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Using Digital Storytelling in Science: Meaning Making with Students aged 10-12 years old

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Using Digital Storytelling in Science: Meaning Making with Students aged 10-12 years old

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POPI ANASTASIOU

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Abstract

Meaning making is an essential aspect of learning as a process of interpreting and negotiating information while sharing it with others. One way of meaning making is through (digital) storytelling. The process of creating and telling a story depends on how one can see their understanding of something come together and make sense and it is considered a (socio) constructivist strategy of learning. The purpose and contribution of this research are to explore how digital storytelling may support engagement in meaning-making as students externalise their understanding of the science topic of matter. To this aim, two digital storytelling activities were constructed – SEeDS (Sequencing of Events enabling Digital Storytelling) and Narration. The two activities included the same content but differed in structure. SEeDS presented the story scenes in an order that was not predefined and Narration in a predefined order. Both activities derived elements from the theoretical concept of Tricky Topics and Stumbling Blocks (SBs). This research was informed by the theory of Problem-based learning.

Participants were sixty-one Greek primary students aged 10-12 years old and twenty-two English secondary students aged 11-12 years old. Half students worked through the SEeDS activity and the rest through the Narration activity. Students worked cooperatively in small teams to implement the two activities. A systematic analysis of the collected data was conducted using qualitative methods. Findings revealed that the two activities had supported the Greek and English students in externalising their understanding of many scientific concepts included in the topic of matter, while it identified gaps in their prior knowledge. The two activities have also facilitated the instinctive use of exploratory talk over the other two types (cumulative and disputational talk) that can often be found in peer talk in science learning. Finally, the two activities appeared to have engaged students in the two contexts, as they allowed them to own the story creation whilst working independently. Finally, the Greek and English students viewed the SEeDS activity as challenging, making it hard to complete and at times tiring and confusing, and the Narration activity as easy to implement, giving students the opportunity to mainly focus on inventing the story plot.

This research makes a valuable contribution to the literature on making meaning in science, offering new insights about the use of problem-based stories supported by mobile technology. The findings provide opportunities to further explore the practical application of problem-based digital storytelling activities, which are hard thinking and challenging, across different age groups and cultural contexts. There is a need for teaching practices to be based on socio-constructivist learning approaches that focus on students' thinking, not performance. Therefore, the implications of this research are relevant to a number of educational contexts and levels.

Acknowledgements

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List of Abbreviations

APS	Analytic Programmes of Study
CPD	Continuing Professional Development
JxL	JuxtaLearn Project
ICT	Information and Communication Technology
NC	National Curriculum
PBL	Problem-based learning
SB	Stumbling Blocks
SEeDS	Sequencing of Events enabling Digital Storytelling
STEM	Science, Technology, Engineering and Mathematics
TA	Thematic Analysis
TCs	Threshold Concepts
TTs	Tricky Topics
TTP	Tricky Topic Process
TTT	Teaching Tricky Topics

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CHAPTER 1: INTRODUCTION

1.2 Meaning making and its importance in learning

Meaning making is a cultural process "created and negotiated within a community" (Bruner, 1990, p. 11). Individuals use symbolic systems to make meaning that is already deeply rooted in culture and language (Vygotsky, 1978; 1987; Bruner 1990). Vygotsky (1987) views the word "meaning" as a unit of verbal thinking that contains thought and speech in a functional relationship. Talk is considered central to the meaning making process and, therefore, to learning because different ideas are brought together and worked upon (Mortimer and Scott, 2003). In this context, learning is built upon the exchange of ideas.

Students are responsible for constructing their knowledge using their existing intellectual tools. Such a construction is achieved through social interaction in which language and dialogue play a fundamental role in shaping meanings (Alexopoulou and Driver, 1996). That kind of interaction provides "a forum, in which the participants calibrate their representations of events and extend their existing mental models to assimilate or accommodate to new or alternative information" (Chang-Wells and Wells 1993, p. 63). Students learn better when they learn together towards a common goal in a *collaborative* or *cooperative learning* environment (Nastasi and Clements, 1991), fostering learning (Chang-Wells and Wells 1993).

