**Education 3-13**

International Journal of Primary, Elementary and Early Years Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rett20

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https://doi.org/10.1080/03004279.2023.2169049

# How do 12- and 13-year-old students respond to metacognitive questions? Findings from math and science classes in French-speaking Belgium

Simon Demorsy, Vanessa Hanin and Stéphane Colognesi

Faculty of Psychology and Educational Sciences, Université catholique de Louvain, Louvain-la-Neuve, Belgium

**ABSTRACT**

This study answers two research questions: (1) How do 12- and 13-year-old students respond to metacognitive questions posed during a complex task in mathematics or in science and (2) Do these responses differ by discipline? Content analysis was applied to responses collected from 92 students from a French-speaking Belgian school. The results showed that students are able to respond to metacognitive questions. However, the responses were not clear and were simplistic when they talked about their strategies. The difficulties students faced in developing their responses were identical in both disciplines.

**ARTICLE HISTORY**
Received 6 February 2022
Accepted 9 January 2023

**KEYWORDS**
Metacognition; content analysis; complex task; metacognitive questions

## Introduction

For several decades, metacognition has occupied an important place in the field of psychological and educational science research (Berger and Büchel 2012; Noël and Cartier 2016; Veenman 2012). Indeed, metacognition leads learners to reflect on their own actions, to become aware of the path that led to the results obtained, to identify their own errors, to point out the reasoning that led to their errors and to look for adequate solutions to remedy them (Rérat and Berger 2020; Veenman 2012; Veenman, Van Hout-Wolters, and Afflerbach 2006). The teaching of metacognitive strategies ranks 9th among the most effective variables to manipulate (out of a total of 138) in terms of improving students' academic performance (Hattie 2009). This finding was notably supported by Ko, Sammons, and Bakkum's (2014) synthesis of effective teaching practices.

However, despite these findings of effectiveness highlighted in the research, it has been shown that instruction related to metacognition does not occur (Depaepe, De Corte, and Verschaffel 2010, 2015; Dignath-van Ewijk 2016; Vlassis, Mancuso, and Poncelet 2014). This is because, on the one hand, understanding the concept of metacognition is complex for teachers (Spruce and Bol 2015; Wilson and Bai 2010), while on the other hand, or as a result, teachers hold beliefs about metacognition that prevent them from integrating instruction related to metacognition in their practice (Barbier and Colognesi 2023). First, teachers believe that they must provide subject-matter knowledge and believe that instruction related to metacognition does not help with this (Vosniadou, Darmawan, and Lawson 2021). They also believe that only certain students have the potential to respond to metacognitive questions/interventions. For some teachers, younger students or those with struggling-student profiles would not understand what is being asked of them (Ben-David and Orion 2013; Braund 2019). In addition, research suggests that teachers believe that instruction related to metacognition and metacognitive strategies is not discipline or domain specific (Braund 2019).

**CONTACT** Stéphane Colognesi stephane.colognesi@uclouvain.be

Yet, research has shown that in order for learners to consciously regulate their actions, explicitness through verbalisation seems necessary (Darling-Hammond et al. 2020; Gersten et al. 2009; Zohar and Peled 2008). One way to do this is to ask students metacognitive questions. These questions are interesting for their relative effectiveness in activating metacognitive regulation (Ge, Chen, and Davis 2005). Thus, the teacher's role is critical in soliciting students' metacognition.

For all these reasons related to improving learning, Perry, Lundie, and Golder (2019) criticised politicians for not including metacognition in the curriculum. In our context, in French-speaking Belgium, there is indeed no explicit mandate to solicit students' metacognition included in the legal requirements. Only a few initiatives exist to train teachers in this (Barbier and Colognesi 2020; Colognesi et al. 2021). But education in our country is currently undergoing an important reform. It shows the will of the politicians to favour the success of the students. This comes from the OECD's finding, through the PISA surveys, that education in French-speaking Belgium is both less successful and more unequal than the other OECD countries, on average (OECD 2019). This is why the government is working on the implementation of an ambitious project to reorganise education, called 'Pact for Excellent Education'. It aims to fundamentally rethink teaching practices and defines seven areas of learning. Among them is 'learning how to learn and make choices' (Socles des savoirs et de compétences du tronc commun: Chartes des référentiels 2017, 5) which refers directly to the elicitation of students' metacognition. There is therefore a challenge in our country to be able to draw up an inventory of the metacognitive capacities of French-speaking Belgian pupils. This will provide useful information for the training of teachers who will be asked to develop the metacognition of their students. In order to explore this aspect, we wanted to (1) question students' abilities to respond to metacognitive questions from their teachers and (2) see if these responses differ according to the discipline taught. To achieve this dual objective, we followed 92 students during a mathematics or a science activity in which the teacher presented them with metacognitive questions before, during and after the completion of the complex task.

