INSPIRATIONAL PRACTICES FOR TEACHING DIFFICULT CONTENT

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Scholarly knowledge that emerges from research cannot be taught in its raw form; it must be adjusted to comply with program learning objectives (Lapierre, 2008; Legendre, 1994), which poses a particular challenge when it comes to teaching and learning scientific concepts that are often abstract. While this necessary "didactic transposition," to use a term coined by Chevallard (1991), should facilitate learning, it seems that it can also create obstacles, gaps or even contradictions between disciplinary knowledge and knowledge learned by the student (Legendre, 1994). Indeed, certain choices regarding the breakdown, organization and dissemination of the knowledge to be learned can cause problems for future teaching (Cormier, 2014; Reuter *et al.*, 2013).

This is the case with chemistry, where, for purposes of simplification, models describing the structure of the atom are taught at the secondary level, following the chronological order of scientific discoveries they are based on, without touching on the model currently accepted by the scientific community, which is taught at the college-level program. And yet, because they do not agree with current scientific theories, the atomic models previously learned are in fact distorted notions that—and all chemistry teachers will agree—are deeply rooted in the minds of students (Stefani and Tsaparlis, 2009), impeding the transition to an accurate conceptualization of the model of the atom (Taber, 2002).

Although these concepts are difficult to modify, through their practices, some college teachers help to promote a change in the way students view the atom. In a PAREA[1] study (Marquis, 2017), I explored teaching practices used to transform scholarly knowledge related to the probabilistic model of the atom, and I drew links between them and the knowledge actually learned by students in order to highlight approaches for teaching content deemed difficult, complex, or that requires more abstract thought. Although the practices presented here are studied from the specific disciplinary perspective of chemistry, the results of the research may augment the didactic reflection of teachers of all disciplines. While new teachers will find ideas to help them plan their courses, the more experienced will be able to use these inspiring practices to evaluate their teaching methods and make adjustments as needed.

INHERENT CHALLENGES TO TEACHING SCIENCE

The role of science teachers is to introduce to their students complex and abstract concepts by explaining them in a simple and understandable manner, all while avoiding oversimplifying them since this can lead to conceptual difficulties later on (Taber, 2005). This refers to professional expertise in the field of didactics, whereas the competencies related to the different teaching, learning and evaluation strategies are more pedagogical (Bizier, 2014). According to Johnstone (1991), the difficulties experienced in learning science could be related, on the one hand, to the nature of science itself, given the abstract and theoretical concepts underlying it. On the other hand, the difficulties could be related to the methods normally used to teach science that fail to take sufficiently into account what students already know about the subject. Learning, in fact, should not only include the robotic memorization of content, but also the reorganization of knowledge that is often already available (Astolfi *et al.*, 2008).

The idea of an obstacle to learning is related to notions of representation or design, concepts that are very important in the teaching of science (Astolfi and Peterfalvi, 1993). These are designated by various expressions, such as *misconceptions*, *distorted notions* and *alternative concepts* (Cormier, 2013). Since the end of the 1970s, research has revealed that when it comes to explaining scientific phenomena, concepts exist that are strongly anchored in the minds of students and often in disagreement with scientific theory (Driver and Easley, 1978; Duit, Treagust, and Widodo, 2008; Duit, 1991; Gabel, 1999; Taber, 2001). These concepts are problematic since they are very difficult to modify, particularly with traditional teaching methods (Ausubel, 1968; Champagne, Gunstone, and Klopfer, 1983, quoted in Guzetti *et al.*, 1993). The identification of these obstacles has led educators to reflect on the conditions that may help overcome them, one of which being that science

[1] Programme d'aide à la recherche sur l'enseignement et l'apprentissage (teaching and learning research assistance program).

teaching practices might not sufficiently address these errone-ous concepts (Astolfi and Peterfalvi, 1993; Reuter *et al.*, 2013).

A FRAMEWORK FOR STUDYING TEACHING PRACTICES

Influenced by the context in which they occur (Reuter *et al.*, 2013), teaching practices concern the actions of teachers as much in the classroom as outside the classroom, and also encompass the cognitive processes at the origin of these acti-vities (Altet, 2002, 2003). Following up on this definition, I consulted various authors interested in two aspects of these practices, namely, the transformation of scholarly knowledge for the purpose of teaching and how it is taught.

