Chapter 4
Developing Children's Questioning Skills for Inquiry in STEM

Marta Carli, Anna Fiorese, and Ornella Pantano

4.1 Introduction

Questioning is a creative act (Murcia et al., 2020; Chin & Osborne, 2008; Burnard et al., 2006). When students ask questions, they engage in higher order thinking, establish relationships between new ideas and prior knowledge, and construct meanings (Shodell, 1995; Cuccio-Schirripa & Steiner, 2000; Chin, 2001). Asking questions is also one of the 'core practices' of science education (National Research Council (NRC), 2012). Children's questions are often driven by curiosity, which is one of their distinctive characteristics; however, in classrooms settings, students ask few spontaneous questions, and even less in the search of knowledge (Dillon, 1988).

An element that can either enhance or hinder children's questioning is the learning environment. A judgmental environment, or one where children's questions are not welcomed, can stifle children's creativity (Biddulph et al., 1986; Chin & Kayalvizhi, 2002). The design of the learning environment also includes the pedagogical approach adopted in the classroom. Several accounts have reported that Science, Technology, Engineering and Mathematics (STEM) disciplines are still too often taught using transmissive-prescriptive pedagogies, particularly in primary school (European Commission, 2007; National Academies of Science, Engineering & Medicine, 2019). To overcome the limitations of these methods, pedagogies based on inquiry have been called for by many international documents (National Research Council [NRC], 1996; NRC, 2000; European Commission, 2007). Inquiry-based learning (IBL) includes a variety of instructional strategies through

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which students engage in scientific practices (Crawford, 2014; Osborne, 2014; NRC, 2012). This approach assigns the students an active role in the construction of their knowledge, increases their interest towards science, and contributes to the development of both science knowledge and skills and of general competencies (Crawford, 2014). To summarise the features of IBL, Pedaste et al. (2015) have developed a synthesised 'inquiry cycle' that combines the strengths of different IBL frameworks. This inquiry cycle has been used as the basis for our case study and is explored in more detail later in this chapter.

The purpose of the current study was to explore what characteristics of a STEM learning environment can develop children's questioning skills. We begin by defining 'asking questions' as a scientific practice and we review the literature for the strategies that enhance children's questioning. We then describe our action-research case study conducted in a fourth-grade classroom of primary school (children aged nine to ten), describing the methods and strategies used to set up a question-enhancing environment, and analysing children's questions to understand to what extent these strategies were successful in fostering children's ability to ask knowledge-based, investigable questions. Finally, we discuss our results, and we map our study onto the conceptual framework for creativity that shapes this book.

4.2 Background

4.2.1 Asking Questions for STEM Inquiry

Science is always rooted in a question. For this reason, 'Asking questions' is one of the 'scientific practices' that should be developed by science education, according to the *Framework for K-12 Science Education* (NRC, 2012). More specifically, students should be trained to formulate scientific questions, which, in the school context, means "questions that can be answered empirically in the classroom" (ibid., p. 57). Such questions can be driven by curiosity about the world, by experience, or by the need to find a solution to a problem. Student questioning is particularly valued in 'open inquiry' settings (Banchi & Bell, 2008), which are not, however, the only authentic type of inquiry (Crawford, 2014). In order to include the whole spectrum of inquiry-based activities—with varying levels of teacher scaffolding—Herranen and Aksela (2019) have grouped all inquiry approaches that include student-generated questions under the notion of *Student-Question-Based Inquiry* (SQBI).

Despite the importance of student questioning acknowledged by the literature, teacher questioning often dominates, and children have few opportunities to develop questioning skills (Reinsvold & Cochran, 2012; Osborne, 2014). In order to promote a change towards a more authentic student-centred pedagogy, Stokhof et al. (2017) suggested a range of strategies that teachers can adopt to support the generation, formulation and answering of student questions.

The goal of the 'generating' phase is to encourage students' questioning; this is an open, divergent phase which needs a question-welcoming classroom culture. In this phase, teachers can elicit student's questioning by engaging them with experiences that are relevant for their life and by providing adequate stimuli that evoke cognitive conflict or wonderment (Stokhof et al., 2017; Biddulph et al., 1986).

The 'formulating' phase is a more convergent one where teachers help the students refine their questions. One of the suggested strategies for this phase is to encourage the students to write down their questions (Chin & Brown, 2000), so that they can be categorised in order to identify the ones that can be used to structure an investigation. This process can be repeated at different stages of inquiry, and, at the end of an inquiry cycle, they can drive the next steps of the investigation (Harris et al., 2012). Collaborative practices such as negotiating the questions in a small group have also been strongly recommended (Stokhof et al., 2017; Herranen & Aksela, 2019). Chin (2004) argued that, when students engage in collaborative work, the question posed by an individual can stimulate similar questioning processes in other members of the group; as a result, group questions are usually more focused and refined than those asked individually. Modelling the formulation of questions is another suggested strategy (Stokhof et al., 2017; Biddulph et al., 1986). For instance, White and Gunstone (1992) proposed encouraging the students to formulate questions beginning with "What if…", "Why does…", "Why are…", "How would...", as such questions are more likely to be based on deeper thinking than simple recall. Finally, questioning can be supported by visual tools and organisers of variable complexity (Stokhof et al., 2017), especially when the children are not experts (Lord, 2011).