## Theoretical framework

### *Metacognition: a multidimensional concept*

Researchers concerned with metacognition have attempted to define the term, despite significant conceptual vagueness. In this regard, Veenman, Van Hout-Wolters, and Afflerbach (2006) highlighted the multitude of notions that exist and mentioned that 'the relation of some specific terms with the overall concept of metacognition is not unequivocally defined' (4). These conceptual difficulties are also related to the fact that there are two main groups of research on metacognition and self-regulation (Dinsmore, Alexander, and Loughlin 2008). The first group is based on the work of Flavell (1976) and Brown (1987). Its central object is metacognition, considered as a 'monster of obscure parenting, but moreover, polycephalous' (Brown 1987, 105), encompassing metacognitive knowledge and self-regulation processes. The second group focuses on the analysis of self-regulatory processes; in this case, cognitive, motivational and emotional variables are all taken into account. In this second group, knowledge about cognition is one factor that participates in the regulation of action (Boekaerts, Koning, and Vedder 2006; Efklides and Misailidi 2010). Our text focuses specifically on the cognitive aspects of self-regulated learning.

Thus, following others (Da Rosa et al. 2021; Desoete and Özsoy 2009; Efklides 2008; Jiang, Ma, and Gao 2016; Zohar and Barzilai 2013), we consider metacognition as a multifaceted concept (Efklides 2008) bringing together three dimensions: metacognitive knowledge, metacognitive experiences, and metacognitive strategies.

The first dimension, *metacognitive knowledge*, has been defined as 'a person's declarative knowledge about interactions between a person, the task and the characteristics of the strategy' that is being considered for use (Flavell 1976, 19). Flavell explained that metacognition then refers to an individual's knowledge of their own cognitive processes. This metacognitive knowledge encompasses cognitive and metacognitive strategies (what?), the way to implement them (how?), the type of task for which it is relevant to mobilise them and the most appropriate time to do so (when?), as well as the usefulness of these strategies (why?).

The second dimension, *metacognitive experiences*, refers to 'the judgments and feelings that an individual has about their learning and thinking' (Braund and Soleas 2016, 107). This refers to all of the awareness and feelings that an individual may have when performing a task and processing the information related to it (Efklides 2008). These include feelings of difficulty, confidence, and so forth (Ben-David and Orion 2013; Efklides 2006). Judgments derived from these metacognitive experiences lead to the development of metacognitive strategies (Efklides 2008).

The third dimension, *metacognitive strategies*, concerns knowledge of the procedures that allow an individual to regulate their problem-solving and learning activities (Brown and DeLoache 1978; Colognesi and Van Nieuwenhoven 2016; Veenman 2005). In this sense, metacognition leads individuals to reflect on their own actions, to become aware of the path that led them to the results obtained, to see their mistakes for themselves, to discover the reasoning that led them to their errors, and to look for adequate solutions (Veenman 2012; Veenman, Van Hout-Wolters, and Afflerbach 2006). In the end, the result is self-regulation (Houart 2017; Noël 1997).

### *Involving metacognition at three different times*

Berger and Büchel (2012) explained that metacognitive strategies can be divided into two groups. On the one hand, there are 'anticipation and planning activities performed before solving a task' (179). On the other hand, there are 'verification activities during and after the resolution of a task' (179). Efklides (2008) listed the different strategies to be adopted: 'orientation strategies, planning strategies, strategies for regulating cognitive processing, strategies for monitoring the execution of the planned action, and strategies for evaluating the outcome of task processing' (280). Ultimately, these strategies can be activated before, during and after the completion of a task (Colognesi et al. 2019, 2020). And since metacognition is not automatic for students (Büchel 2015; Schunk 2001), in order to get students to make use of these strategies, the teacher can ask different types of questions at different times during the completion of a task.

Before the task, orientation refers to clarification of the goals to be achieved (e.g. Can you explain what you understood about the proposed task? What are your personal goals in relation to the task?). Planning enables the requirements of the task to be considered and the procedures and steps to be carried out to be envisaged (e.g. How are you going to proceed? What steps do you think you will take?). This can also appear in the form of statements to oneself, such as 'This is difficult for me, let's do it step by step' (Veenman, Van Hout-Wolters, and Afflerbach 2006, 6) or 'I don't know what this word means' (Veenman, Van Hout-Wolters, and Afflerbach 2006, 6).

