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Where does the stone go when we drop it? Development of French schoolchildren’s knowledge of gravity

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In this study, we explored children’s knowledge of gravity at different ages (5–6, 7–8, and 9–10 years), by asking the same question (“*Where does a stone go when we drop it?*”) in three different contexts (on Earth, in a spaceship orbiting the Earth, and on the Moon). We tested the influence of context and children’s age on both the answers and the justifications they provided. We expected that children of all ages would find it easier to make correct predictions in the Earth context than in the other two contexts. We were also interested in the kinds of justification children construct and how these justifications change during ontogenesis. Seventy-two French children were individually interviewed at their school. None of them had received any direct teaching about gravity. Results showed that children found it easier to predict the fall of the stone on Earth than its behaviour in the other two contexts, but that the younger children predicted the fall of the stone on the Moon more accurately than the older children. This unusual developmental effect only occurred for the Moon context. We also found that the categories of justifications changed with age, with a move away from *intuitive* considerations towards *mechanistic* ones.

Keywords: Knowledge development; Elementary school students; Gravitation understanding; Contexts

1. Introduction

The study of knowledge acquisition and development in science, particularly for counterintuitive concepts, can offer powerful insights into many aspects of conceptual development, including the origin, nature and structure of concepts (Nobes and Panagiotaki, 2007). By so doing, it can also provide valuable information about conceptual change and learning (diSessa et al., 2004). Moreover, studying the acquisition of non-intuitive concepts can yield useful information about the relative roles of cultural mediation and direct experience in the development of this knowledge. Some areas of scientific knowledge cannot be experienced because they rely on abstract laws or imperceptible

entities (e.g., viruses) (Harris and Koenig, 2006). Indeed, they can actually prove to be counterintuitive. For instance, how can we know that the Earth is a sphere or that it revolves around the Sun if we cannot directly observe it? Although we may assume that it is “easier” to grasp nowadays, due to technological progress and all sorts of cultural mediation, such as books, television and formal education, children still appear to have difficulty with the concept that the Earth is round and that people can live all over its surface without falling off. Their everyday experience of the Earth is of a flat surface, where things fall down if they are not supported (Agan and Sneider, 2004; Nussbaum, 1979). A situation in which what we perceive and what we experience are in contradiction with what we are supposed to know is a highly ambiguous one.

Philosophy traditionally makes a distinction between two stages in knowledge construction. The first stage is triggered by the reception of information from the external

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world. The second stage can be described as the construction of a representation or the implementation of a set of processes leading to the integration of the received information (Doron and Parot, 1991). Although this description of knowledge building allows us to view conceptual development rather more clearly, it does not explicitly take into account the potential impact of human thought, providing feedback about the knowledge modelling or the interdependence between what we need to know and what we actually know. In order to build and develop knowledge, we must also be able to distinguish between what is “true” knowledge and what is “false”. This distinction becomes more salient when children have to learn “counterintuitive knowledge” (i.e., when their experience differs from the expected, or “true”, knowledge). According to von Glasersfeld (2001), knowledge is “true” or “false” because society conceives it thus, so the status of knowledge may change from one society to another, especially when it is “counterintuitive” or abstract. The scientific way of thinking is the one that is expected in Western society today. For instance, children are taught that the Earth is shaped like a sphere and is not flat. Von Glasersfeld (2001) makes a distinction between the knowledge we have to “learn”, such as the days of a week, and the knowledge we have to “understand”, such as scientific laws or how to do sums. We can assume that these different kinds of knowledge require different ways of reasoning in order to retain them. Space science, where knowledge has to be understood, rather than learnt, is a useful field to explore, as children cannot easily experience the concepts involved.

In this study, we sought to improve our understanding of the development of the concept of gravity in its universal form. To this end, the force of gravity was probed both on Earth and in space. After discussing the current state of research on the development of the gravity concept as the backdrop to our project, we describe the method we used in our study of 72 French children aged 5–10 years, who were asked about the trajectory of a stone when dropped in three different contexts: on Earth, in a spaceship orbiting the Earth, and on the Moon. Results are discussed in relation to the development of knowledge about gravity and new perspectives for research.

2. Knowledge acquisition and development of gravity

Gravity is a commonly experienced phenomenon that can be tested locally on Earth, yet it is explained by an abstract physical law and its universal form is counterintuitive. For example, gravity applies everywhere in outer space, which is ordinarily inaccessible to most of us. This characteristic of gravity is important when it comes to analyzing the role of cultural mediation in knowledge development. Several studies have investigated the acquisition and development of the concept of gravity. In their review of the literature on the learning of gravity, Kavanagh and Sneider (2007a,b) listed several misconceptions about gravity that are often found in the literature. Typical examples

include “gravity needs air”, “there is no gravity in space”, “objects in orbit are weightless, so gravity does not affect them”, “the force of gravity diminishes rapidly with increasing altitude”, “force is needed to keep an object in orbit”, “planets closer to the Sun or that spin faster have more gravity”, and “gravitational forces between objects are not equal and opposite”. Also highlighted in their paper were findings for the explanations given for the free fall of an object, first by kindergarten children then, moving on to explanations based on heaviness, by 7- to 9-year-olds.