In the 'answering' phase, teachers can support students by asking them procedural questions concerning planning and conducting experiments (Harris et al., 2012). In this regard, Chin (2006) proposed a specific strategy called self-questioning, which should also gradually increase students' autonomy. Her proposal is grounded in Vygotsky's theory of self-regulation (Vygotsky, 1962), which describes the shift from an 'external' speech, where the activity of the child is directed by an external agent, to 'self-regulation' where it's the internal speech that drives the child's behaviour. In the intermediate stage, children internalise the external agent's messages by talking aloud to themselves. A teacher who has the habit to guide children's work using questions can therefore promote a shift from external to internal questioning, so that it gradually becomes the children's own habit, by carefully scaffolding this intermediate stage.

Moving from these insights, Stokhof et al. (2019) developed a 'scenario' to guide effective students' questioning comprising five phases. In the first and last phase, teachers use mind maps (an initial 'expert mind map' as a reference for designing the learning path and a final 'classroom mind map') to guide students' questioning and evaluate students' learning. The three central phases are devoted to formulating, generating, and answering students' questions, by adopting the above-mentioned strategies.

4.2.2 Evaluating Children's Questions

In order to evaluate the 'quality' of students' questions for STEM inquiry, we can adopt either a quantitative or a qualitative point of view. The latter evaluates the orientation and complexity of the questions and it is more meaningful when we aim to investigate children's questioning in relation to the development of creativity.

Dori and Herscovitz (1999) proposed to classify children's questions according to the level of the cognitive process required to answer them, using taxonomies such as Bloom's (Bloom, 1956; Anderson & Krathwohl, 2001). Based on this criterion, a first level of categorisation consists in dividing the questions into 'lower-order' and 'higher-order' questions. The classification by Hofstein et al. (2005) belongs to this type of categorisation: it defines 'low-level' questions, referred to facts or basic explanations, and 'high-level' questions, which require further investigation to be answered. Higher-level questions are more influential in constructing knowledge compared to lower-level questions. Similarly, Di Teodoro et al. (2011) distinguished 'surface' and 'deeper' questions, describing deeper questions as questions that provide students the opportunity to create, analyse or evaluate.

Watts et al. (1997), instead, classified students' questions according to their role in the process of conceptual change. They distinguished 'consolidation' questions, aimed at confirming understandings, 'exploration' questions, aimed at expanding knowledge, and 'elaboration' questions, aimed at evaluating claims and reconciling cognitive conflicts.

Scardamalia and Bereiter (1992) differentiated between 'basic information' and 'wonderment' questions. The former are oriented to the type of basic information normally conveyed by textbooks. Wonderment questions, instead, are those generated by an authentic curiosity and can be oriented to understanding, prediction, planning, or clarification of anomalies and inconsistencies. Chin and Brown (2000) have associated 'wonderment' questions with a deeper approach to learning and they have found that these questions are at a higher cognitive level.

Finally, a categorisation more directly related to classroom inquiry was proposed by Chin and Kayalvizhi (2002), who introduced a distinction between 'investigable' and 'non-investigable' questions, depending on whether or not they lead to inquiry cycles that can be carried out in the classroom. This definition is in line with the one by the *Framework for K-12 Science Education* reported above, where being 'empirically answerable', or not, is always understood in the classroom context. 'Investigable' questions include different types of questions: 'comparison' questions, aimed at making a selection among a number of items to be tested; 'cause-and-effect' questions, related to causal mechanisms and relationships; 'prediction' questions, aimed at testing a hypothesis; 'design-and-make' questions, related to problem solving; and 'exploratory' questions, dealing with the preliminary stages of inquiry. 'Non-investigable questions', on the other hand, include questions seeking for basic facts, but also, at the opposite end, complex questions that are not directly accessible to the students (either because they are too general or because investigating them requires sophisticated knowledge, skills or equipment), and finally, questions that cannot be answered by science. We notice that, in Chin and Kayalvizhi's (2002) definition, questions that can be answered by research by secondary sources are considered 'non-investigable questions', although this activity is considered authentic inquiry by several accounts, such as the *National Curriculum for Science in England* (Department for Education, 2014). However, here the authors are not discussing what inquiry is and what it is not; their categorisation refers to questions that can lead to practical investigations in the classroom.

4.2.3 Questioning, Inquiry, and Creativity

Among the possible definitions of creativity, Murcia et al. (2020) defined it as 'the ability to generate original ideas that are appropriate to the task at hand'. This definition contains the two core features of creativity on which researchers generally agree: originality (or novelty) and value (or appropriateness) (Runco & Jaeger, 2012). Based on a careful examination of the literature, the authors have also developed an innovative framework, the *'A' to 'E' of children's creativity*, constructed as an adaptation of the *Four Ps of Creativity* proposed by Rhodes (1961) and also presented in Chap. 1 of this book. The new framework also contains four 'Ps', which are: 'product' (criteria for creative outcomes: originality and fit-for purpose), 'person' (perspectives on who does the original thinking: educator, child's creative doing or child's creative thinking), 'process' (characteristics of children's creative thinking) and 'place' (the elements that support creativity in an educational context). We spend some more words on the 'process' and 'place' dimensions since they are relevant in our study, the former being connected with the practice of 'questioning' and the latter to the learning environment, which in our case is an inquiry-based setting.