During the task, monitoring refers to going back over what has been done and checking it to identify elements that are outside the plan or that are wrong (e.g. What led you to make this choice?). Verification monitoring consists of observing one's method, criticising it, justifying it and modifying it, correcting it if necessary (e.g. Is there anything in your plan that needs to be changed?).

Post-task evaluation of the product refers to taking inventory of the completed task. This is done by considering the goal, processes, strategies, planning, and skills (e.g. Did you achieve the goal and why?). And the process evaluation allows for a look back at the entire process, to bring out the strengths and weaknesses of the method that was used in order to improve it (Gagnière 2010; e.g. If you do the same activity again tomorrow, what strategies will you adopt to be more effective?).

### *Metacognition, age, and student profiles*

The first metacognitive abilities and thinking begin to emerge between the ages of 3 and 5 (Flavell 2004). After that, knowledge about memory and metacognition emerges (Alexander, Carr, and Schwanenflugel 1995). Although it has been shown that young students in early elementary school (age 6) can already answer metacognitive questions (Colognesi 2021), it is only between the ages of 8 and 10 that metacognitive strategies are acquired (Veenman, Wilhelm, and Beishuizen 2004). Flavell (1992; cited by Veenman, Wilhelm, and Beishuizen 2004) explained that metacognition is fully involved in the 'formal stage', starting from the age of 12 (the average age of the participants in our research). During this stage, the child develops hypothetico-deductive reasoning, which involves the monitoring function of metacognition. However, during the previous developmental stages, elements of metacognition have already appeared, such as the awareness that not everyone sees things in the same way (Veenman, Wilhelm, and Beishuizen 2004).

Furthermore, a study by Schneider and Lockl (2006) found that an individual's metacognitive knowledge will develop over the school years, in addition to their intellectual development. Veenman, Wilhelm, and Beishuizen (2004) explained that a person's metacognition changes over time.

Although metacognitive strategies are related to our cognitive system, they do not determine our intellectual abilities (Sternberg 1990, cited in Veenman, Van Hout-Wolters, and Afflerbach 2006). For example, the study by Veenman, Wilhelm, and Beishuizen (2004) showed that with a fairly high metacognitive background, a person with lower intellectual abilities could compensate for their deficits and learn.

The transversal or discipline-specific nature of metacognition can also be questioned. The initial assumption was that metacognition was a general, transversal ability that applies to all domains (Brown 1987). But since then, several studies have been carried out that contest this assertion. They show that metacognition is domain and discipline specific in young students, and that a gradual shift from discipline-specific to general metacognition occurs between the ages of 10 and 13 (Geurten, Meulemans, and Lemaire 2018; Veenman and Verheij 2003; Veenman and Spaans 2005). Thus, the students in our sample, aged 12–13, were in this transitional stage.

## Method

We formulated two research questions:

> Q1: How do 12- to 13-year-old students respond to metacognitive questions posed to them during a complex task in math or in science?
>
> Q2: Do these reactions differ depending on the discipline?

The research was based on the investigation of activities in a natural environment (Denzin and Lincoln 1994). Specifically, mathematics and science classes were the focus of our study. We chose them because in these disciplines, learners can work through problem situations that provide a link between the discipline and reality (Greer 1997; cited in Depaepe, De Corte, and Verschaffel 2015), and it is known that metacognition is a characteristic part of working through problem situations (De Vecchi and Carmona-Magnaldi 2015). Developing metacognitive strategies will allow students to improve their monitoring and regulation of problem-situation solution processes (Mevarech and Amrany 2008).

In addition, we chose to focus on students between the ages of 12 and 13. Starting at this age, students' metacognitive strategies are fully present (Veenman, Wilhelm, and Beishuizen 2004). Furthermore, research on metacognition and mathematics has focused mainly on students at the end of primary school and not, to our knowledge, on the metacognitive strategies of secondary school students. In science, we also found very little research related to metacognition in primary or early secondary education.