By the age of 9–13 years, children start to express the idea of gravity being an invisible force. In a previous study, Noce et al. (1988) analyzed commonsense knowledge through the potential links between three concepts (weight, air, and gravity) in order to explain the free fall phenomena. They interviewed 10-year-old and 13-year-old Italian schoolchildren, first-year biology students at university and adults who were non-experts in physics. The participants had to perform a paper-and-pencil test in which the following question was asked: “An astronaut has landed on the Moon. From the door of the spaceship, he drops a spanner he had been holding in his hand. What happens to the spanner? Justify your answer”. Out of the eighty-eight 10-year-olds, 79 (90%) said that the tool would float and only 8 (9%) said that it would fall. Forty-two (48%) of them defined gravity as a force which only exists on Earth, and air was frequently invoked as a requirement for gravity to be exerted. According to the authors, there were no substantial differences between the young and older children, with only 4% of them being able to give the correct answer. It has also been shown that younger children (preschool and kindergarten) in the United States explain the free fall of objects on Earth through tangible actions whereas once they start school, they become used to the idea of an unseen force (Selman et al., 1982).

More recently, Bar et al. (1994) performed a study of weight and free fall. According to the authors, “throughout the history of science, action-at-a-distance has been regarded as problematic” (Bar et al., 1994, p. 152), and this may explain why it is such a difficult concept to understand. In their study, they sought to identify common ideas concerning free fall, by testing the consistency of children’s ideas concerning weight and free fall in different contexts. They conducted oral interviews with 400 Israeli children aged 4–13 years old, none of whom had received any formal instruction about weight and free fall. Authors created three categories of answers (support, heaviness and gravity) in order to analyze responses to the question “Why do things fall?” They observed that 4- to 5-year-old children’s answers reflected animist or theological thinking (“things fall because they have to”), although the children also adduced various physical explanations (“boats float because of water currents”) or explained that objects fall because they are not supported. Twenty percent of the 5–10-year-old children said that things fall because of heaviness and most of the 9–13 year-old students explained that

objects fall because of the Earth's force of attraction. Seventy percent of the 13-year-olds were aware that the force of attraction is responsible for things falling. The authors concluded that the different kinds of answers could be linked by the "commonsense theory" (Ogborn, 1985): gravity seems at the same time to be a force that keeps everything down, causes things to fall on Earth, and is related to the presence of air.

In another study involving older students, Bar and Zinn (1998) tested Israeli children's general framework of thinking about action-at-a-distance, such as gravity or magnetism. They asked 9- to 18-year-old children about (1) the need for air in magnetic interactions, and (2) the link they saw between gravity and magnetism. Their results indicated that children usually draw a connection between air and magnetic attraction (i.e., "a magnet needs air to work") and between magnetism and gravity (i.e., "a magnet cannot work on the Moon because there's no gravity there"). In the second part of their study, they found that about 50% of the 14- to 18-year-old children thought that gravity cannot operate without air. More than 60% of them thought that there is no magnetic attraction in a spaceship and 40% that a magnet cannot work on the Moon because it can only act under gravity (they therefore thought that gravity operates neither in a spaceship nor on the Moon). In a more in-depth investigation of beliefs about the force of gravity on Earth, Palmer (2001) conducted individual interviews of 112 students from Southeastern Australia: 56 aged 11–12 years old and 56 aged 15–16 years old. Students had to decide whether or not gravity was exerted in nine different situations, after being shown pictures of moving and non-moving objects close to the Earth's surface (e.g. "the person is jumping up from a trampoline"; "the brick is dropping downwards"), and then had to justify their answers. Eleven percent of the 11–12 year-olds and 29% of the 15–16 year-olds circled all items and gave a reason or an explanation that indicated that gravity was being exerted on each object. Authors noted a number of alternative conceptions that were clearly at odds with the scientific point of view, such as "gravity does not act on objects that are moving vertically upwards", "gravity does not act on stationary objects", "gravity acts upwards on objects which are moving vertically", and "gravity does not act on falling objects". Moreover, during the interview, 66% of the 11–12 year-olds and 68% of the 15–16 year-olds used both alternative and expected conceptions of gravity together, indicating a fragmented view of this concept. According to Palmer (2001), students "have multiple beliefs that are highly context-dependent", and the characteristics of the task influence the items of knowledge that are used by students to solve problems.

Very few studies have compared predictions about the effect of gravity in different contexts (on Earth and beyond, in the solar system, or in the Universe). Additionally, several concepts are usually studied together in order to highlight information about gravity. These seem to show that the force of gravity is only poorly understood and that

air is frequently thought to be a prerequisite. Nevertheless, few of these studies have confirmed their observations and results by means of rigorous statistical tests. Moreover, no studies of the acquisition and development of the concept of gravity have been performed in France up to now, and few studies have concerned preschoolers and younger schoolchildren. We, however, take the view that understanding young children's conceptions about gravity can provide relevant insights into the early development of the gravity concept and thereby inform the development of educational programs through the provision of appropriate recommendations.

3. The present study

The main goal of our project was to analyze the acquisition and development of knowledge about gravity in three different contexts: on Earth, in a spaceship orbiting the Earth, and on the Moon, in children aged 5–18 years old. In this paper, we present preliminary results obtained with children aged 5–6, 7–8, and 9–10 years old, based on their answers to three key questions.

We, too, set ourselves three questions:

- Can children predict the trajectory of a stone in different contexts?
- What kinds of justification do children use to explain the stone's trajectory?
- Can a developmental effect be inferred from their answers and justifications?