The characteristics of children's creative thinking included in the 'process' dimension of the *'A' to 'E' framework* are grouped into five clusters: Agency, Being Curious, Connecting, Daring and Experimenting. Each of these clusters contains a set of more specific actions: for instance, 'Being curious' includes questioning, wondering, imagining, exploring, discovering and engaging in 'what if' thinking. This latter element is related to the notion of 'possibility thinking' suggested by Craft (Craft, 2002, 2007; Craft et al., 2012) as a driving feature of creativity and described as the process through which children make the transition from 'what is' to 'what might be' or 'what can I do with this'; or, equivalently, it involves the posing, in multiple ways, of the question "What if…?". 'Question posing' has been identified as one of the seven key features of possibility thinking by Burnard et al. (2006), alongside with play, immersion, innovation, risk-taking, being imaginative, self-determination and intentionality. Chappell et al. (2008) have described a taxonomy of question posing that includes the framing of the question being posed (from 'leading' questions that drive children's activity, to 'follow-through' questions related to the details of execution of an idea), their degree of possibility (from 'broad' to 'narrow': the broader the inherent possibility, the more creativity is fostered), and their modality (including verbal and non-verbal forms). The authors also identified nine types of 'question responding', including predicting, testing, evaluating, compensating, completing, repeating, accepting, rejecting and undoing. This categorisation is relevant to our study since it describes a set of actions that can be initiated by a scientifically investigable question.

The 'place' is related to the learning environment that an educator can set up to facilitate children's creative thinking. Among the 'resources' she can use are intentional provocations, stimulating materials, adequate materials for everyone and time for creative exploration. The educator can also work on her communication by setting up intentional learning conversations, hearing and valuing children's ideas, open inquiry questioning and facilitating conversations between children. Finally, it is essential that the educator creates a pressure free, non-prescriptive and non-judgemental environment. These characteristics of a learning environment resonate well with those of inquiry-based settings. In fact, inquiry-based learning has been listed among the pedagogies that can foster the development of creativity. Inquiry-based and creativity-oriented pedagogies share a child-centred perspective that highlights the role of experiential learning. In the context of the EU project *Creative Little Scientists* (CLS, 2011–2014, also presented in Chap. 2 of this book; Creative Little Scientists, 2014a), Cremin et al. (2015) have identified a number of synergies between inquiry based learning (IBL) and creative approaches to learning, including:

- *Play and exploration*, as investigations (particularly open-ended ones) support the development of creativity.
- *Motivation and affect*, as wonder and interest can lead to scientific inquiry.
- *Dialogue and collaboration*, as the social and collaborative nature of creative contexts can enhance understanding of scientific processes.
- *Problem-solving and agency*, as engagement with problems, which is essential in IBL, fosters children's agency and ownership of learning.
- *Questioning and curiosity*, recognised as essential in driving both inquiries and creative processes.
- *Reflection and reasoning*, related to creativity as the generation and evaluation of ideas.
- *Teacher scaffolding and involvement*, on which the efficacy of both IBL and creativity approaches depend, and which include providing a 'rich' environment, promoting group work, and the opportunity for children to engage in exploring different materials and resources.

Based on these elements, the consortium of the CLS project have developed a definition of creativity specifically tailored for science: in this context, creativity can be understood as 'Generating ideas and strategies as an individual or community, reasoning critically between these and producing plausible explanations and strategies consistent with the available evidence' (Creative Little Scientists, 2014b). This definition, connected with the one above by Murcia et al. (2020), resonates well with the definition of 'good' questions for investigations shaped by the literature on questioning for inquiry. In fact, according to these definitions, questions that are both 'wonderment' and 'investigable' are 'creative' in that they are original (they aim at extending knowledge) and appropriate (they lead to an investigation); they are connected with possibility thinking since they are of the 'what if', 'what might be', or 'what can I do' type, while, for instance, basic information questions are restricted to 'what is'; and they foster the generation of strategies for setting up a classroom inquiry.

Moving from this background, we set up a case study in order to investigate what strategies a teacher could adopt in order to help the children develop questioning skills in the context of STEM disciplines. Our research hypothesis was that an inquiry-based learning environment, enhanced by the use of a specific scaffolding strategy, could increase the quantity and quality of the questions posed by the students.

4.3 Our Case Study

In order to test our research hypothesis, we designed an inquiry-based learning unit on the topic of light, which was then implemented in a fourth-grade classroom (children aged nine to ten) of 24 pupils (12 male, 12 female) in a rural primary school in Italy.