### *Participants*

Secondary education in Belgium is organised in three degrees: first degree (ages 12–14), second degree (ages 14–16) and the third degree (ages 16–18). The students participating in this research were in the first degree. They came from the same school: a general education school with a high socio-economic index in the capital of Belgium. All secondary 1 (12-year-old students) and secondary 2 (13-year-old students) classes of the school were involved. Thus, five secondary 1 and six secondary 2 classes experienced an activity in mathematics. Six secondary 1 and six secondary 2 classes experienced a science activity. These tasks are presented below. In each class, 4 student volunteers were orally questioned with metacognitive prompts. These four student volunteers were randomly selected from the pool of student volunteers in each class. This constituted a sample of 92 students: 20 secondary 1 and 24 secondary 2 students in math, and another 24 secondary 1 and 24 secondary 2 students in science.

This study conforms to the internationally accepted ethical guidelines and the ethical code of the Belgian Science Policy Office (www.belspo.be). We followed Bélanger and Richard's (2017) recommendations regarding the ethics of research in classroom context. Thus, the agreement of the school administration and the teachers was requested to start the research project. The participants and their parents signed a document giving their free, informed, and continuing consent to participate in the study, while respecting their anonymity. They also agreed to the use of the recordings for research purposes.

### *Procedure and data collection*

Each class completed a complex math or science task during a 50-minute session. The tasks were chosen based on the criteria for a complex task identified by De Vecchi and Carmona-Magnaldi (2015). This was to ensure that they were complex tasks that allowed students to activate their metacognitive strategies (Efklides 2008). In mathematics, students had to solve a problem related to the Fibonacci chain. In science, the task was related to identification of an animal jawbone. These two tasks are available in Appendix 1.

The same teacher implemented the activities in all classes for the same subject at the same grade level. Thus, there were four teachers: S1 math, S1 science, S2 math, and S2 science. The teacher was known to the students because he was their regular teacher. The researcher was present in the classrooms to ensure that the activities were carried out identically, and to collect data. Several questions (Colognesi 2015) were asked of the participating students before, during, and after the task. These are listed in Table 1. The teacher asked all 4 participating students in each class the pre- and post-task questions. Each one answered orally in front of the entire student group. The questions during the task were asked by the teacher or the researcher. The answers to these questions were made directly to the interviewer, one-to-one in an individual way.

All responses were recorded and transcribed. This corresponded to a total of 158 pages, or 84,688 words in total.

**Table 1.** Questions asked at different moments in the task (translated from French).

| Timing of the question | Questions asked of students |
|---|---|
| Before the task | • What do you understand about the task? What are your personal goals in relation to the task?<br>• How will you proceed: what steps do you think you will go through? |
| During the task | • I see that you have just modified, deleted, added, moved … Can you describe what you are doing?<br>• And now, how do you plan to continue completing the task? |
| After the task | • Did you achieve the goal, and why?<br>• If you do the same activity again tomorrow, what strategies will you adopt to be more effective? |

### *Data analysis*

Content analysis was applied to the data collected, following the recommendations of L'Écuyer (1990). A mixed model was chosen. This allowed us to base our coding on categories predefined by the theoretical framework, but also to develop new ones.

The qualitative aspect of the analysis is present through the description of the 'specific characteristics of the various elements (words, sentences, ideas) grouped under each category' (L'Écuyer 1990, 31). While the quantitative aspect of the analysis allowed in particular to highlight the distribution of the contents according to each category.

To ensure the reliability of the data analysis (Creswell 2007), three researchers were involved in the process. They read the verbatim transcripts several times, carried out the coding individually, and then discussed their codings until a consensus was reached.

First, the data set was broken down into units of meaning. This resulted in 1733 units of meaning: 1104 for mathematics and 620 for science. It should be noted that more than 50% of the meaning units in mathematics were identified as occurring during the activity. The other half was equally divided between the two other moments. In science, the units of meaning were also largely present during the task (about 40%), with about 30% before the task and about 30% after the task.

Second, these units of meaning were coded according to broad themes (related to the three dimensions of metacognition presented in the theoretical framework) and categories. Each unit of meaning could get exactly one code.

Finally, once the different units of meaning were listed under the themes and categories, a count of occurrences was made, in relation to the meaning units from the mathematics and science activities. We decided not to break out the verbatim quotes from secondary 1 and secondary 2 students and did not count them separately. This is because after a first attempt to compare the two groups, no major difference emerged in the type of answers given by the participants.

## Findings

In this section, we present the main findings from the analysis of the students' responses. Categories emerged for each theme that had been selected based on the three dimensions from our theoretical framework: strategies, feelings and knowledge. The theme of strategies was subdivided into four categories: explaining one's action, justifying one's choice, self-evaluation and projecting oneself. The theme of feelings was subdivided into two categories: insecurity and security. The theme of knowledge was subdivided into two categories: prior knowledge and knowledge from identified tasks already performed.