TRANSFORMATION OF KNOWLEDGE SO THAT IT CAN BE TAUGHT

The theoretical model used to study the practices used to transform knowledge for the purpose of teaching it is based on an American school of research that focuses on the type of knowledge that teachers possess in their subject, and which is unique to them: "pedagogical content knowledge" (or PCK) (Shulman, 1986, 1987, 2007). It is this, for example, that dis-tinguishes the chemistry professor from a chemist. Shulman (1987) places this transformation of knowledge by teachers in an iterative process called a *model of pedagogical reasoning and action*, illustrated in Figure 1, which involves reflection on their practice in order to improve learning.

The process begins with the understanding of the knowledge and goals of the program, then the organization of these by the teacher, who then transforms them with the objective of teaching them (the processes involved at this specific stage will be discussed later on). Following a series of didactical deci-sions, the teacher plans various teaching and learning activities that they will implement during classroom interaction. The evaluation stage that follows includes as much the verification (formative or summative) of students' understanding during and at the end of a lesson (or teaching sequence) as the tea-cher's assessment, decisions and own performance related to teaching the knowledge. Armed with this information, the teacher can then begin a reflective review of their practice that will allow them to consider new ways of understanding the program goals, knowledge, students and teaching. Shulman points out that these are not fixed steps, even though the processes in this model are presented in sequence and some of them may occur in a different order.

FIGURE 1 — MODEL OF PEDAGOGICAL REASONING AND ACTION
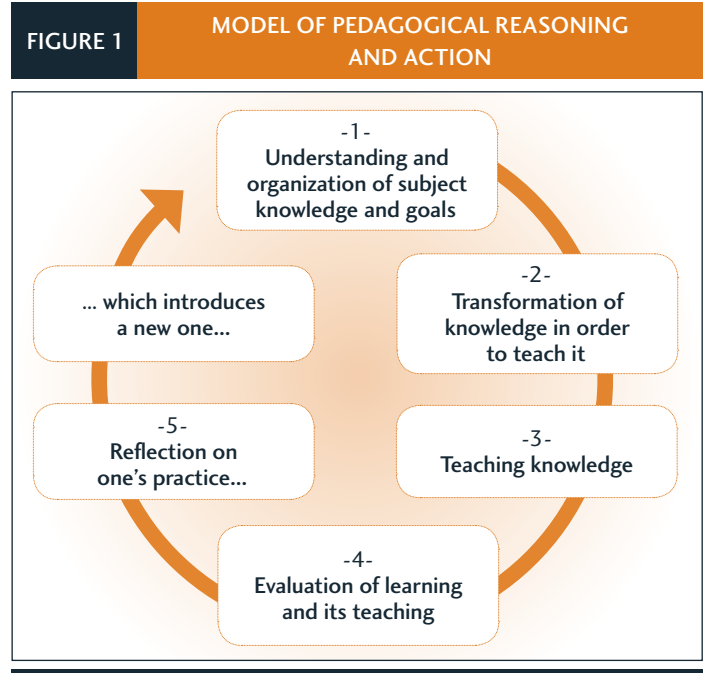
Source : Figure adapted from Shulman (1987, p. 15)