We adopted an action research approach. The teacher who conducted the experimentation (2nd author) was a student teacher during her master thesis internship. Before the intervention, she observed the children and how the classroom teacher used to conduct science lessons. The classroom timetable featured science lessons twice a week (2 h a week). These lessons were usually conducted using traditional science teaching, where facts and principles are taught using a transmissive-prescriptive approach, mainly following the textbook. Experimental activities were occasionally proposed, just as a verification exercise, carried out personally by the science teacher while students played the role of observers. The inquiry-based learning unit conducted by the student teacher thus constituted a novelty for the children.

The learning unit comprised five lessons in total. The first introductory lesson was aimed at launching the topic and at gathering information about the children's initial knowledge and questioning skills. In the following three lessons, the children were divided into small groups (four to five pupils) and they were involved in three inquiry cycles, each one developing a different aspect of the topic (light propagation; interaction between light and objects; reflection from plane mirrors). The groups were formed with the help of the classroom teachers (not only the science teacher but also the teacher of Italian, who used group work more often during her lessons) based on their knowledge of the children, with the aim of favouring a constructive climate within each group. In order to facilitate group dynamics and to favour active participation of all the children, each child was assigned a role in the group: one or two children were in charge of the materials used during the investigations, one read the lab worksheets aloud, one was responsible for writing down all the questions, one was the 'spokesperson' and another one was in charge of the general management of the group. The roles changed from one lesson to another so that each child could experiment with different roles.

Each inquiry cycle was completed within a lesson and was structured in different ‘inquiry phases’ (Pedaste et al., 2015):

- *Orientation* or *Engage*, aimed at stimulating children’s interest and curiosity about a topic or a problem.
- *Conceptualisation*, aimed at identifying the concepts involved in the problem, and further sub-divided into a *Questioning* phase (leading to the formulation of a research question), and a *Hypothesis Generation* phase, where a testable hypothesis is generated.
- *Investigation*, where children try to find an answer to their research question through the sub-phases *Exploration*, *Experimentation* and *Data Interpretation*.
- *Conclusion*, in which the students resume their research question and see whether their results provide an answer and/or supports their hypothesis.
- *Discussion*, including the two sub-phases *Communication* and *Reflection*, the latter intended as a process of personal reflection on the inquiry, and the possible elaboration of new questions for a further inquiry cycle.

The children were encouraged to write down their questions both at the beginning and at the end of each inquiry cycle. Scaffolding strategies aimed at facilitating the formulation of questions were introduced and/or removed gradually in order to evaluate their effect on children’s questioning; they are summarised in Table 4.1 together with the cycle(s) in which they were used.

A detailed description of each inquiry cycle is provided in the ‘Results’ section, where children’s questions are reported and analysed, in order to better link the content of each lesson to the questions that were formulated. Finally, the last lesson was devoted to an ‘authentic task’ related to the topics of the unit.

Table 4.1 The strategies used to facilitate children’s questions

Strategy	Inquiry cycle(s)	Description
Stimulating materials	All cycles	An engaging or surprising experience was proposed at the beginning of each cycle.
Self-questions (Chin, 2006)	All cycles	The planner used by children to structure their investigation contained some questions formulated on the model of Chin’s (2006) self-questions.
Modelling	2nd cycle	The teacher provided examples of ‘investigable’ questions. This scaffolding strategy was removed after the 2nd cycle in order to ‘fade out’ direct teacher’s support.
Collaborative questioning	2nd and 3rd cycles	The children, divided into small groups, formulated questions collaboratively as well as individually.
Question hands (Lord, 2011)	2nd and 3rd cycles	The children were provided with the printed shape of a hand, in which they had to write five different questions, one for each finger. Its aim was to encourage the children to formulate multiple questions, going beyond the spontaneous ones.

4.4 Methodology

We monitored children's questions as the learning path developed, in order to look for evidence of an evolution in their questioning skills.

For each inquiry cycle, we analysed the questions that the children reported in their notebooks, labelling each question according to two categorisations:

1. *'Basic information'* vs *'Wonderment' questions*. This categorisation refers to the one by Scardamalia and Bereiter (1992) (see Table 4.2) and is aimed at evaluating the depth of children's approach to learning (Chin & Brown, 2000).
2. *'Investigable'* vs *'Non-investigable' questions*. This categorisation refers to the one by Chin and Kayalvizhi (2002) and it is aimed at identifying questions that can be answered empirically in the classroom (see Table 4.3).

We highlight once again that, in this context, by 'investigable' we mean 'classroom-investigable', in line with the definition by Chin and Kayalvizhi (2002) and by the *Framework for K-12 Science Education*. In our definition we have also specified that we focus our attention on 'practical' investigations, i.e., investigations where pupils directly manipulate or engage with the materials they are studying (Millar, 2010). Although we acknowledge research by secondary sources as an authentic investigation type, this kind of investigation was not considered in this study where the children could actually set up practical classroom investigations with the materials and objects they had at their disposal. In the following we will use the term 'investigable' with no further specification for simplicity.