Figure 1, inspired by a proposal by Coppe et al. (2018), gives an overview of these themes and categories, and also of their relative frequency of occurrence, both in mathematics classes (blue box, on the left) and in science classes (green box, on the right). For the sake of clarity, percentages are based on the total number of units of meaning, overall or per subject, a total of 1733 units (1104 units in mathematics and 629 in science). The students most often answered the metacognitive questions by referring to strategies (theme 1: 66.8% of the total units of meaning in mathematics and 67.3% in science). They mentioned aspects relating to feelings (theme 2) next most frequently; this occurred relatively more often in science (25.9% of the total meaning units) than in mathematics (19.6%). Finally, the students talked about knowledge (theme 3) in their answers to metacognitive questions, more in mathematics (13.6% of the total meaning units) than in science (6.8%). Each theme is discussed below, and examples of quotes are provided to illustrate the points; these have been translated.

### *Theme 1: strategy-related responses*

This theme includes all types of strategies verbalised by the students. It was the richest theme in terms of its presence in the students' responses in both subjects, occurring in 66.8% of the total

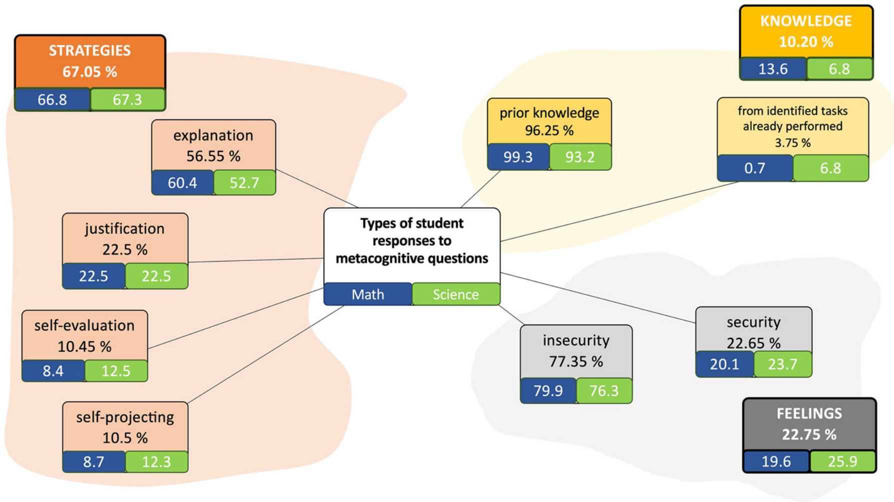


**Figure 1.** Overview of types of student responses to metacognitive questions.

units of meaning in mathematics and 67.3% in science. And when the students expressed themselves about their strategies, both before, during and after the tasks, their responses fell into four categories: they explained their actions (how they did it), they justified their choice (why they did it), they evaluated themselves (judged the strategies they used), and they made plans (how they would do it again when faced with a similar task).

## *Explanation of actions*

The highest number of units of meaning addressing strategies was in the first category, explanation of actions. This was true for both mathematics (60.4% of the units of meaning related to strategies) and science (52.7%). The students explained their actions in several ways.

First, they specified the objectives they set for themselves. They then referred to simple actions that they would take to respond to the instructions given to them. These actions were all taken before the task was carried out. The learners thus formalised the instructions with an action verb when they were asked to explain what they had understood about the task. And these types of explanations were in response to questions before working on the task.

> They made excavations in a region called Ostia. And it is necessary to explain, finally to find to which animal it belongs. (S2–before)[1]

Then, in order to explain what they planned, were doing or had done, the students specified actions. Most of them did so by mentioning a single action. This type of response can be described as not very elaborate. They simply linked the action with information found in the instructions or the objective.

> Well, I'm … , I'm eliminating in steps. (S1–during)

> But uh I delete the ones I don't believe who, well whose jaw doesn't belong. (S2–during)

Much more rarely, some students described hierarchical actions. These were multiple actions that were found in the student's reasoning and were connected by linking words such as 'and', 'then', 'and then', 'therefore', and so forth.

> I highlighted for me what was important. So, I highlighted how many pairs of rabbits. And I also highlighted 'breed at two months of age'. (M2–during)

> Uh, actually, I said what animal I was thinking of, who the skull belonged to. And so, I try to justify why by different elements present in the documents. (S2–during)

### *Justification of actions*

The second category, justification of actions, appeared in exactly the same proportion in both disciplines (22.5% of the units of meaning related to strategies per subject). Responses falling into this category were mostly present before and during the task. Most often, the students justified their choices in a fairly simple manner, without elaborating, as if it were obvious.