Again, according to Shulman (1987), transformation—the stage where the teacher moves from their personal understanding of the content and transposes it for the purpose of teaching—is the most important phase of the reasoning process and educational action. It allows the teacher to transform their disciplinary knowledge into knowledge to be taught, in such a way that this knowledge, through a didactic perspective, is presented to the students in a form best adapted to their skills and their varied prior knowledge. As illustrated in Figure 2, this process requires the implementation of four sub-processes (that can be iterative).[2]
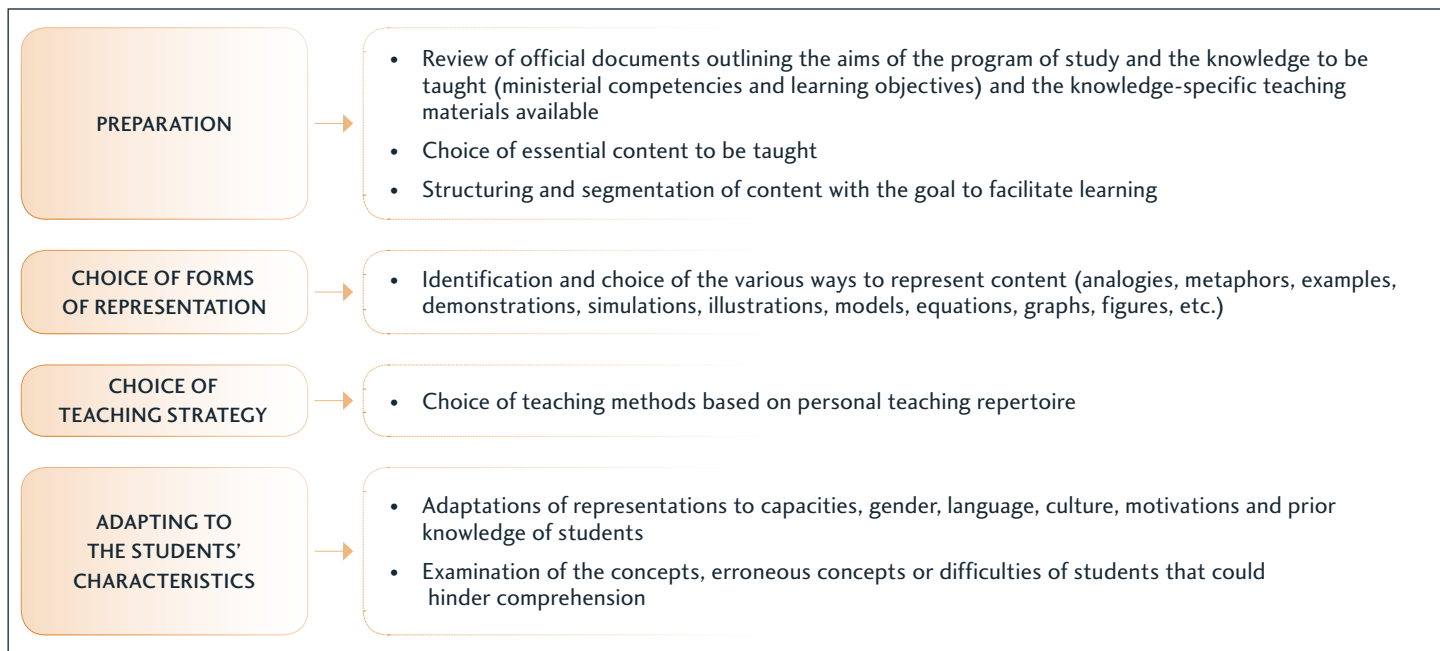
TEACHING KNOWLEDGE

In order to understand how the teaching of knowledge occurs after they have been transformed during planning, I reviewed two theoretical models that focus on the cognitive processes used byd teachers while teaching: the works of Schön (1983, 1994) and those of Wanlin and Crahay (2012).

[2] Initially, this transformation can be compared to the didactic transposition theory of Chevallard (1991). In fact, these two processes differ in the nature of the "operations" that are performed on the knowledge. While Shulman's model (1987) describes the pedagogical transformations made by teachers on the knowledge to be taught thanks to their pedagogical knowledge of the content, Chevallard's didactic transposition theory allows a better understanding of the separation created between knowledge, from their production to their teaching.

FIGURE 2	PHASES OF THE KNOWLEDGE TRANSFORMATION PROCESS[3]

PREPARATION →
- Review of official documents outlining the aims of the program of study and the knowledge to be taught (ministerial competencies and learning objectives) and the knowledge-specific teaching materials available
- Choice of essential content to be taught
- Structuring and segmentation of content with the goal to facilitate learning

CHOICE OF FORMS OF REPRESENTATION →
- Identification and choice of the various ways to represent content (analogies, metaphors, examples, demonstrations, simulations, illustrations, models, equations, graphs, figures, etc.)