The two categorisations described above are not independent. In fact, 'Basic information' questions are always 'non-investigable' as they are oriented to obtaining factual or procedural information that can be easily retrieved in a textbook or by asking the teacher (e.g., "What's inside the box?"). In this category we included questions referred to knowledge that children should possess already, e.g., repeating the conclusions of an inquiry cycle. We will label these questions simply as 'basic information'. At the opposite pole, 'wonderment', 'investigable' questions are the ones that not only reflect an authentic curiosity and can bring to an advancement in knowledge, but that can also be answered empirically in the classroom (e.g., "Are there other ways to modify the direction of light?"). Finally, a question can be of the 'wonderment' type but 'non-investigable', when it expresses a genuine curiosity to which, however, it is not possible to answer in the classroom setting, either because

Table 4.2 'Basic information' vs 'wonderment' questions

Type	Description
Basic information questions	Questions oriented at the kind of information normally conveyed in textbooks. This category includes 'uneducated questions', i.e., yes/no questions having a similar motivation to obtain basic factual information.
Wonderment questions	Questions oriented at generating explanations and to extend knowledge in terms of understanding, prediction, application, planning of inquiry, or reconciliation of a cognitive conflict.

Table 4.3 'Investigable' vs 'non investigable' questions

Type	Description
Investigable questions	Questions that can be answered by 'practical' classroom investigations. They include questions dabout comparison, cause and effect, prediction, design-and-make, and exploratory questions.
Non-investigable questions	This category includes basic information questions, complex information questions that are not accessible to 'practical' classroom inquiry, and questions that cannot be answered by science.

it is very broad (e.g., "What is light?"), or because it requires knowledge or tools that are not accessible to the children (e.g., "Why can't we make light bend?"). These are questions which might be answered by research by secondary sources, which was not, however, considered in the context of this study.

4.5 Results

In the following we describe each lesson, discussing the strategies that were used and reporting and analysing the questions that were formulated by the children.

4.5.1 Introductory Lesson

The teacher started by presenting the 'big questions' guiding the learning unit ("What is light? Where does light come from and how does it move in space? How does light behave when it meets objects?"). In order to create a non-judgmental climate, the questions were proposed one at a time, inviting the children to write their ideas on post-its which were then collected and used to build a cognitive matrix representing the initial knowledge of the classroom.

After that, the teacher proposed the 'dark box' experience: an object and a flashlight were placed inside a black box, where a hole had been made for the children to look inside. The teacher could turn the flashlight on/off or move it so that light was either reflected on the object or not. The purpose of the experience was to identify the elements needed for vision (eye, light, object) and sketch their relationships.

Through this lesson we also wanted to gather information about the children's initial questioning skills. For this reason, it was conducted using a transmissive-prescriptive approach, in which the teacher demonstrated the experiment without involving the children in inquiry. The children were asked to write down their questions individually, but no specific scaffolding materials were provided. Since these methods resemble the ones the children were used to, the quality of the formulated

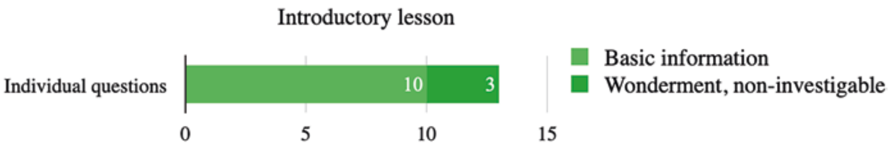

Fig. 4.1 Number and type of questions formulated during the introductory lesson. The actual number of questions of each type is reported in the bars

questions can be used as a benchmark against which to compare the questions that emerged during the inquiry-based lessons.

Of the 13 individual questions that were formulated, ten were of the 'basic information' type (e.g., "Is there a torch inside the box?"). The remaining three were 'wonderment' but 'non-investigable' questions, since they were very broad or unrelated to the experience (e.g., "Why can't we distinguish colours?"). Figure 4.1 summarises the number and type of questions formulated during this lesson.

4.5.2 First Inquiry Cycle

The first inquiry cycle was dedicated to light propagation. As the initial engaging experience, a laser was pointed to the wall and then flour was used to make the light path visible. During and after the experience, the children were encouraged to write down their questions individually. Of the 12 individual questions that were written, seven were 'basic information' ones (e.g., "Why was flour illuminated?"); among the 'wonderment' questions, only one was 'investigable' ("Can we do the same using steam?").

After that, flashlights and flexible plastic tubes were provided, and the children investigated light propagation in groups. In order to support the children's investigation and to scaffold the shift from external to internal questioning, three 'self-questions' (Chin, 2006) were reported in the children's planner:

1. How can we organise our investigation in order to answer our question?
2. What is the best way to collect information from our investigation?
3. How can we interpret this information to answer our research question?

At the end of the cycle, all of the 14 individual questions reported by the children were 'non-investigable'; five of these were of the 'wonderment' type ("Why can't we make light bend?") while the others were 'basic information' ones. Figure 4.2 compares the number and type of questions at the beginning and at the end of the cycle.

These results support the fact that 'wonderment', investigable questions hardly emerge spontaneously from the children. For this reason, in the second cycle we introduced more specific scaffolding strategies.

