration than in the sample exam paper, or the task requires a higher level of awareness to ensure meaningful usage of the corresponding formulas found in the "4-digit Data Booklet".

In part b) of Problem 17, for instance, 7 points can be obtained for the correct calculation of the annuity. However, simply substituting into the appropriate formula certainly does not serve the original aim of the task. While most of the points are allocated based on a detailed solution path rather than the obtained result itself, and the traceability of intermediate steps is highly recommended, the question arises whether the formula from the "4-digit Data Booklet" can be transferred without further consideration, making the process of tracking it from period to period unnecessary. The task itself is as follows:

Problem. *Dóri's parents decide to deposit* $100,000$ *HUF at the beginning of each year for 18 years, with the above-mentioned compound interest rate (4% annually), to cover their newborn child's tertiary education expenses.*

b) *Demonstrate that this way, by the end of the 18th year, there will be more than* $2,600,000$ *HUF in the account!*

Substituting into the formula $S_n = a \cdot q \cdot \frac{q^n-1}{q-1}$ gives us the value of the annuity growth a at the end of the n-th year, assuming that the deposits occur at the beginning of each year, which is the correct final result.

Problem. *During Dóri's university studies, she wants to use the accumulated amount to cover her expenses.* $2,600,000$ *HUF is initially deposited in an account,* *from which she plans to withdraw equal amounts annually for six years at the beginning of each year. The remaining balance on the account continues to earn* 4% *compound interest at the end of each year. Her goal is to withdraw the last amount of the* $2,600,000$ *HUF right at the beginning of the sixth year and empty the account with it.*

c) *How much money should Dóri withdraw at the beginning of each year to achieve her goal? Provide your answer rounded to the nearest hundred HUF.*

The above problem can be seen as a reverse installment construction, where Dóri lends her money to the bank, and the financial institution "repays" it for her annually in equal amounts. It is essential to note that while the loan repayment typically occurs at the end of a given period, here, the outstanding balance decreases by the same amount x at the beginning of each year, which does not imply a relevant difference. Therefore, the process is essentially the same as repaying a loan, where the initial amount is $2,600,000 - x$, and this amount will run short by the end of the 5th year, equivalently at the beginning of the 6th year. Although this thread makes it unnecessary to track the process annually, realizing the analogy requires such a deep understanding of the topic that, in my opinion, it would fairly be awarded by the total 7 points that can be achieved by solving the task comprehensively.

Undoubtedly, the original intention of the task is clearly to make the student model the path of money from one period to another. They are also meant to recognize that the total amount obtained in this way is the sum of the first n terms of a geometric sequence, for which the formula S_n can be applied. All of this, however, can be avoided by substituting into the appropriate formula, and it is almost impossible to say afterward if the choice was conscious or not.

The 18th Task contains only parts a) and b), which is unusual, taking the structure of past years' tests into consideration. This was more common in the initial few years after the two-level matriculation examination had been introduced. Back then, the exam was characterized more by problems with higher points and fewer and more interconnected subtasks. The distribution and independence in terms of solvability speak for themselves – this way, a great number of points does not depend on a single good idea or, contrarily, its lack, and any errors that may occur will not be carried forward, so having a poorer understanding of some topics does not determine a low overall score. A great example of the above-mentioned attribute is when instead of asking for the measure of an angle in a particular subtask, its value is given afterward, and candidates are 'only' required to prove it by calculations, making it possible to use this information for the next sub-problem even if they were not able to get it on their own. Preserving these characteristics is not only a feature to be maintained but also an expectation since 2017, in addition to the advantages mentioned above.

Geometric probability is another entirely new concept, that helps us deal with a problem with infinitely many outcomes, without detailing continuity, by measuring the number of outcomes geometrically, in terms of length, area, or volume, in 1D, 2D, or 3D, respectively. It provides a helpful approach by transforming probability problems into geometry problems. Thus, the probability of an event can be obtained by taking the measure of the set of points corresponding to the event and dividing it by the measure of the total outcome space.

One of its classic examples is shooting at a target, where hitting the target itself has a probability of 1. It could seem odd that hitting a specific point on the target has a probability of 0. However, this event does occur. This may take some time for students to cope with, as in the classical model, only the probability of an impossible event equals 0.

Given the significance of geometric probability, it should be placed among the compulsory tasks. Introducing it gradually can be less risky and more manageable, especially within simpler problems. In this context, 6 out of the 8 points are for the geometry calculations. However, if students are not familiar with the new concept, they might struggle to start and may not attempt to solve the problem at all. Geometric probability is even more powerful when we apply it to problems that are not inherently geometric. Thus, in the future, it is suggested that we go beyond geometric objects, e.g., calculating the probability of catching the bus if you show up at 12:30 and the bus comes randomly between 12 a.m. and 1 p.m.

Discussion

From the analysis of the sample paper, it can be seen that the requirements of the intermediate level have not undergone any fundamental development. One should also examine last fall's exam, as one question sheet obviously cannot cover every aspect of the changes. Here, a quadratic inequality over the set of integers, a financial problem that includes compound interest, and the calculation of the region between two concentric circles can be found. The appearance of these types of tasks already predicted the upcoming changes. Solving previous years' test papers can also be an efficient way to prepare for the matriculation exam, thanks to the high level of similarity in the types of problems.

The purpose of the development of the NCC was undoubtedly to place even greater emphasis on mathematical modeling, and to encourage students to take what they have learned and apply it to different situations. This process began in 2005 and has continued ever since. Given that one of the most criticized aspects of Hungarian education is its excessive focus on declarative knowledge (Csapodi & Hoffmann, 2021), this shift is quite promising. Although I agree with this direction, and the same trend can be observed in tertiary education and the job market, it also widens the gap between the intermediate and the advanced levels. My concern is that, at the intermediate level, the reduction of the curriculum will not enhance understanding of the remaining concepts but will lead to a lack of comprehensive and in-depth apprehension.

Finally, it should be noted that the current problems that relate to real-world situations are immensely oversimplified models of reality. For example, the essence of statistical analyses is lost because, instead of using real large datasets, one can only deal with a few numbers by hand. Integrating digital tools could offer a solution to this issue. (Trgalová et al., 2018)

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