To answer these questions, we controlled for two variables: (1) context (Earth – spaceship orbiting the Earth – Moon) and (2) children's age (5–6 years – 7–8 years – 9–10 years). We examined two dependent variables: the children's answers and their justifications. Statistical analyses were used to test our assumptions.

Our hypotheses were that (1) children would give the "expected" (i.e., scientific) answer more frequently for the familiar context (on Earth) than for the unfamiliar ones (in a spaceship, on the Moon), (2) children would have difficulty justifying their answers (because they had never been taught about gravity), (3) older children would give the expected answers more frequently than younger ones (thanks to cultural mediation), and (4) older children would give more justifications based on physics than younger ones (thanks to cultural mediation).

4. Participants and material

4.1. Sample

Seventy-two French children took part in the study. They were divided into three age groups: 24 children aged 5–6 years ($M = 5$ years and 7 months; $SD = 4$ months); 24 children aged 7–8 years ($M = 7$ years and 8 months; $SD = 5$ months); and 24 children aged 9–10 years ($M = 9$

years and 7 months; $SD = 4$ months). These children were drawn from three city-center schools in Toulouse (a city in Southwest France). They had similar socioeconomic backgrounds and there were similar numbers of boys and girls in each group.

4.2. Apparatus

The children were shown three plastic-coated pictures (Fig. 1), each measuring approximately 17×13 cm, during the interview. Each drawing represented the context in which the action took place: on Earth, in a spaceship orbiting the Earth, or on the Moon (the order of presentation of the different contexts was counterbalanced to avoid a learning effect).

5. Method

5.1. Measures

We analyzed the children's responses to the three questions and the justifications they gave. The questions were based on Noce et al. (1988)'s task, which consisted in ask-

ing children to predict the fall of a spanner on the Moon and justify their answer. In our study, we asked two-part questions about the behaviour of a stone that is dropped in three contexts: on Earth, in a spaceship orbiting the Earth, and on the Moon. In the first part, children had to choose between three different answers (three possible trajectories of the stone). The second part took the form of an open question eliciting justifications for the previous answer.

The questions were:

- **On Earth**, Billy drops a stone. According to you, does the stone go this way (down), this way (floats) or this way (up)? Can you explain to me why the stone does that?
- **In a spaceship orbiting the Earth**, Billy drops a stone. According to you, does the stone go this way (down), this way (floats) or this way (up)? Can you explain to me why the stone does that?
- **On the Moon**, Billy drops a stone. According to you, does the stone go this way (down), this way (floats) or this way (up)? Can you explain to me why the stone does that?