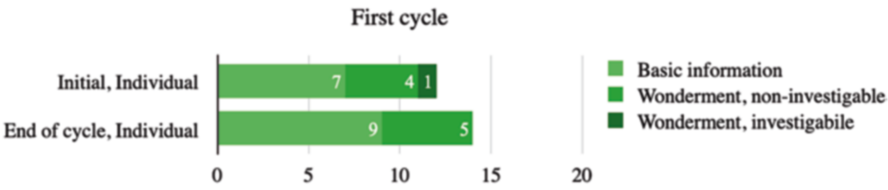

Fig. 4.2 Number and type of questions formulated during the first inquiry cycle. The actual number of questions of each type is reported in the bars

4.6 Second Inquiry Cycle

The second inquiry cycle regarded the interaction between light and objects. As the initial experience, a flashlight and different objects (a steel bowl, a glass jar, coloured cardboard) were shown to the children, and they were asked to write down their questions individually. The analysis of these questions reflected the situation already observed in the previous cycle, with only five questions asked, all but one of the 'basic information' type.

After that, the teacher introduced two scaffolding strategies, i.e., modelling and collaborative questioning, the latter supported by 'question hands'. The teacher 'modelled' the formulation of investigable questions by proposing some examples of this type of questions herself. Then, the children formulated questions collaboratively and reported them on a 'question hand'; in order to minimise the possibility that some questions were lost in the process, one child per group was specifically assigned the task of writing down all the questions. In the following we will refer to the questions that have been formulated this way as 'group questions'.

After the introduction of these strategies, a drastic increase was observed in both the number and the quality of the questions. In fact, 19 group questions were formulated, including seven 'basic information' questions (e.g., "What is the steel bowl for?"), one 'wonderment' but 'non-investigable' question ("Why isn't light reflected by paper?"), and 11 'wonderment', 'investigable' questions (e.g., "Can light be reflected by all of these objects?"). The questions formulated at the end of the cycle were even more, both at the individual and at the group level. Most of the questions were of the 'wonderment' type (17 of the 19 individual questions, and all of the 20 group questions); nine individual and 14 group questions were also 'investigable' (e.g., "Can other objects reflect light in a different way?"). Figure 4.3 compares the number and type of questions at the beginning and at the end of the cycle.

4.6.1 Third Inquiry Cycle

The third inquiry cycle was about light reflection from plane mirrors. The lesson started with the teacher shining a laser into an open box (grazing to the surface so that the light path was visible); on opposite sides of the box, some centimetres apart,

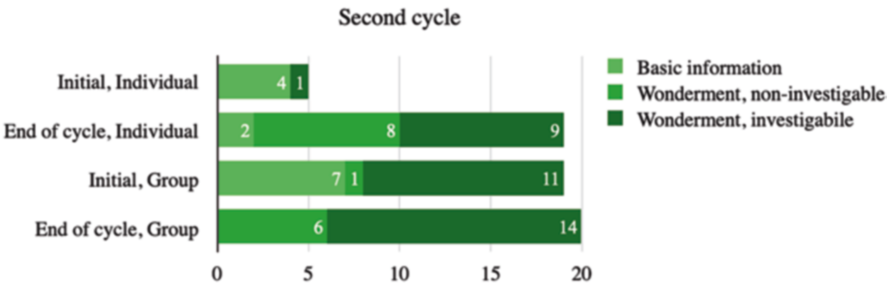

Fig. 4.3 Number and type of questions formulated during the second inquiry cycle. The actual number of questions of each type is reported in the bars

she had glued two mirrors so that the laser was reflected on them and reached the other end of the box. This time, the children formulated more individual questions (18) than in the previous cycles. There was a higher number of 'wonderment' 'investigable' questions (six, e.g. "If two mirrors make three rays, how many rays would there be with three mirrors?"), even though 'non investigable' questions were still the majority (12) and seven of them were 'basic information' ones.

The teacher then showed the children the materials available for their investigation (flashlights, mirrors, a sheet of paper with a goniometer printed on it, black cardboard with a slit cut in it) and proposed the question hands activity, but this time she removed her modelling, in order to encourage the groups to work independently ('fading'). Less 'group questions' (ten) were collected this time. This may be due to fading out the support of modelling, or to the fact that the goal of the investigation (finding a rule for reflection) was more focused. However, six of the group questions were 'wonderment' 'investigable' questions (e.g., "What happens to the light after it is reflected on the mirror?"); the others were of the 'basic information' type.

At the end of the cycle, less questions were formulated compared to the previous cycles (13 individual, eight group questions), but most of them were 'wonderment' questions (nine individual, seven group questions); the majority of these ones (six) was also 'investigable' (e.g., "Can we modify the light path using other objects?"; "If we bent the tube and we put a mirror inside, could light reach the end of the tube?"). Figure 4.4 compares the number and type of questions at the beginning and at the end of the cycle.

At the end, the children collaboratively constructed a concept map representing the knowledge of the classroom at the end of the learning path.