CHOICE OF TEACHING STRATEGY →
- Choice of teaching methods based on personal teaching repertoire

ADAPTING TO THE STUDENTS' CHARACTERISTICS →
- Adaptations of representations to capacities, gender, language, culture, motivations and prior knowledge of students
- Examination of the concepts, erroneous concepts or difficulties of students that could hinder comprehension

Source: Figure adapted from Shulman (1987, p. 16)

Schön (1983, 1994) believes that, in professional practice, there are sometimes moments of reflection during action (reflection *in* action)—when one thinks of what one does when performing a task—and moments of reflection about the action itself (reflection *on* action)—when one thinks, for example, of what one usually does to succeed in successfully executing a particular action. According to Perrenoud (1998), the reflection in the heat of the pedagogical action consists mainly of the mental activity that takes place when the teacher makes several micro-decisions in connection with the management of the class and with class progress. Like Schön, the teacher distinguishes reflection "in the heat of the action" from reflection "on the action," the latter consisting of reflecting on their own action to compare it, among others, with how one could have or would have done better. This then makes reference to a reflection after the fact in a perspective of analyzing a past action.

Closely aligned with this perspective of reflection *in* action, Wanlin and Crahay (2012) propose an integrated model of interactive thinking that was developed following a review of the English literature on teacher thinking. According to this model, presented in Figure 3, the lesson plan developed during the planning of the teaching is the starting point, since the planned activities are the basic processing unit of teaching, and the reflections during teaching are subordinate to them (Wanlin and Crahay, 2012). This plan can take the form of mental images, a script, handwritten or electronic notes, etc.
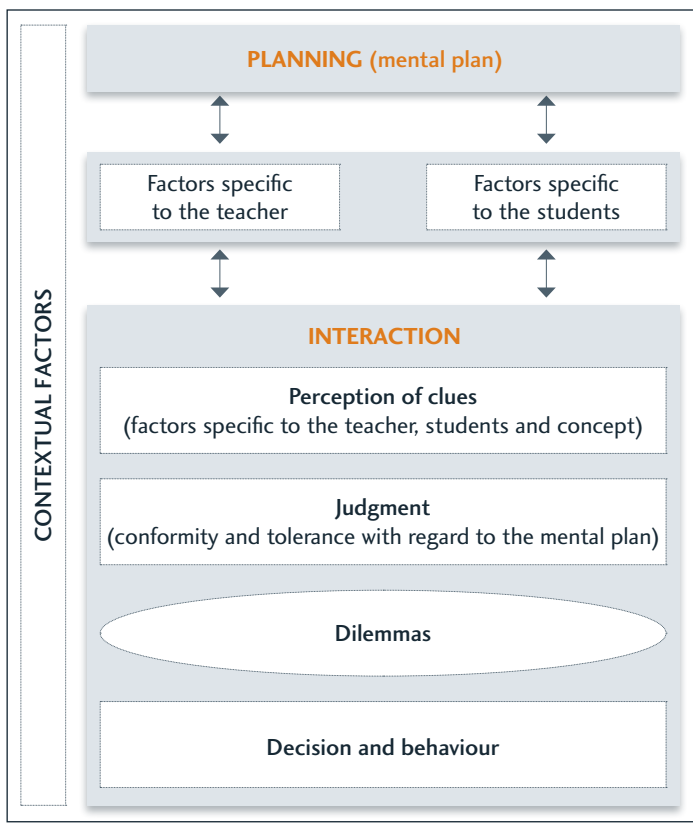
The reflection that occurs during interaction (during the interactive phase of the course) would mainly consist of asking questions about the continued application of the plan. During the course, the teacher would gather clues related to the course flow (relating to themselves, students or other contextual factors) that could lead to unexpected observations or dilemmas in need of management. According to Wanlin and Crahay, dilemmas are "situations perceived by the teacher as being problematic, in which contradictory beliefs, goals or clues compete" (2012: p. 24). The teacher will then judge how much the perceived clues exceed their tolerance thresholds and will make a decision that may trigger various behaviours.

[3] Ed. note: Some readers may find a certain similarity with the components of didactic questioning introduced by Bizier (2014), notably stemming from the works of Shulman.

FIGURE 3 · THE INTEGRATED MODEL OF TEACHERS' INTERACTIVE THOUGHT

PLANNING (mental plan)

Factors specific to the teacher | Factors specific to the students

INTERACTION

Perception of clues
(factors specific to the teacher, students and concept)

Judgment
(conformity and tolerance with regard to the mental plan)

Dilemmas

Decision and behaviour

CONTEXTUAL FACTORS

Source: Figure adapted from Wanlin and Crahay (2012, p. 31)

It is on the basis of these particular models that I sought to better understand the teaching practices used to transform knowledge related to the probabilistic model of the atom during the planning stage, as well as the practices implemented for the teaching of these models.