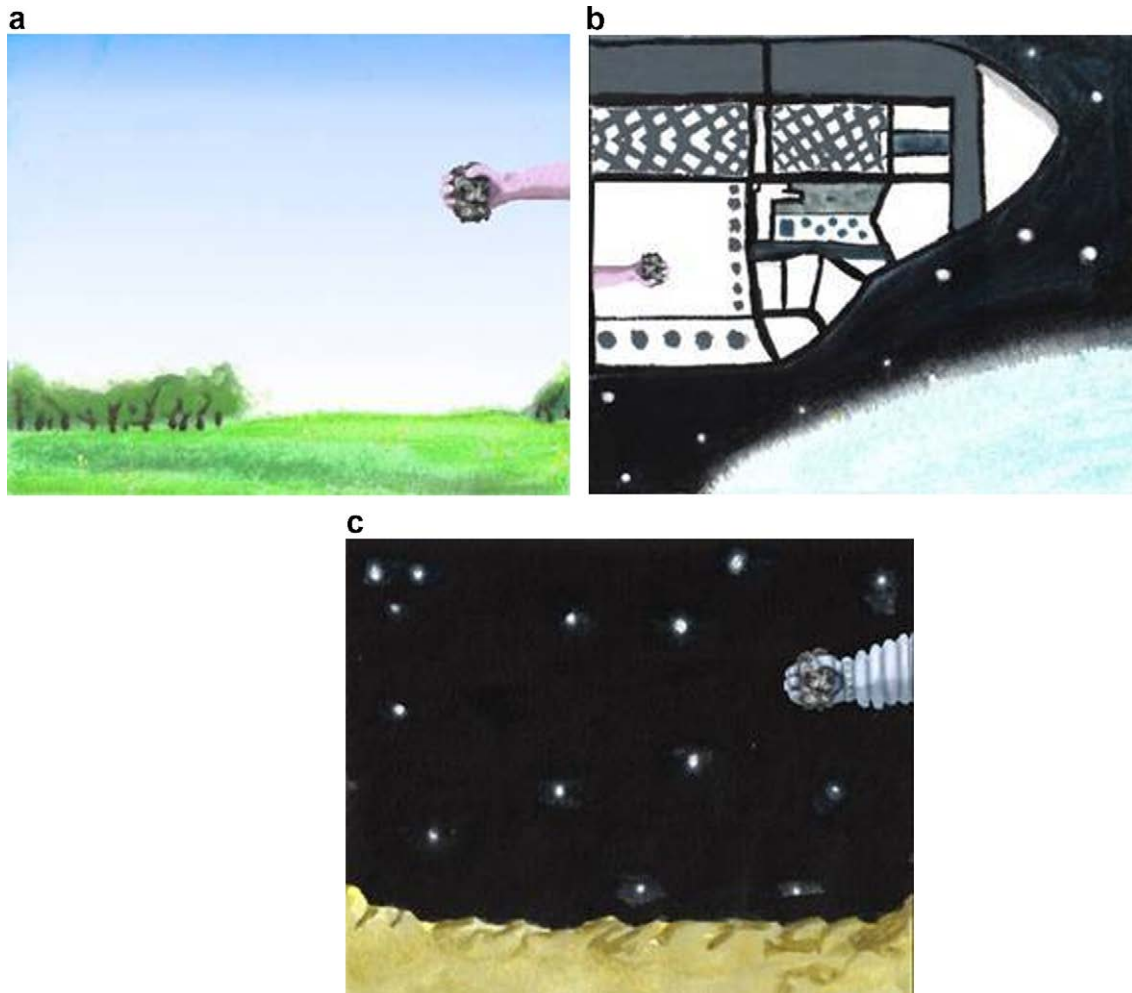


Fig. 1. Illustrations used for the question about gravity in three different contexts: on Earth (a), in an orbiting space ship (b) and on the Moon (c).

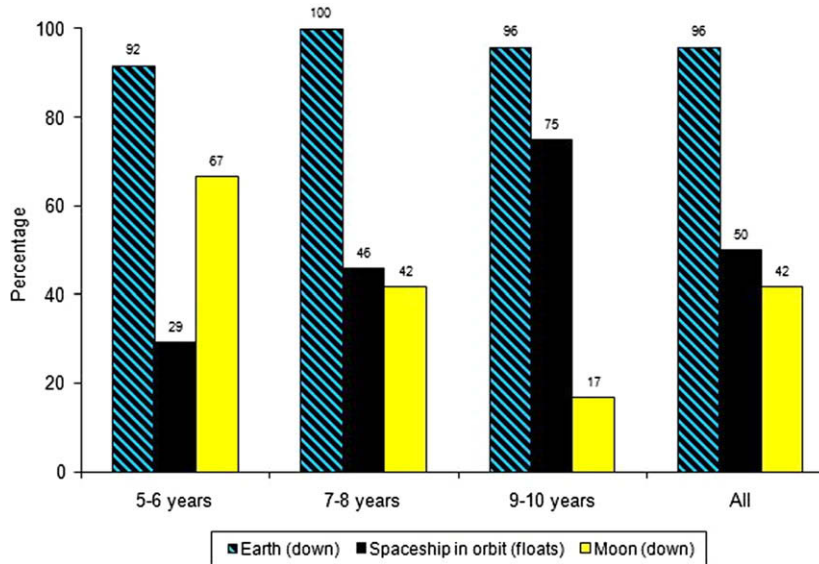


Fig. 2. Percentage of expected answers to the question “Billy drops a stone. According to you, does it go up, go down or just float?” for each context and for each age group.

Answers were classified as either expected or unexpected, according to the context in which the action took place. Each child was given an overall score made up of the sum of the answers in all three contexts (0 for an unexpected answer and 1 for an expected answer).

Justifications were divided into four categories, based on the most typical answers we observed. The first category (*intuitive* justifications) contained justifications that mentioned a feature of the stone or the protagonist (Billy) (“because of the stone’s shape”, “because of Billy’s hand”). The second category (*environmental* justifications) contained justifications that mentioned a characteristic of the environment (“because we are in space”; “because of the atmosphere”). The third category (*mechanistic* justifications) contained justifications that mentioned the notion of force (or gravity) (“because of the sun’s attraction”, “because the Earth is like a magnet”). The final category (*other* justifications) was used to designate failure to provide any sort of justification at all (“I don’t know”) and answers that could not be classified (“to make flowers”).

5.2. Procedure

Children were interviewed individually at their school. They were free to stop the interview whenever they wanted. The questions were explained and reformulated when necessary.

6. Results

The responses and justifications provided by the three groups of children for the three questions about the effect of gravitation in the three different contexts are presented below. We describe the responses and the kinds of justification given for each question according to the context and the age of the children.

6.1. Influence of context and children’s age on the answers

6.1.1. Effect of age

An analysis of variance (ANOVA) of the children’s mean scores showed that there was no overall effect of age on the number of expected answers, taking all the contexts together. In each age group, children had a mean score of 1.88.

For the Earth context, most of the children chose the expected answer (“down”), independently of age group (Fig. 2).

For the spaceship context, half of all children chose the expected answer (“float”), with the number of expected answers increasing with age. Older children gave the expected answer more frequently than younger ones, with significant differences between the 5–6 year-olds and 9–10 year-olds and between the 7–8 year-olds and 9–10 year-olds ($\chi^2(1) = 10.10, p < .0005$ and $\chi^2(1) = 4.27, p < .05$).

For the Moon context, less than half the children gave the expected answer (“down”), although the younger children gave this answer more frequently than the older ones. Here, the developmental path showed a decline. The 5–6 year-olds correctly predicted the fall of the stone on the Moon significantly more frequently than the 7–8 year-olds and 9–10 year-olds ($\chi^2(1) = 3.02, p < .05$ and $\chi^2(1) = 12.34, p < .0001$). Additionally, the 7–8 year-olds gave the expected answers for the Moon more frequently than the 9–10 year-olds ($\chi^2(1) = 3.63, p < .05$). These results can be directly compared with those of Noce et al. (1988), who observed that approximately 90% of 10-year-old Italian children predicted that a tool would float on the Moon. In our study, 83% of French 9–10-year-olds thought that the stone would float on the Moon.