> I wrote down the information I know because I read the texts. And then I deduce the answer. (S1–during)

Nevertheless, when they did elaborate, it was by adding details, which occurred more frequently in science (57.9% of all justification-coded units of meaning) than in mathematics (26.5%). This may be a development that seems logical to the student.

> I draw a heart for a pair in the first month and I put nothing in it because they are not yet fertile. For the second month, I put the same heart again and there, I put '2' because it is the second month. And then I colour it black because they are ready to have children and … uh … I add another white heart because they have had a child. And so on. (M2–during)

In science only, the details came from information found in the documents made available to the students. Precision as a justification for an action was sometimes the result of an intuition that their way of doing things or the solution that they found was not correct.

> I'm going to recalculate because I think that 31 is absolutely not enough because I didn't count the others, in fact. (M1–during)

> I have listened to all the others speak and I will take into account the methods of others to see … Because I believe that my method is not very good. (M1–after)

### *Self-evaluation*

The third category, self-evaluation, includes all of the moments when the students said what they thought about the way they had performed (8.4% of the units of meaning related to strategies in mathematics, 12.5% in science). Comments falling into this category occurred mostly after the task had been completed. It was at this point that they were asked to express their point of view in terms of whether or not they had achieved their objectives. Only a few students gave explanations for their self-evaluation. The majority did not. Indeed, the students did not seem to know how to justify why they felt they had successfully completed the task.

> Uh no, I didn't get it. - No … well almost. (S1–after)

> I think I got it right because I double-checked it and I had circled each pair of rabbits with each colour and it matched. (M2–after)

The majority of students felt that they had probably met the goals in science (40 students of 46), but only half of them in math (22 students of 44).

### *Self-projecting*

The fourth category includes statements in which students mentioned anticipated strategies, that is, when they ' projected themselves' into the eventual completion of a similar task (12.3% of the units of meaning related to strategies in mathematics versus 8.7% in science). This projecting was carried out in two ways: The students either expressed that they would keep one or more strategies, or they mentioned planned changes. However, those changes remained simple and were not, in our opinion, strategies that were specifically effective for the tasks in question (e.g. writing, better reading).

> I think I would keep the same strategy, because I think I was effective and I don't know how else to do it. (M2–after)

> I think I'm going to find the animal first and then I'm going to write everything down. I think that's more what I'm going to do. (S1–after)

### *Theme 2: responses related to feelings*

When students responded to metacognitive questions, they also talked about their feelings (22.5% of the total units of meaning: 19.6% in mathematics and 25.9% in science).

These feelings were most related to insecurity (79.9% of the units of meaning related to feelings in mathematics and 76.3% in science) and somewhat less to security (20.1% of the units of meaning related to feelings in mathematics and 23.7% in science).

## Feeling of insecurity

Feelings of insecurity took on a very important role, almost identical in both disciplines. This insecurity was related to the task, the students themselves, or the conditions under which the task was performed. Task insecurity was present in relatively high proportions in both mathematics (46.9% of the insecurity-coded units of meaning) and science (39.6%). Aspects related to incomprehension were found, where students said that they did not understand the terms used in the wording of the task, or the way in which the information was presented.

> I don't understand because we are told: every month, a new pair, whereas we are told that in fact it's two months before there can be a new pair … so we have to wait two months before there is a new pair. But there, we are told that it is every month, so I don't understand. (M2–before)

> But the problem is that I've been thinking a bit and I don't understand how to turn this into a simpler calculation. (M2–after)

Some comments also referred to insecurity related to the students themselves, expressing a feeling of low confidence about success, and also the emotions felt, mainly stress, anger, and irritation. This type of uncertainty was present in 29.3% of the insecurity-coded units of meaning in mathematics and 29% in science.

> I'll never make it. (M2–during)

> I actually tried something at first, but it pissed me off. (…). (M2–during)

Insecurity was also related to the conditions of the task (3.6% of the insecurity-coded units of meaning in mathematics; 7.6% in science), expressing the feeling of lacking time and lacking available information.

> I didn't have time to finish but … because I only just realised a mistake I made. I didn't do enough at all because the first pair of rabbits, I forgot that the pairs of rabbits were still having children each time. So I didn't have time to finish. (M2–after)

> Well, I'm still hesitating between a few animals because we could have had a little more time, I think. And … well, there you go. (S1–after)

> I would like to have a more precise description to know what it looks like the most … (S1–during)

## Feeling of security

As for the feeling of security, which was the same overall in mathematics as in science (20.1% of the feelings-related units of meaning in mathematics vs. 23.7% in science), there were two aspects that appeared in the students' responses: confidence about carrying out the task and confidence in oneself.

