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Perception and suggestion of the use of Concept Maps in Ordinary Differential Equations[1]

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ABSTRACT

This article presents a research carried out with 92 university students from the Engineering course at the University of Brasília with the main objective of evaluating the use of Conceptual Maps as a didactic resource in the teaching of Ordinary Differential Equations based on Ausubelian theory, which consists in the acquisition of human knowledge through a hierarchical organization of concepts. The results safely revealed that the Concept Maps significantly influenced the learning of the university content explored. The experience proved to be a strategy with perspectives to improve educational practices, serving as a pedagogical tool for the advancement of investigations about the teaching and learning processes in the university academic universe.

Keywords: conceptual map; meaningful learning; higher education.

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Percepção e sugestão do uso de mapas conceituais em equações diferenciais ordinárias

RESUMO

Este artigo apresenta uma pesquisa realizada com 92 discentes universitários dos cursos de Engenharia da Universidade de Brasília, com o objetivo principal de avaliar o uso de mapas conceituais como recurso didático no ensino de equações diferenciais ordinárias, com base na teoria ausubeliana, que consiste na aquisição do conhecimento pelo ser humano por meio de uma organização hierárquica dos conceitos. Os resultados revelaram, de forma segura, que os mapas conceituais influenciaram significativamente na aprendizagem do conteúdo universitário explorado. A experiência mostrou ser estratégica, na perspectiva de melhorar as práticas educativas, indicando o uso de mapas conceituais como ferramenta pedagógica para o avanço das investigações acerca dos processos de ensino e aprendizagem no universo acadêmico universitário.

Palavras-chave: mapa conceitual; aprendizagem significativa; ensino superior.

Percepción y sugerencia del uso de mapas conceptuales en ecuaciones diferenciales ordinarias

RESUMEN

Este artículo presenta una investigación realizada con 92 estudiantes universitarios de la carrera de Ingeniería de la Universidad de Brasilia con el objetivo principal de evaluar el uso de mapas conceptuales como recurso didáctico en la enseñanza de ecuaciones diferenciales ordinarias basadas en la teoría ausubeliana, que consiste en la adquisición de conocimiento humano a través de una organización jerárquica de conceptos. Los resultados revelaron con seguridad que los mapas conceptuales influyeron significativamente en el aprendizaje del contenido universitario explorado. La experiencia resultó ser una estrategia con perspectivas de mejora de las prácticas educativas, sirviendo como herramienta pedagógica para el avance de las investigaciones sobre los procesos de enseñanza y aprendizaje en el universo académico universitario.

Palabras clave: mapa conceptual; aprendizaje significativo; enseñanza superior.

INTRODUCTION

One of the concepts of Darcy Ribeiro's project for the University of Brasília (UnB), at its creation, was that the university student should have the opportunity to opt for a professional orientation when he or she was more mature and better informed about the different fields he or she could devote themselves to (Ribeiro, 2011). At UnB, the Faculdade do Gama (FGA) implements this concept. It offers 280 vacancies per semester, distributed among the undergraduate courses in Aerospace Engineering, Automotive Engineering, Energy Engineering, Electronic Engineering and Software Engineering, allowing an equal distribution of 56 vacancies for each course (SALES; ANDRADE, 2020).

Upon entering Faculdade do Gama, the student begins the Basic Engineering Cycle (a set of common disciplines among the five Engineering courses), and must, after the first semester, choose one of the five Engineering courses (SALES; SOARES; EVANGELISTA, 2021). Gama School was created in 2008, in the context of the Support Program for Restructuring and Expansion Plans of Federal Universities (BRASIL, 2007), established by Decree No. 6.096/2007.

A reality in exact courses at several universities, public and private, including Faculdade do Gama, is the high failure rate in Calculus. This theme, for example, was addressed by Ferreira and Zuin (2018), who, in view of this reality, proposed an educational material aimed at teachers of Differential and Integral Calculus, with the objective of improving the teaching and learning of the derivative, under the algebraic and geometric approaches, allied to the History of Mathematics. Similarly, Evangelista (2020) proposed the use of comics, also in the subject of Calculus, with the intention of bringing students closer to the content, motivating them, and making the classroom environment more attractive.