6.1.2. Effect of context

A comparison of the numbers of expected answers given for each context revealed a significant effect of context on

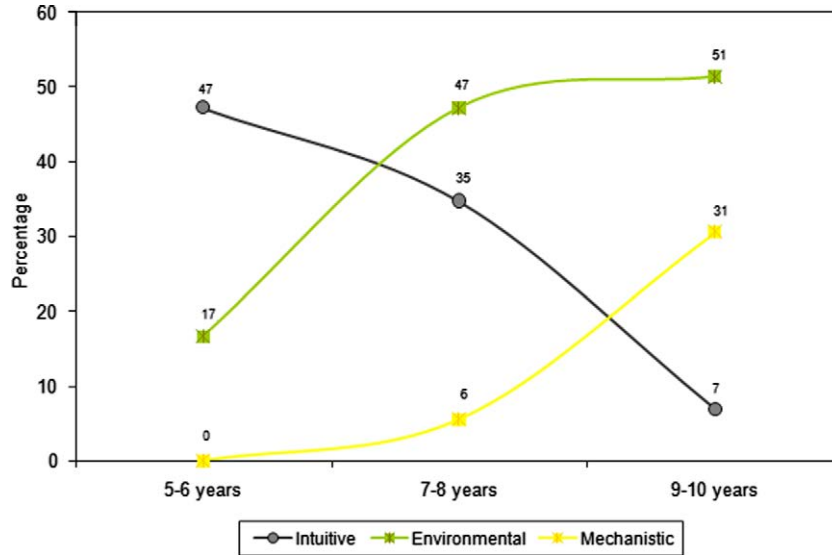


Fig. 3. Types of justification given for the stone's trajectory according to age group.

the number of expected answers across all ages ($Q^1(2) = 42.0$, $p < .0001$), and for each age group ($Q(2) = 17.0$, $p < .001$ for 5–6 year-olds; $Q(2) = 18.3$, $p < .001$ for 7–8 year-olds and $Q(2) = 25.3$, $p < .0001$ for 9–10 year-olds).

More specifically, we also observed (Fig. 2) that significantly more expected answers were given for the Earth context than for the spaceship context across all ages ($\chi^2Mc^2(1) = .75$, $p < .005$), as well as in 5–6 year-olds and 7–8 year-olds ($\chi^2Mc(1) = 6.76$, $p < .0001$ and $\chi^2Mc(1) = 4.11$, $p < .05$). Similarly, there were more expected answers for the Earth than for the Moon across all ages ($\chi^2Mc(1) = 14.59$, $p < .0001$), as well as in 7–8 year-olds and 9–10 year-olds ($\chi^2Mc(1) = 4.97$, $p < .05$ and $\chi^2Mc(1) = 12.00$, $p < .0005$). Finally, the 9–10 year-olds gave the expected answer more frequently for the spaceship context than for the Moon context ($\chi^2Mc(1) = 7.68$, $p < .01$).

6.2. Influences of context and age on the justifications

6.2.1. Effect of age

The justifications for the stone's trajectory were divided into four different categories. In the first, “*intuitive*” category, justifications referred to features of the protagonist (Billy) or the stone, such as “because stones are heavy”, “because stones don't fly”, “because of the stone's shape (or position)”, and “because of Billy's hand position”. The frequency of intuitive justifications (Fig. 3) varied between age groups ($\chi^2(2) = 29.35$, $p < .0001$), being significantly lower in 9–10 year-olds than in 5–6 year-olds and 7–8 year-olds ($\chi^2(1) = 29.57$, $p < .0001$ and $\chi^2(1) = 16.84$, $p < .0001$).

In the second, “*environmental*” category, justifications explicitly referred to the environment, such as “because

we are (not) in space”, “because in space we float”, “because there is (not) air (gas, oxygen)”, “because it looks like the Earth (Moon)”, “because it is (not) in the ozone layer”, and “because the ozone layer pushes down the stone”. The frequency of environmental justifications varied between age groups ($\chi^2(2) = 21.88$, $p < .0001$), being significantly higher in 9–10 year-olds and 7–8 year-olds than in 5–6 year-olds ($\chi^2(1) = 19.33$, $p < .0001$ and $\chi^2(1) = 15.46$, $p < .0001$).

We decided to call the third category “*mechanistic* justifications” because it contained answers where children managed to explain the phenomenon with reference to physical causes that could constitute part of a correct explanation. Justifications corresponded only partially to scientific explanations, as the children had neither the grounding in mathematics and physics nor the right vocabulary to provide rigorous explanations for such phenomena. This category therefore included arguments such as “because the Earth (space, Sun) attracts the stone (or Billy)”, “because a magnetic core exists (or does not exist)”, “because there is (no) gravitational force”, “because a force pulls it towards the ground”, “because there is (no) attraction in space (or above the ozone layer)”, and “because it is weightlessness”. The frequency of mechanistic justifications (Fig. 3) varied across ages ($\chi^2(2) = 36.03$, $p < .0001$), being higher in 9–10 year-olds than in 7–8 year-olds and 5–6 year-olds ($\chi^2(1) = 15.21$, $p < .0001$ and $\chi^2(1) = 25.97$, $p < .0001$).