> *I understood that one person put in two rabbits.* (M1–before)

> We know that the youngest pair of rabbits cannot have babies in the first month, so when they are two months old, they can have babies. (M1–before)

> After two months, the first rabbits can reproduce, if I am not mistaken. (M2–before)

> Now I understood that those who were born to other pairs also still do. (M2–after)

### *Theme 3: knowledge-based responses*

When students answered the metacognitive questions, they also reported calling upon prior knowledge and knowledge from identified tasks already performed. Even though that type of response was not very common overall (about 10% of the total units of meaning), appealing to knowledge was more frequent in mathematics than in science.

### *Prior knowledge*

Responses concerning prior knowledge represented 99.3% of the knowledge-related units of meaning in mathematics and 93.3% in science. In both mathematics and science, a large majority of the units of meaning that addressed knowledge occurred in responses to metacognitive questions before and during task completion. This included both rather general knowledge, and knowledge that was directly related to the discipline of mathematics or science.

> As he has 12 months in a year, that every two months, he will have new rabbits, then I decided to divide by two. (M1-during)

> First of all, they say that the city of Ostia is 3 km from Rome. There are animals that don't live in Rome. Then, there is his dental formula and their diet that will help me. (S1–before)

> It is to do multiplication: $\times 2 \times 2 \times 2$. (M1–before)

> Uh yes, because I trusted my basic knowledge and what was in the documents, well, putting my knowledge, rather the size of the animal, for example. And uh, I compared the size of the jaw, so there you go. I think that I was not mistaken on that. (S2–after)

## Knowledge from identified tasks already performed

The second category in this theme is knowledge from students' experiences, making connections with tasks that were similar that they had to complete before. This link was explicit and mentioned by the student. Very few students referred to this: only one in mathematics (0.7% of the knowledge-related units of meaning) and three in science (6.8%). This shows that this was a new situation for the students.

> I actually remember doing this this summer, I think. So, well, actually, I'm doing it again. (M2–during)

> Thanks to the lessons we have learned in the course. We have already had a task of classifying the animals on the map: all the animals are in the same country. (S1–before)

## Discussion

The purpose of this study was to answer two research questions, as follows: (1) How do 12- and 13-year-old students respond to metacognitive questions posed to them when performing a complex task in mathematics or science? and (2) Do these responses differ by discipline? To answer these questions, we looked at the responses of 92 secondary 1 and 2 students to metacognitive questions asked before, during, and after the task.

In relation to the first question, it appears that the students interviewed were generally able to say something in response to the questions asked of them. This tends to support what was stated in the work of Flavell (1992): metacognition can be fully activated at age 12. We found that participants responded to the questions by mentioning three different types of elements: strategies, feelings and/or knowledge. These broad aspects are not unlike the three dimensions of the concept of metacognition (Da Rosa et al. 2021; Efklides 2008 Jiang, Ma, and Gao 2016; Zohar and Barzilai 2013).

Responses related to the theme of strategies did show that metacognitive questions prompted students to reflect on their actions, become aware of their path, see their mistakes for themselves, and seek appropriate solutions (Veenman 2012; Veenman, Van Hout-Wolters, and Afflerbach 2006).

This can be done by anticipating/planning before the task and checking during and after the task (Berger and Büchel 2012; Colognesi et al. 2020), as was shown in responses where students tried to make their anticipated or completed actions explicit, justify their choices, self-assess, and project themselves into another go-round with a similar task.

One could therefore be delighted to read these lines. However, this was not the case. Instead, our results showed that the students' answers were not very elaborate. They explained their actions in a very simple way, and were not able to develop why they did this or that action. They evaluated themselves in a vague, weakly argued or unfounded way. They projected themselves into a similar task either by believing that they should keep the same way of doing things, or by mentioning strategies that are not very effective (better reading, writing information).

The fragility observed in the responses relating to strategies was not evident when the students responded by addressing their feelings. They were, in fact, able to verbalise what made them feel insecure (whether it was the task, the conditions under which it was performed or their feelings of competence or emotions) or secure. It was as if they were more familiar with feelings related to metacognitive experiences, with being able to put into words, for example, feelings of difficulty, confidence, and the like (Ben-David and Orion 2013; Efklides 2006, 2008). And to a lesser extent, this was also the case when some students said they drew on knowledge in working on the task.