4.6.2 Final Lesson

The unit was concluded by engaging the children in an authentic task, consisting in designing an instrument to see around corners or obstacles. The groups were given a box and two mirrors, and they were free in the design of their project. Moving

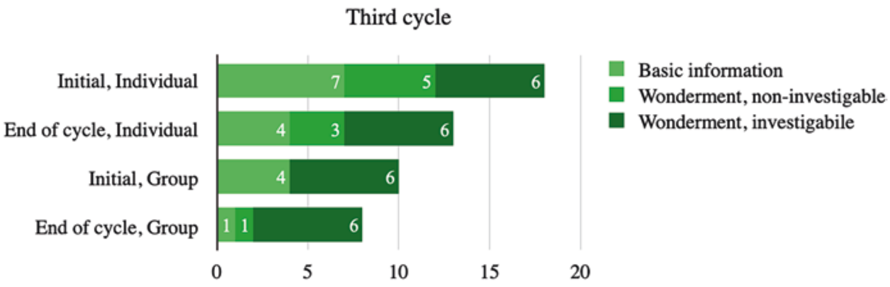

Fig. 4.4 Number and type of questions formulated during the third inquiry cycle. The actual number of questions of each type is reported in the bars

from their initial observations, the children started to formulate questions at different levels. Some of these were of the procedural type (e.g., "Can we cut the box?"; "Can we use adhesive tape?") while others regarded the children's hypotheses about the project (e.g., "If we cut the box above and on the other side, and we put one mirror on each side, what may happen?"; "If we take the box and we make a hole on one side, and then we put one mirror on one side and the other mirror on the other side, can we reach our goal?"). The fact that the children spontaneously asked themselves questions in order to proceed and that they set their own task accordingly can be regarded as evidence of a maturation in their attitude towards questioning. The projects were shared and discussed with the rest of the classroom, and a real instrument was built combining the ideas of all the groups.

4.7 Discussion

The evaluation of the children's initial questioning skills showed that the children asked few spontaneous questions, and those few were oriented at obtaining factual or procedural information. Since the pedagogy adopted during this meeting (transmissive-prescriptive) simulated the one normally used by the teacher, it could be inferred that this pedagogy does not contribute to the development of children's questioning skills. After a few lessons conducted with an inquiry-based approach and introducing adequate scaffolding materials, a change in the children's questioning skills was observed. Figure 4.5 highlights and quantifies this change by reporting the number of questions of each 'type' at the end of each inquiry cycle.

In total, 18 children out of 24 formulated at least one 'wonderment question' over the different inquiry cycles. The children who had the most difficulty in formulating and writing down the questions were pupils of foreign origin, who demonstrated general difficulties with the Italian language.

Looking at Fig. 4.5, we notice that 'group questions' are, on the whole, at a higher level than those formulated individually, supporting the claim that working collaboratively can stimulate the development of questioning skills. In fact, the

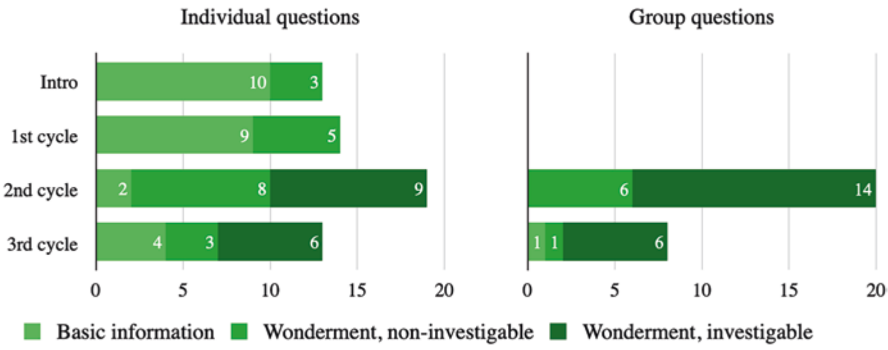

Fig. 4.5 Number and type of questions formulated after each of the three inquiry cycles, compared to the introductory lesson. The actual number of questions of each type is reported in the bars

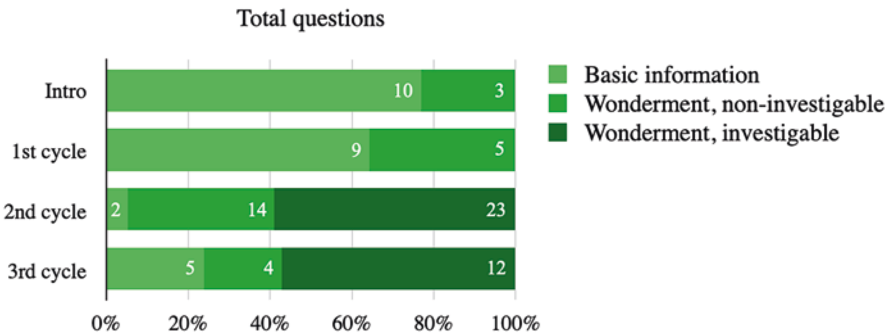

Fig. 4.6 Fraction of questions of each type formulated after each of the three inquiry cycles, compared to the introductory lesson. The actual number of questions is reported in the bars