6.2.2. Effect of context

Table 1 shows that the 5–6 year-olds and 7–8 year-olds used *intuitive* justifications for the Earth context more frequently than the 9–10 year-olds, who mainly justified their answers with reference to *environmental* characteristics.

Most of the time, for the spaceship orbiting the Earth and Moon contexts, the 5–6 year-olds either provided *intu-*

¹ Q = Cochran test.

² Mc = McNemar's test.

Table 1
Number (percentage) of justifications according to context and age group.

Type of justification	On Earth			In a spaceship			On Moon		
	5–6 years (n = 24)	7–8 years (n = 24)	9–10 years (n = 24)	5–6 years (n = 24)	7–8 years (n = 24)	9–10 years (n = 24)	5–6 years (n = 24)	7–8 years (n = 24)	9–10 years (n = 24)
<i>Intuitive</i>	14 (58%)	13 (54%)	3 (13%)	10 (42%)	7 (29%)	2 (8%)	10 (42%)	5 (21%)	–
<i>Environmental</i>	4 (17%)	9 (38%)	12 (50%)	3 (12%)	12 (50%)	13 (55%)	5 (21%)	13 (54%)	12 (50%)
<i>Mechanistic</i>	–	1 (4%)	7 (29%)	–	1 (4%)	7 (29%)	–	2 (8%)	8 (33%)
<i>Others</i>	6 (25%)	1 (4%)	2 (8%)	11 (46%)	4 (17%)	2 (8%)	9 (37%)	4 (17%)	4 (17%)

itive justifications or simply failed to justify their answers. The nature of their justifications differed significantly from those of the 7–8 year-olds and 9–10 year-olds for these two contexts ($p < .05$ for all differences). The 7–8 year-olds and 9–10 year-olds mainly invoked *environmental* justifications for both the spaceship and the Moon. *Mechanistic* justifications really only made an appearance in the 9–10 year-olds (approximately 30%), with no difference between contexts.

7. Discussion and conclusion

The aim of this study was to analyze the acquisition and development of knowledge about the concept of gravity in French schoolchildren aged 5–6 years old, 7–8 years old and 9–10 years old. Because we wished to explore the understanding of gravity in its universal form, we analyzed children’s predictions about this phenomenon in three different contexts, and investigated the nature of their justifications.

7.1. Answers

Most of the children (96%) correctly predicted the stone’s trajectory on Earth, but this figure fell to 50% for

the spaceship and 42% for the Moon. These results confirmed that children give expected answers more frequently for familiar contexts than for unfamiliar ones (first hypothesis). Children in each age group were able to make the expected prediction for the Earth (falling stone), but this was not the case for the other contexts. Interestingly, as we can see in Fig. 4, while predictions for the spaceship followed the usual developmental pattern, moving from unexpected answers to the expected one, the opposite effect emerged for the Moon context.

These results contradicted our third hypothesis (that older children provide expected answers more frequently than younger ones), because the number of expected answers was dependent both upon the age of the children and upon the context. There are various possible explanations as to why the 5–6 year-olds gave the expected answer for the Moon more frequently than the 7–8 year-olds and 9–10 year-olds. It may be that the preschoolers transposed what they intuitively knew about phenomena on Earth to the context of the Moon, as these two astronomical objects both belong to the same domain of knowledge (the Moon can be regarded as being similar to the Earth). As children grow older, their predictions may be modified through cultural mediation (TV, books, etc.), formal education or oral

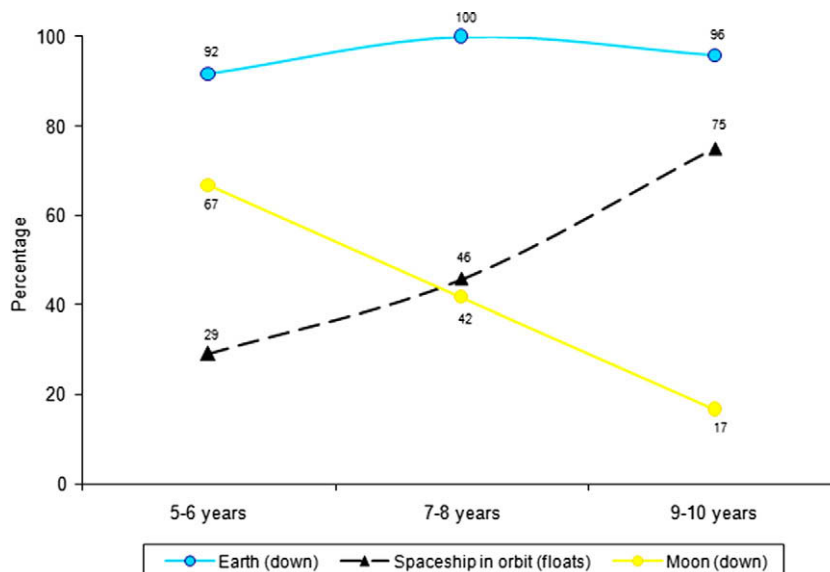


Fig. 4. Age-related changes in the number of expected answers to the question “Billy drops a stone. According to you, does it go up, down or just float?” for each context.