The second question focused on comparing student responses in the mathematics and science classrooms. The comparisons we made (categories, way of answering the questions, representativeness of the categories) did not show any major difference between the two disciplines. The results showed that a large majority of the difficulties students had in developing their responses to the questions were the same regardless of the discipline (Geurten, Meulemans, and Lemaire 2018; Veenman and Verheij 2003; Veenman and Spaans 2005). This leads to the hypothesis that these difficulties are not inherent in a particular discipline, but lie rather in the students' lack of practice or training; at least, as far as mathematics and science are concerned.

### *Limitations*

This research is not exempt from limitations. First, the adult asked the questions of the student. The student had to answer in front of the whole class for the before and after questions, and in an individual interview for the 'during' questions. There were therefore two modalities of response: in front of peers, which can be embarrassing, and face-to-face with the adult. It would be interesting to replicate the study with other ways of responding: allowing students to respond in writing in a personal journal, for example, or to a classmate. Second, only two disciplines, science and mathematics, were considered. It seems appropriate to broaden the questioning to other disciplines, such as geography and language arts. Third, despite the fact that the same teacher presented the activity in the classes for the same grade and discipline, and that we checked that the activity's implementation was in line with what had been planned, differences may have existed between classes depending on whether the participating students trusted their classmates enough to dare to answer this kind of question publicly.

### *Practical implications*

Metacognition is not automatic for students; it requires teacher intervention (Büchel 2015; Schunk 2001). And while studies have shown that teachers do not necessarily prompt metacognition in their students (Depaepe, De Corte, and Verschaffel 2010, 2015; Vlassis, Mancuso, and Poncelet 2014), our study showed that when it is prompted, students have weak responses to metacognitive questioning, at least, with respect to strategies. An important practical implication therefore concerns being able to offer students training on these metacognitive aspects. There are several issues at stake. On the one hand, it is necessary to get them to understand why they are asked to engage in such reflection, which requires bringing them to understand the usefulness and relevance of metacognitive questions in terms of learning. If students think that these questions are useless, they will not get involved to any great extent. On the other hand, students also need to have the words to respond appropriately to metacognitive questioning.

This would undoubtedly involve work on how to access the strategies, including explicit teaching of them (Ko, Sammons, and Bakkum 2014), but also on the specific vocabulary needed to 'say what is in one's head'.

It also seems that more specific training of teachers in these aspects is necessary. Our research does not allow us to provide any solutions to this issue. This is the subject of our parallel work (Barbier and Colognesi 2020). While the relationship between the teacher and the student may be important in allowing students to 'open up' about their metacognitive strategies, it is nonetheless necessary to know how to solicit them and how to equip students to respond adequately. The tasks and verbatims we propose in this article could become training material in this sense.

## Conclusion

It is now well-established that engagement in metacognition improves academic achievement (Colognesi et al. 2020; Ko, Sammons, and Bakkum 2014; Rérat and Berger 2020; Veenman 2012; Veenman, Van Hout-Wolters, and Afflerbach 2006; Zimmerman, Bonner, and Kovach 2000). Yet, our study showed that when students are asked to respond to metacognitive questions before, during, and after a complex task, they do so in a simplified way, without elaborating upon or justifying what they say. And this is true for both subjects. This raises the question of training students in activating metacognition, in addition to training teachers.

## Note

1. The labels that go with the quotes show what group of students the quote came from; these do not refer to specific individuals. S1 = Science secondary 1 (12-year-old students); S2 = Science secondary 2 (13-year-old students); M1 = Mathematics secondary 1; M2 = Mathematics secondary 2. Time of response is indicated as before, during, or after the task.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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## Appendix 1

In mathematics, the students had to complete a task on the Fibonacci sequence. This was chosen as an activity that could be done by students without the need for new knowledge. The instructions given to the students were the following: *In 1202, Leonardo Fibonacci proposed a fun problem that describes the growth of a rabbit population with simplified assumptions: in the first month of the year, a man puts a pair of rabbits (male and female) in a place surrounded on all sides by a wall. How many pairs of rabbits will we get at the end of the year if, starting with one pair, each pair generates a new pair every month? Note that a pair of rabbits can only reproduce when they are two months old*.

In science, we chose to work on animal jaw analysis research. The instructions given to the students were as follows: During an excavation in the Ostia region, a jawbone was found. Identify it using the documents provided. Write a report noting all the steps you take to identify the animal.