Concept maps were idealized by Joseph D. Novak in the mid-1970s and are hierarchical visual orders whose purpose is to organize, preserve and represent knowledge, using propositions to make conceptual relationships explicit. These propositions are the elements that differentiate concept maps from other visual methodologies because they justify the existing relationships between the preconceptions.

Concept maps were based on Ausubel's Theory of Significant Learning (TAS), developed between 1963 and 1968 and reiterated in 2003, which predicts the structuring of knowledge into concepts and propositions, justifying their use in the teaching and learning process to represent mental models, stimulating students' visual sense.

According to Ausubel (2003), SCT demands a relationship between prior knowledge and new knowledge, with the learner acting intentionally to create meaning between the two. Exemplifying the theory, Ballejo and Viali (2018) addressed Ausubel's SCT in working with 6th

grade students and indicated that these students created an affective connection with the use of GeoGebra software, facilitating the learning of perimeter understanding.

The concept mapping technique can be used at any school level: infant, elementary, middle, and high school. In university education, for example, Cogo et al. (2009) evaluated the possibility of using concept maps by undergraduate nursing students from a public university in a distance learning discipline called Introduction to Anamnesis and Physical Examination in Nursing. The research showed that the use of concept maps as a didactic resource is important to help students memorize the concepts learned in the teaching and learning process, in addition to integrating new knowledge with previous knowledge, establishing interrelationships. Sales, Coelho, and Sales (2012) evaluated the didactic potential of concept maps when used in the subject Human-Computer Interaction, of the Software Engineering course. In their work, Souza and Nardi (2015) presented a proposal for structuring the study of Physics concepts, using concept maps for various levels of education.

Through the initiative called Program Learning for the 3rd Millennium (A3M), the University of Brasilia has encouraged research, the production of new knowledge and the development of innovative educational practices in the teaching and learning process, making it possible to institutionalize methods and innovative practices of teaching and learning in their courses. In this context, this paper presents an evaluation of the use of concept maps as a didactic resource for teaching and learning the concepts of ordinary differential equations in Calculus 2, a subject of the Basic Engineering Cycle at Gama School of the University of Brasilia.

Thus, this paper aims to present the perceptions of students and teachers about the use of concept maps as a pedagogical tool for explaining ordinary differential equations, as well as to list its benefits as a teaching resource. For this purpose, the article is organized as follows: section 2 presents the theoretical basis of the research (Concept Maps and Meaningful Learning); section 3 discusses the research methodology; section 4 discusses the results found, that is, the considerations of students and teachers about the use of concept maps and the advantages as a pedagogical tool; and section 5 concludes.

THEORETICAL BACKGROUND

In this section, we present two simultaneous lines of research that provide theoretical sustainability to our work, applying concept maps and Meaningful Learning to the teaching of ordinary differential equations.

In general, a concept map is a hierarchical graphic representation of concepts present in a cognitive structure, to establish evident relationships. Novak and Gowin (1996, p.18) devised the concept map in a scenario where "[...] key concepts appear surrounded by ovals; appropriate connecting words form key propositions."

To build a concept map is to define the focal concept (or the key question), which should be structured in a hierarchical manner, then move on to the specific concept, establishing cognitive relationships between them:

> [...] Concept Maps should be hierarchical; that is, the most general and most inclusive concepts should be at the top of the map, with increasingly more specific, less inclusive concepts placed successively below them. (NOVAK; GOWIN, 1996, p. 32).

Concept maps can be used for three purposes: didactic resource and/or tool, data collection, and learning assessment. For example, Barbosa and Matos (2018) used this resource as an assessment tool for the development of the course completion work (TCC) by students and concluded that it is an effective strategy for learning assessment, since it fully mirrors the student's reflections. In another similar case using concept maps in the evaluative context, Neri et al. (2019) verified their use in the evaluative process of conceptual and procedural learning based on collaborative work and the use of interdisciplinary projects by four high school students, participants of the research group Nutec (Cognitive Technologies Research Center) of the Federal University of Uberlandia.