RESEARCH METHODOLOGY

For this research, I conducted a multi-case study involving six chemistry teachers from diverse colleges who were selected according to certain criteria. They had to have at least five years' experience, have taught the course at least three times, and have taken accredited teacher training, or be recognized in their field for their interest in education.

To emphasize knowledge transformation practices, I conducted semi-structured interviews that I analyzed in parallel with the didactic materials they had designed for a lesson. I then conducted video recordings of the planned teaching sequence, which were viewed in the company of each of the teachers during a follow-up interview, in order to validate how the lesson was delivered and to shed light on the micro-decisions made during the interaction. This shed light on several moments of reflection *in* action and on certain reflections *on* action. The objective was not to verify whether the teachers taught exactly according to the plan they had prepared, but rather to see how they juggled all the constraints of the situation, given their plan.

To evaluate how teaching practices have made it possible to learn a concept that is considered difficult, I focused on the knowledge that students have actually learned through diagrams illustrating how they imagined a nitrogen atom (with a written explanation), before and after the teaching sequence on the probabilistic model of the atom. The technique used is similar to the method of free recall (De Grave, Schmidt, and Boshuizen, 2001), which rather than consisting of the drawing up a list of erroneous concepts that students have with regard to the theoretical concept, entails compiling proposals, explanations and descriptions to obtain a relatively complete picture of the concept learned. The results show that the participating teachers succeeded in bringing about a change in the way the students imagine the atom model and that, therefore, the teaching practices implemented proved to be effective. Consequently, these practices can be considered as potential sources of inspiration and deserve our attention.

Learning does not only consist in the mechanical memorization of content, but also the reorganization of knowledge that is often already available.

HOW DO TEACHERS TRANSFORM KNOWLEDGE DURING THE PLANNING STAGE?

The research revealed a wide range of teaching practices, in spite of the fact that some practices were shared by several professors. These will be introduced below according to the four sub-processes involved in the transformation of knowledge (Shulman, 1987), namely the preparation, the choice of the forms of representation, the choice of the teaching strategy and the adaptation to the characteristics of the students.

PREPARATION

The teachers who participated referred to different sources in order to prepare their courses, especially with regard to prescribed knowledge (program documents and colleagues), and their ways of doing things evolved as experience was acquired. For example, a textbook of one publishing house seems to be used a lot to choose content and to prepare lessons in the early stages of the career, but teachers distance themselves and refer to it more infrequently as the years progress.

It was also observed that teachers are well aware of the prior knowledge of others within a course and given program, and that this is a factor on which they base their choices for core content to teach, with a view to defining knowledge. Some of them elect to teach more content for which there are applications (notably mathematics), while others prefer to explicitly teach more conceptual content. Thus, there seem to be two major paths concerning the choice of content, depending on the teachers' beliefs, in that some may prefer teaching more practical, more algorithmic notions, while others will privilege the teaching of theoretical concepts.

Half of the participating teachers decided to exclude content that they considered to be less important in order to avoid it generating additional difficulties for the students. With acquired experience, teachers seem to develop knowledge regarding these more secondary concepts that can cause difficulties for students, which enables them to more carefully select the content to be taught and to focus on those that require more consideration.

CHOICE OF FORMS OF REPRESENTATION

In order to stimulate students and facilitate the understanding of various difficult concepts, the participating teachers develop a variety of different forms of content representation using objects, figures, analogies and videos, as well as by introducing humour and connecting with the concerns of students. All design teaching materials: PowerPoint presentations, course notes (as continuous text or to be completed), etc. To some extent, this material represents the results of the many acts of knowledge transformation made by the teacher.

CHOICE OF TEACHING STRATEGY

The same teachers plan learning activities where the students play an active part not only so that they can forge links on their own and discover concepts collaboratively, but also to gauge their understanding on a regular basis. Some examples include the following:

- Discussions among students where each student elaborates on their own prior knowledge (based on designs of the atom model), so that students understand that they must modify the way they view the atom.

- Team exercises on interactive whiteboards (in an active learning class), to judge students' ability to perform these exercises and thus adapt interventions and feedback.