number of wonderment questions accounts for 70% of the group questions formulated after the second inquiry cycle, and for 75% of the group questions formulated after the third inquiry cycle, compared to less than 50% for the individual questions. We also notice that, in the second inquiry cycle, after the introduction of modelling and question hands, a drastic increase in the total number of questions and in the fraction of 'wonderment' questions was observed, and the majority of these was also 'investigable'. During the third cycle, a decrease in the number of final questions was observed. This might be due to the fact that the focus of the experience (light reflection) was tighter than in the previous inquiry cycle (light-objects interactions in general), in line with what suggested by Chappell et al. (2008) about the relationship between creativity and the 'breadth of possibility' in question posing. However, the fraction of 'wonderment' and 'investigable' questions remained significantly high, suggesting that the 'quality' of the questions did not decrease. Figure 4.6, which shows the *fraction* of (individual + group) questions of each type and their absolute number, highlights what we have just claimed.

Scardamalia and Bereiter (1992) noted that, generally, students tend to formulate 'basic information' questions for unfamiliar topics, and 'wonderment' questions for more familiar ones. The increase in the fraction of 'wonderment' questions may therefore also indicate the children have actually developed new knowledge about the topic, a statement reinforced by an analysis of the disciplinary content of the questions; for instance, there was an increased use of specific language (light is 'reflected', the 'direction' of light, the 'light path'). Moreover, some of the questions asked at the end of the third inquiry cycle recalled and integrated not only the contents, but also the practical activities experienced in the previous ones (e.g., "If we bent the tube and we put a mirror inside, could light reach the end of the tube?"). This suggests that the children improved in asking 'wonderment' questions as they became more familiar with inquiry. The children had never previously experienced this approach to learning, and they became more and more confident on how to proceed as they understood the method. These results confirm the depth of learning suggested by the presence of a large fraction of 'wonderment' questions and indicate that both familiarity with the content and the possibility of engaging with practical experiences are important to develop questioning skills.

To conclude this section, we now map our study onto the *'A' to 'E' Framework* that shapes this book (Murcia et al., 2020). Our perspective on who does the original thinking (the 'person' in the framework) was on the children, and mainly on children's creative thinking. We investigated in particular children's questioning, one of the elements of the dimension of being curious in the 'process' of children's creative thinking, by evaluating the questions they reported in their notebooks or in the question hands (a 'product'). In our study, questioning was connected with other elements of this dimension, such as wondering, exploring, discovering, and experimenting. At the end of the unit, we also found evidence of another dimension of creative thinking, connecting, as the children recalled and integrated concepts and ideas from all the inquiry cycles.

Our study mainly explored the third element of the framework, the 'place'. In fact, our research question regarded the characteristics of a learning environment that increase the quantity and quality of the questions posed by the children. We found evidence of the efficacy of all the dimensions proposed in the framework. Concerning the resources, we used both intentional provocations (modelling and self-questions) and stimulating materials (questions hands), and we allowed time for creative exploration. As for communication, we worked mostly on open inquiry questioning, which was the focus of the research. Finally, paying attention to a non-prescriptive, non-judgmental environment where children's questions and interactions were welcomed and encouraged was another distinctive element of a favourable socio-emotional climate. In fact, the strategy that most of all seems to have positively impacted the quality of the questions was collaborative questioning.

4.8 Conclusions

In this chapter we have presented a case study that we carried out in a fourth-grade classroom (children aged nine to ten), the purpose of which was to see whether an inquiry-based learning environment could increase the quantity and quality of the questions posed by the children. To this end, we developed a learning unit on the topic of light, featuring different inquiry cycles, and we used specific scaffolding strategies (modelling, question hands) to help the children formulate 'investigable' questions.

The analysis of the questions generated by the children during the different inquiry cycles suggests that the adopted approach not only stimulated the children's curiosity and 'wonderment', but also their ability to formulate empirically answerable questions. As the children engaged in the different inquiry cycles, the quantity and—most of all—the quality of the formulated questions increased. In fact, the majority of the questions formulated by the children at the end of the unit were 'wonderment' questions, i.e., questions that reflect a genuine interest and a deep approach to learning, and most of these questions were also investigable through practical classroom inquiry. Though it was not possible to observe a complete development of the children's questioning skills during the short time of the intervention, there is evidence supporting the beginning of a development of this skill, and, overall, of a growth in children's creativity.

Too often teacher questioning dominates. In our experience with pre-service primary teachers, many of them interpret 'asking questions' as 'engaging the children through questioning strategies', rather than encouraging the children to formulate their own questions. The latter is, however, a crucial skill not only for developing science competencies, but also for responsible citizenship. Our research demonstrates that the quality and quantity of children's questioning can be improved through effective pedagogy, and that this is connected with a development in different dimensions of creative thinking. Besides being a fundamental resource for the personal growth of the children, these competencies will enable them in the future to address the complex issues that characterise our society, and to participate in its life.

Ethical Statement The project was carried out in the context of an agreement between the School and the University of Padua (agreement no.: 2120/11-64966) for hosting student teachers during their master thesis internship. The data were collected and the results were disseminated in accordance with the ethical rules of the agreement; in particular, no personal or sensitive data were collected.

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