Still concerning the use of concept maps as an evaluative tool, Côrrea and Correia (2019) presented a proposal in which the teacher intentionally creates the concept map with incorrect propositions, so that students find the error. The results, with this structure, emphasized the students' sensory memory and exposed new evaluative alternatives in school contexts, such as true or false or multiple-choice tests, game of the seven errors, subjective questions, etc. Regarding data collection, Maximo-Pereira, Souza and Lourenço (2021) gathered their results by means of a summary table, emphasizing the objective of the work, to weave the technical characteristics of concept mapping with concepts from the History of Science, and showing that this didactic resource is a useful tool for educational actions that use concept maps in the area of science teaching.

Regarding the use of concept maps as a learning tool, Machado, and Carvalho (2020) used this technique to check the perceptions and knowledge of college students in the study of scientific articles. The students used the concept maps with the support of Cmap Tools and Cmap Cloud software. Similarly, Blaszko and Ujiie (2019) concluded as useful and effective the use of concept maps as a didactic and methodological resource by Pedagogy course academics and as a pedagogical tool for the teacher.

It is worth recalling that, in the 1970s, Novak developed the concept map methodology, whose essence is centered on human learning and knowledge representation and based on Ausubel's (2003) Meaningful Learning Theory. To this end, "[...] Novak made an unprecedented attempt to discover an individual's own organization of cognitive structure through the use of his (Novak's) original 'cognitive mapping' technique." (AUSUBEL, 2003 p. XIV).

Ausubel (2003) defines cognitive structure as an area of the human brain where ideas are acquired, stored, and organized in a hierarchical manner. It is unique to everyone, "[...] all newly acquired meanings are also necessarily unique" (AUSUBEL, 2003, p. 1). In this understanding, the cognitive structure of everyone is like an extremely organized and hierarchical conceptual network, according to the degree of abstraction. It is the space where the various ideas are connected, according to the relationship established between them. The individual goes on learning and understanding the new concepts and the ideas that are structured with the previously learned concepts (SILVA et al., 2013).

Under this perspective, the present study adopted the use of concept maps as a pedagogical tool to enable the learning of the contents of ordinary differential equations by college students. Since concept maps allow the organization and representation of knowledge, the goal is to make students grasp more quickly the meaning of the taught contents, facilitating their learning.

METHODOLOGY

The high rate of failure in Calculus is a reality in exact courses in several universities, public and private. Mello and Mello (2001) explain this fact, listing the viewpoint of students and teachers that failure and failure are normal in this subject; the lack of prior knowledge that should have been acquired by students in previous levels of education; the lack of interest and motivation on the part of students; the lack of good training of teachers; the large number of new concepts brought by the subject; and the scarcity of alternative teaching methodologies. Despite what has been pointed out, we share the idea that these problems cannot remain in education without seeking solutions.

The content of ordinary differential equations is part of the menu of this subject, which has numerous practical applications in various areas of knowledge, and whose solutions are used, for example, to design bridges, automobiles, airplanes, electrical circuits, among others. Concept maps serve as an additional pedagogical and didactic tool available to teachers to make their classes more attractive and facilitate the understanding of subjects considered difficult by students.

In particular, the topics of ordinary differential equations involve many theories and several formulas, which motivated this research about the use of concept maps in this content. The objective was to help the students who memorized the numerical expressions but could hardly relate the new knowledge to the already sedimented knowledge, noting that the grades obtained in the tests did not correspond to those desired, and that some measure was needed. Thus, the methodology adopted is the use of questionnaires as a research technique, because the questionnaire,

> [...] if used correctly, it is a powerful tool in obtaining information, having a reasonable cost, ensuring anonymity and, being of easy handling in the standardization of data, it ensures uniformity. It is clear, then, that this is a model of easy application, simple, cheap, and fully skilled [...] (CHAER; DINIZ; RIBEIRO, 2011, p. 263).

From the month of September 2019, after 25% of the classes taught, the teacher introduced the use of concept maps as an auxiliary tool in the teaching of ordinary differential equations for undergraduates of the 2nd semester of the Engineering courses of the Faculdade do Gama of the University of Brasilia, taught to 130 students, and divided into three stages, detailed below:

Stage 1: Theory and explanation

In this step, the teacher-author explained the theory, which guided the construction of the concept maps; she explained how to elaborate them; and highlighted the benefits of their use, such as the hierarchical visualization of the topics taught, the organization of ideas between new and already consolidated knowledge, identifying the focal issue and its consequences.