transmission (“the Moon’s different from the Earth”, “nobody can live there because there’s no air/no atmosphere”). Nowadays, we are surrounded by information about activities in space (e.g. satellite images, ISS videos of astronauts repairing the space station, etc.), but far less is said about the Moon, so we can hypothesize that this kind of cultural information helps children to predict what might happen in a spaceship but may, at the same time, disturb their intuitive knowledge about the Moon. We can also ascribe our results to the common misconception that if there is no air, there is no gravity (Kavanagh and Sneider, 2007b) and thus, as there is no air on the Moon, children assume that gravity is not exerted there and that the stone must float. We have shown that the developmental effect regarding the gravity concept must be analysed in relation to the context into which gravity is investigated. Our results confirm Palmer’s conclusion (2001), even though in our study, the notion of context was taken in its broadest sense (Earth, spaceship orbiting the Earth, Moon), while in his study it referred to the main characteristics of the action.

7.2. Justifications

Nearly half the 5–6 year-olds used *intuitive* justifications to explain their answers, whereas approximately 50% of the 7–8 and 9–10 year-olds cited a characteristic of the environment (“there’s no air”, “in space we float”). Only the 9–10 year-olds invoked the existence of a force to explain the stone’s movement (Fig. 3). The children’s justifications therefore displayed a developmental effect (fourth hypothesis).

The nature of the justifications also varied according to the context. At 5–6 years, children provided mainly *intuitive* justifications for the Earth and Moon, but were unable to formulate any clear explanations for what happens in a spaceship. At 7–8 years, children mainly justified their answers for the Earth using *intuitive* considerations, but made frequent references to *environmental* characteristics for the spaceship and the Moon. It would appear that, as far as they were concerned, the Moon belonged to the same domain as the spaceship. Finally, at 9–10 years, children explained their answers mainly by citing *environmental* characteristics, this being the case for all three contexts. The notion of force also started to feature in their justifications for each context. These kinds of justifications may reflect the fact that at this age, they have moved on to *mechanistic* considerations. These results confirm that children have difficulty justifying their answers (our second hypothesis) and that older children give more *mechanistic* justifications (based on physics arguments) than younger ones (our fourth hypothesis).

7.3. Conclusion

Our results show that gravity is a difficult concept to grasp and needs to be considered in the light of the context

in which it is exerted. We found that many children regarded gravity as a special property of the Earth, and older children seemed to have implicit recourse to the common misconception that “gravity needs air” through their *environmental* justifications. While they gave the expected answers for Earth (presence of air), they failed to predict the movement of the stone on the Moon (absence of air), possibly in the belief that there is no gravity there. We also found that even though children seemed overall to have good intuitions about the trajectory of a stone when it is dropped on Earth (gravity effect), they lacked scientific justifications. Indeed, 85% of them (all ages taken together) produced an expected answer associated with a non-*mechanistic* justification, and even in the 9–10 year age group approximately only 29% gave the expected answer associated with a *mechanistic* justification.

These preliminary results already provide some useful pointers for educators and teachers, highlighting the need to take into account the context in which gravity is exerted in order to adapt their teaching content. As Kavanagh and Sneider have already emphasized (2007a), the teaching of gravity should include constructivist aspects (conflicts, sociocognitive situations), and students’ intuitive and qualitative knowledge in different situations needs to be assessed, as it was in the present study. Moreover, teaching should be based on the identification and refutation of the most common misconceptions, such as the widely-held view that gravity is linked to air or that there is no gravity in space. It has recently been shown that taking such misconceptions into account in order to refute them leads to positive and robust conceptual changes regarding astronomical concepts (Frède, 2008). Moreover failure to understand the universality of gravity (which applies not only on Earth but everywhere in the Universe) seems to be the main obstacle for correctly predicting its effects, and it therefore needs to be taught at a very early age.

One way of dealing with the apparent contradiction between the universality of gravity and the fact that a falling stone apparently behaves differently on Earth and inside a spaceship orbiting the Earth would be to explain how objects are placed in orbit. This method might prove appropriate even for young children. Based on our own experience, drawings and dynamic computer models can be used to explain that the trajectory of a stone depends on the amount of force that is initially applied to throw it from the surface of the Earth, towards the horizon in front of us. If this initial force is strong enough, the stone will “fall” beyond the horizon (like rockets) and can be placed in orbit. By analogy, we could explain that satellites or spaceships orbiting the Earth are objects that are continually falling towards the Earth (gravity effect) but that they “never” reach its surface because their velocity is sufficiently great to keep them moving horizontally above the surface of our planet. Inside an orbiting spaceship, all objects fall towards the Earth, but simultaneously undergo the same acceleration as the spaceship and thus appear to be motionless inside the spaceship. If the spaceship

suddenly lost its velocity, it would fall down to the Earth in a straight trajectory towards its centre, just as a stone dropped from a tree would do. In order to portray a situation similar to that of an orbiting spaceship, but on the surface of the Earth, we could also show a simulation of a lift in free fall with unattached objects inside. It is important to teach the idea that the concepts of acceleration and speed are meaningless without a coordinate reference system. Put more simply, the same phenomenon (e.g., gravity) can give rise to different observations depending on the place (reference system) where it is observed.