- Questions asked using i-clickers, to evaluate the students' level of understanding of the subject in real time.

- Game-related activities, to enable students to assimilate the concepts themselves by helping each other.

- A summary problem to solve at the end of the lesson, so that students can integrate the various concepts being studied.

ADAPTATION TO THE CHARACTERISTICS OF STUDENTS

The research results show that teachers have a good knowledge of the characteristics of their students thanks to the information they collect through different means (questionnaires, presentations, informal discussions, formative evaluations, classroom activities, etc.) and that they adapt their planning to the cognitive and personal characteristics of their students.

◗ DOES THE COURSE GO AS PLANNED?

The participating teachers all develop a lesson plan, which they described as they reviewed their teaching materials during the first interview. In stimulated recall interviews, it was observed that they make several decisions *in* action, following perceived clues that in some cases lead to them modifying what had been planned. The main indicators underlying the decision-making process that were identified consist, generally, of questions coming from the students or their reactions to the questions asked by the teacher, of the difficulties displayed during the exercises or of non-verbal signs perceived among students. The decisions made by the teachers can refer to how they respond to a student's question, by how they broach a subject or even use another form of representation of the content than the one planned. The lesson plan is therefore a more or less flexible tool that teachers adapt taking into account the vagaries of the class.
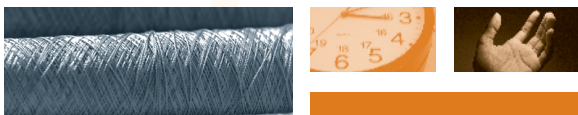
In most cases, these reflections that take place *in* action and *on* action lead teachers to modify their course plan for the next time they deliver the same course. These modifications introduced over the years contribute to ensuring that the plan is better adapted to the students' characteristics and difficulties and, consequently, it becomes increasingly less necessary to modify the plan in action.

Taking the time to develop a teaching strategy integrating the consideration of students' prior knowledge is certainly a promising approach.

◗ **APPROACHES TO BETTER TEACH DIFFICULT CONCEPTS**

An analysis of the observed practices allows me to develop certain approaches to facilitate the learning of the difficult concepts that are complex or abstract, not only in chemistry or in science courses, but in all subjects. These are not revolutionary practices, as they are already adopted by many teachers; however, they are a starting point for those who would like to unravel some of the problematic situations they might encounter in a class, focusing on different stages of the didactic transposition process.

- Draw out the students' prior knowledge by considering that they can maintain certain erroneous concepts that are very difficult to undo (this can be during diagnostic activities before teaching or during a formative evaluation during teaching).

- Reflect on the methods that can be implemented to consider these erroneous concepts during the class.

- Plan course teaching by considering teaching strategies that make it possible to transform knowledge so that it is easier for students to learn (for example, find or design forms of representation that will be of particular interest to students and make class content more meaningful, and identify learning activities that will allow students to assimilate the content).

- Pay attention to the different clues that arise during class interactions in order to be able to adapt the course plan in class and for future courses.

- Adopt a reflexive practitioner's posture, by regularly evaluating one's own teaching, and by reflecting *in* action and *on* action, in order to continuously improve one's practices (Schön, 1983, 1994).

◗ **CONCLUSION**

Vergnaud stated that "didactics studies each stage of the act of learning and highlights the importance of the teacher's role as mediator between the student and knowledge" (2001, p. 273, in Bizier, 2014). It then becomes a question of *relationships to knowledge*, those that teachers have with scholarly and disciplinary knowledge, and those that students have vis-à-vis the knowledge to be learned (Bizier, 2014). In this perspective, taking the time to develop a teaching strategy that incorporates the consideration of students' prior knowledge, whether it be accurate, partially or totally erroneous, is certainly a promising avenue for fostering in-depth learning, especially if it involves difficult, complex or abstract concepts (Marquis, 2017). This will require the teacher to analyze a situation in the perspective of the content to be taught, using their disciplinary and didactic expertise, in order to make the pedagogical choices that are necessary to plan their courses. ◗

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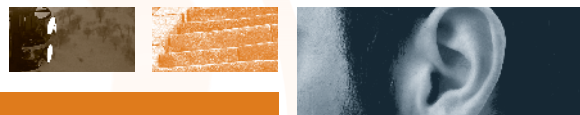
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