Stage 2: Construction of the concept map

This stage was aimed at constructing concept maps in the classroom. Acting together, the teacher and the students elaborated on the classroom board, concept maps, in which the students were able to identify their valuable use, recognizing the interaction of the new information with the previously acquired knowledge.

Stage 3: Verification of learning

In this stage, through the application of a questionnaire to the students and the professor of the subject, we verified the learning of specific contents of ordinary differential equations by the students using concept maps. Of the 130 students enrolled in the course, 92 agreed to participate in the research after reading and signing the free consent form, representing 70.8% of the group, generating a confidence level greater than 90%, with a margin of error of 5%. The teacher responsible for this class also agreed to participate in the research after reading and signing the free consent form.

The questionnaire applied was composed of two blocks of questions:

- The first block, about the respondents' profile, addressed questions about age, gender, the semester the student was studying, the way he/she entered the university, the Engineering course he/she wished to study at FGA, the electronic device(s) used in the study activities, and the resources used to seek more knowledge in the disciplines.

- The second block included questions about the use of concept maps as a didactic resource for teaching and learning ordinary differential equations.

It should be noted that the questionnaire was applied in the penultimate class of the subject before the final evaluation. As for the demographic variables, the profile of the respondents was outlined as follows: 74 males (80.4%) and 18 females (19.6%), aged between 17 and 26 years, mostly between 18 and 19 years (73.9%). The respondents took the course between the 2nd and 5th semesters of the Engineering courses, with a predominance of students in the second semester (78.3%).

The subject was taught by a professor with an undergraduate, master's, and doctoral degree in mathematics. The professor has 10 years of teaching experience in higher education, having taught more than 14 classes of Calculus 2 during this decade of university teaching.

Having described the methodological path, the next section presents the discussion of the results obtained in the research. The data obtained through the participants' answers to the questionnaire were tabulated and inferences were drawn from them, based on analysis. All the percentage values of the survey are rounded to one decimal place after the comma.

DISCUSSION AND ANALYSIS

This section is divided into three subsections: the first presents the results obtained through the answers to the questionnaire about the students' profile; the second details the evaluation of the use of concept maps as a didactic resource for learning ordinary differential equations from the students' perspective; the third presents the evaluation of the use of concept maps as a didactic resource for teaching ordinary differential equations from the teachers' perspective.

4.1 Profile, learners' interests and devices used in the study activity

The data collected with the respondents revealed the following ways of entering the university: 51.1% entered through the Program of Serialized Assessment (PAS); 6.5% through the traditional entrance exam; 41.3% through the Unified Selection System of the Ministry of Education (SiSU/MEC) and 1.1% through the remaining vacancies entrance exam. The other data collected about the profile of students were the Engineering course they would like to follow at FGA, the devices used in study activities and the resources used to seek more knowledge in the discipline.

Table 1 shows the percentage of Engineering courses the respondents intend to take during their undergraduate studies. The Aerospace Engineering course is predominant, and in the

"Other course" option, Civil Engineering, Mechanical Engineering and Digital Games were mentioned. Two students answered, "don't know".

Table 1 – Undergraduate courses targeted

Graduate Course	Percentage of Students
Aerospace Engineering	31,5%
Automotive Engineering	2,2%
Energy Engineering	18,5%
Software Engineering	27,2%
Power Engineering	15,2%
Other courses	5,4%

Source: prepared by the authors, 2021.

As for the devices used in study activities, the results can be seen in Table 2, which highlights the smartphone and the notebook as the most used.

Table 2 – Devices used in the study activities

Device	Percentage of Students
Smartphone	81,5 %
Notebook	72,8 %
Desktop Computer	34,8 %
Tablet	9,8 %
Netbook	2,2 %
Kindle	2,2 %

Source: prepared by the authors, 2021.

Table 3 shows the resources used by students to seek more knowledge in the disciplines. In several subjects of the Engineering courses at FGA, the professors make study materials available through the institution's virtual learning environment (https://aprender.unb.br/). The websites of specialized companies, blogs, and wiki of works by other students in the same class were the least used resources to seek more knowledge in the disciplines.