We also found that the youngest French children in our study predicted the stone's trajectory on the Moon better than their older peers, suggesting that cultural mediation has a negative effect on learning and on the acquisition of knowledge about gravity. However, this assumption needs to be tested more extensively. The teacher's own understanding of gravity may also influence students' misconceptions. Several studies have shown that teachers labour under the same common misconceptions about gravity as their students, believing, for instance, that there is no gravity on the Moon or that the heavier an object is, the faster it falls, and not fully understanding the notion of "weightlessness" (Ameh, 1987; Galili 1993, 1995; Kruger et al., 1990; Reynoso et al., 1993; Smith and Peacock, 1992). It has already been shown that French elementary school teachers have misconceptions about the Earth and its dynamics (seasons, moon phases, night and day cycle) (Frède, 2006). In a future study, it would be interesting to collect French elementary school teachers' conceptions about gravity using the same three questions that were asked here, in order to assess their level of understanding and how it could influence children's answers. It might be also interesting to investigate dedicated scientific mediation (e.g., planetariums and science mediators), which can be a further source of poorly understood concepts.

Finally, we would like to stress two key conclusions of this study. First, we observed heterogeneous developmental paths concerning the ability to predict the trajectory of a dropped object depending on the context (on Earth or in space, with a reverse developmental path for the Moon). Second, we demonstrated that justifications follow a linear developmental path, moving from *intuitive* to *mechanistic* considerations.

In order to pursue this line of research, we plan to extend our study to children aged 12–13, 14–15 and 17–18 years, using a questionnaire about gravity containing approximately 50 questions. Our goal will be to describe subsequent developmental paths and changes in misconceptions and justifications regarding gravity in secondary school, in order to be able to draw up more specific recommendations for teaching this concept.

References

- Agan, L., Sneider, C. Learning about the Earth's shape and gravity: a guide for teachers and curriculum developers. *Astronomy Education Review* 2 (2), 90–117, 2004.
- Ameh, C. An analysis of teachers' and their students' views of the concept 'gravity'. *Research in Science Education* 17 (2), 212–219, 1987.
- Bar, V., Zinn, B. Similar frameworks of action-at-a-distance: early scientists' and pupils' ideas. *Science and Education* 7, 471–491, 1998.
- Bar, V., Zinn, B., Goldmuntz, R., Sneider, C. Children's concepts about weight and free fall. *Science Education* 78 (2), 149–169, 1994.
- diSessa, A.A., Gillespie, N.M., Esterly, J.B. Coherence versus fragmentation in the development of the concept of force. *Cognitive Science* 28 (6), 843–900, 2004.
- Doron, R., Parot, F. *Dictionnaire de Psychologie*. PUF, Paris, in French, 1991.
- Frède, V. Pre-service elementary teacher's conceptions about astronomy. *Advances in Space Research* 38 (10), 2237–2246, 2006.
- Frède, V. Teaching astronomy for pre-service elementary teachers: a comparison of methods. *Advances in Space Research* 42 (11), 1819–1830, 2008.
- Galili, I. Weight and gravity: teachers' ambiguity and students' confusion about the concept. *International Journal of Science Education* 15 (2), 149–162, 1993.
- Galili, I. Interpretation of students' understanding of the concept of weightlessness. *Research in Science Education* 25 (1), 51–74, 1995.
- Harris, P.L., Koenig, M.A. Trust in testimony: how children learn about science and religion. *Child Development* 77 (3), 505–524, 2006.
- Kavanagh, C., Sneider, C. Learning about gravity I. Free fall: a guide for teachers and curriculum developers. *Astronomy Education Review* 5 (2), 21–52, 2007a.
- Kavanagh, C., Sneider, C. Learning about gravity II. Trajectories and orbits: a guide for teachers and curriculum developers. *Astronomy Education Review* 5 (2), 53–102, 2007b.
- Kruger, C., Summers, M., Palacio, D. An investigation of some English primary school teachers' understanding of the concepts of force and gravity. *British Educational Research Journal* 16 (4), 383–397, 1990.
- Nobes, G., Panagiotaki, G. Adult's representations of the Earth: implications for children's acquisition of scientific concepts. *British Journal of Psychology* 98, 645–665, 2007.
- Noce, G., Torosantucci, G., Vicentini, M. The floating of objects on the Moon: prediction from a theory or experimental facts? *International Journal of Science Education* 10 (1), 61–70, 1988.
- Nussbaum, J. Children's conceptions of the Earth as a cosmic body: a cross-cultural study. *Science Education* 1, 83–93, 1979.
- Ogborn, J. Understanding students' understanding: an example from dynamics. *European Journal of Science Education* 7 (2), 141–150, 1985.
- Palmer, D. Students' alternative conceptions and scientifically acceptable conceptions about gravity. *International Journal of Science Education* 23 (7), 691–706, 2001.
- Reynoso, E., Fierro, E., Torres, G. The alternative frameworks presented by Mexican students and teachers concerning the free fall of bodies. *International Journal of Science Education* 15 (2), 127–138, 1993.
- Selman, R., Krupa, M., Stone, C., et al. Concrete operational thought and the emergence of the concept of unseen force in children's theories of electromagnetism and gravity. *Science Education* 66 (2), 181–194, 1982.
- Smith, R., Peacock, G. Tackling contradictions in teachers' understanding of gravity and air resistance. *Evaluation and Research in Education* 6 (2&3), 113–127, 1992.
- Von Glasersfeld, E. Radical constructivism and teaching. *Perspectives* 31 (2), 191–204, 2001.