Table 3 – Resources used in the search for more knowledge in the disciplines

Resource	Percentage of Students
YouTube	82,6%
Video Classes	80,4%
Material in digital media made available by the teacher	64,1%
Digital Book	66.3%
Educational Websites	51,1%
Physical Book	40,2%
Research Websites	37%
Scientific articles	16,3%

Wiki of other students' work from previous semesters	13%
Wikipedia	10,9%
Websites of specialized companies	9,8%
Blogs	7,6%
Wiki of other students' work from the same class	3,3%

Source: prepared by the authors, 2021.

As for the assessment of the importance of the subject, the students assigned values from 1 to 5, 5 being the maximum score. When the questionnaire was applied, in the penultimate class of the subject, the students were asked about the degree of importance they attributed to the subject before taking it, and how important the subject was for the engineer's education. The results are shown in Table 4.

Table 4 – Importance of the Calculus 2 subject

Importance of discipline	**Frequency**					**Average**	**Standard Deviation**
	Value 1	Value 2	Value 3	Value 4	Value 5		
Importance of the discipline (before taking it).	2 (2,2%)	5 (5,4%)	3 (14,1%)	30 (32,6%)	42 (45,7%)	4,1	1
Importance of the discipline for the engineer's education (after taking the discipline).	1 (1,1%)	1 (1,1%)	7 (7,6%)	31 (33,7%)	52 (56,5%)	4,4	0,8

Source: prepared by the authors, 2021.

4.2 Evaluation of the use of concept maps as a didactic resource for learning ordinary equations from the students' perspective

Some questions were designed to evaluate the use of concept maps as a teaching resource for learning ordinary differential equations from the perspective of the students. The students should assign a score from 1 to 5, 1 being the lowest value and 5 the highest, as answers to these questions. The results are presented in Table 5.

Table 5 – Evaluation of the use of MC as a teaching resource for learning ODE

Questions	Frequency						Average	Standard Deviation
	Value 0	Value 1	Value 2	Value 3	Value 4	Value 5		
Note for using concept maps as a teaching resource.	0	2 (2,2%)	3 (3,3%)	10 (10,9%)	27 (29,3%)	50 (54,3%)	4,3	0,9
Did the use of concept maps in Calculus 2 facilitate learning the content?	1 (1,1%)	1 (1,1%)	2 (2,2%)	13 (14,1%)	25 (27,2%)	50 (54,3%)	4,3	0,9
Did the use of conceptual maps in the course make the contents more attractive and easier to understand?	1 (1,1%)	2 (2,2%)	9 (9,8%)	15 (16,3%)	24 (26,1%)	41 (44,6%)	4	1,1
Did the making of the concept maps help in connecting the subjects covered in the course?	1 (1,1%)	1 (1,1%)	1 (1,1%)	10 (10,9%)	31 (33,7%)	48 (52,2%)	4,3	0,8
Did you learn Calculus 2 content more easily with the use of concept maps?	1 (1,1%)	4 (4,3%)	4 (4,3%)	22 (23,9%)	23 (25%)	38 (41,3%)	3,9	1,1
Did you feel more motivated in the subject with the use of the concept maps?	1 (1,1%)	6 (6,5%)	11 (12%)	31 (33,7%)	17 (18,5%)	26 (28,3%)	3,5	1,2

Source: prepared by the authors, 2021.

Another set of questions addressed the students' prior knowledge of concept maps and their use in other contexts and in other disciplines. The allowed answers for these three questions were "yes" or "no". In the question Do you use the concept map approach as didactic support for other subjects? the respondents could choose between "yes", "no" and "sometimes". The results of these questions are shown in Table 6.

Table 6 – Evaluation of the use of MC as a teaching resource for learning ODE

Questions	Frequency			
	Yes	**No**	**Sometimes**	**Did not answer**
Did you already have some knowledge about conceptual maps before taking this course?	75 (81,5%)	16 (17,4%)		1 (1,1%)
Do you use concept maps in other contexts?	43 (46,7%)	47 (51,1%)		2 (2,2%)
Should concept maps be used in other subjects?	66 (71,7%)	26 (28,3%)		0
Do you use the concept map approach as a didactic support for other subjects?	17 (18,5%)	15 (16,3%)	59 (64,1%)	1 1,1%)

Source: prepared by the authors, 2021.

At the end of the questionnaire, the students answered the following question: What was your perception or comment on the use of concept maps in ordinary differential equations? Below are some answers:

> "Complete visualization of topics covered" (Student 1).
>
> *"Helps fix content, improves learning"* (Student 2).
>
> *"Organizes disconnected ideas"* (Student 3).
>
> *"The subject was clear in my head [...]"* (Student 4).
>
> *"It helps me understand the step-by-step of the content and the flow of the subject. The teacher is very didactic"* (Student 5).
>
> *"Gives an overview of the content and shows how the topics are related"* (Student 6).
>
> *"Flow of the concepts and connections between them, nice image to study"* (Student 7).
>
> *"Many maps"* (Student 8).
>
> *"Could have more maps"* (Student 9).
>
> *"This didactic is especially important and relevant for the learning of college students"* (Student 10).
>
> *"It facilitates the understanding of the subject content in a clear and visual way"* (Student 11).
>
> *"I thought it was particularly good, a way to guide the student who is behind in the subject"* (Student 12).

4.3 Evaluation of the use of concept maps as a didactic resource for learning ordinary differential equations from the teachers' perspective

Five questions were prepared to evaluate the use of concept maps as a didactic resource in the teaching of ordinary differential equations from the teacher's perspective. The teacher was asked to assign a score from 1 to 5 to each answer, 1 being the lowest value and 5 the highest. There were three questions with a score assigned as 5, listed below:

- Does the use of concept maps in the subject of Calculus facilitate student learning of the content?
- Do concept maps help in the association of different subjects in the subject for the students?
- What grade do you assign to the use of concept maps as a teaching resource?

The questions that were evaluated with a score of 4 were:

- Do students learn the subject content more easily with the use of conceptual maps?
- Do students feel more motivated with the use of conceptual maps?

And, also, at the end of the questionnaire, there was an open space for recording the teachers' perception of the use of concept maps as a pedagogical tool, in which we highlight:

- Negative points: finding the FOCAL question, key to the secret of MC construction.
- Positive points: organizing theory in a visual way, relationships of key concepts and their consequences.
- Note: Many students lack autonomy and discipline in the way they study. The MC would be a visual learning tool, in which the student could follow the development of a content in a hierarchical way, assisting in individual and collective study. Fiori and Lucena (2020) corroborate with the use of scientific didactic illustration in the three professional spheres: academic, school, and professional.

Two particularities of this research are: a large class, around 130 (one hundred and thirty) students; and the predominance of male students (more than 80%), aged between 17 and 26 years, the majority being between 18 and 19 years (73.9%).

Of the 130 students enrolled, 84 (64.6%) passed, 40 (30.8%) failed, and 6 (4.6%) cancelled the course. It is worth noting that before the application of the maps, the failure rate was around 70%.

FINAL CONSIDERATIONS

This paper presented the main results of the evaluation of the use of conceptual maps as a didactic resource for teaching and learning ordinary differential equations in Calculus 2, a subject of the Basic Engineering Cycle at Gama School of the University of Brasilia.

It can be considered that, for the group under study - students of the undergraduate Engineering courses of the Faculdade do Gama, University of Brasilia, and the professor of the subject - the importance of adopting different teaching resources in teaching was evident, since the use of concept maps as a teaching resource in the teaching of ordinary differential equations was approved by most students and the professor, for several reasons: to facilitate learning of the content, to make the content more interesting and understandable, to help connect the subjects covered in the subject and to facilitate learning.

The concept map is a didactic resource that proved to be effective in the proposed work, the teaching of ordinary differential equations, because its use provided evolution in the students' learning, allowing them to learn to interconnect concepts and structure them in a hierarchical manner. Moreover, the use and the joint construction of the concept maps by the teacher and the students made the class more active, interesting, and participatory.

It is concluded that the concept map, in the teacher's perception, is an important pedagogical tool, and can be used to promote meaningful learning, to stimulate collaborative activities, to aid the evaluation process, and to collect data. On the other hand, it is noteworthy that, in the students' understanding, the use of concept maps develops critical thinking, improves academic performance, and visual organization of the learned contents. Therefore, it is suggested to the academic community the use of concept maps, according to the results listed. As future work (and already in progress) is the planning of the use of concept maps in other subjects of Calculus and other disciplines of the Engineering courses, in addition to the planning of the application of added resources at the Faculty of Gama of the University of Brasilia.

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