Learning together through problems is also a meaningful (Hmelo-Silver, 2004) socio-constructivist approach that encourages learners to develop deep learning strategies and construct knowledge (Hmelo-Silver, 2004). Problem-based learning typically starts with a problem and ends with a corresponding solution (Gao, 2012) and focuses primarily on the process of learning than on the end product. In this line, PBL can be seen as a socio-constructivist approach to learning that acknowledges the construction of knowledge as the product of social interaction, interpretation and understanding (Adams, 2006; Vygotsky, 1962). In the process of meaning making, students try to make sense of what is being communicated, to bring together existing ideas with new ones. At times, there is no tension between existing and new views, and learning can, thus, progress easily for the individual

(Mortimer and Scott, 2003). At other times conflicts may arise, and their resolution is necessary for new and existing ideas to be integrated. Research has shown that the more challenging and more complex a learning task is, the better the learning results it can generate (Brown *et al.,* 2014). Meaning making requires critical thinking and constructive arguments, which are considered key features of the deep approach to learning. On the contrary is the surface approach, defined by an inclination towards memorising and reproducing terms and discrete facts and results in surface understanding (Entwistle and Marton, 1994; Biggs, 1987; Marton and Säljö, 1976).

Language is considered a system of resources for meaning making, yet how meanings are made in school science differ from how other communities create meaning (Young and Nguyen, 2002). Teaching and learning school science is "a means by which a community of individuals sustains the shared beliefs and values of the community through the ways in which they construct meaning" (Young and Nguyen, 2002, p. 349). Science is "seen as a product of the scientific community, a distinctive way of talking and thinking about the natural world, which must be consistent with the happenings and phenomena of that world" (Mortimer and Scott, 2003, p. 13). Therefore, teaching and learning science involve an introduction to the language of the scientific community that includes concepts, conventions, laws, theories, principles, and ways of working of science (Mortimer and Scott, 2003). Empirical evidence suggests that social interaction and discourse can facilitate learning in science (Candela, 1999). Such an interaction engages learners and enables them to listen, reason, share their understanding and construct arguments to support their standpoint. As talk proceeds, each participant makes sense of what is being communicated, and the words used in the social exchanges provide the right tools needed for individual thinking (Mortimer and Scott, 2003).

1.2 Meaning making through digital storytelling

Socio-constructivism emphasises learning as meaning making from experience through ongoing interaction with the world (Szurmak and Thuna, 2013). When learning something new, one is "essentially trying to make sense of it, discern its internal logic, and figure out how it's related to what is known already" (Clark and Rossiter, 2008, p. 66). One needs to make a story about what is being learnt; in other words, to make the elements of what is not

yet fully understood hang together so that there is coherence (Clark and Rossiter, 2008). The process of making a story depends on how one can see their understanding of something come together and make sense. Millar and Osborne (1998) propose that science education needs to "make greater use of one of the world's most powerful and pervasive ways of communicating ideas—the narrative form" (p. 2013). Their argument is based on the premise that stories in science can prove helpful in "communicating ideas and making ideas coherent, memorable, and meaningful" (Millar and Osborne, 1998, p. 2013).

Involvement in the creation of a story plays a vital role in understanding the content and context of the story because the place that events have in a story attributes meaning to the whole story and helps to organise and grasp it (Bruner, 1990) mentally. Story events need to be sequenced in terms of time and causality so that understanding can be reached. Vygotsky (1978) was among the pioneers who reviewed the value of sequencing story events based on one's understanding in developing students' use of scientific or everyday concepts. His work involved using still pictures to illustrate a sequence of events incorporating materials based on either scientific or everyday concepts. The sequence order in which story events are narrated is a fundamental feature of stories because it can "strongly influence what is learned and sometimes even whether the material is learned at all" (Ritter and Nerb, 2007, p. 3). This research acknowledges that the ordering and sequencing of story events helps students to reflect on and externalise their understanding of the learning material and teachers to identify gaps in students' prior knowledge.

1.3 Research Objectives and Importance

Considering the above, the main purpose of this research is to explore how digital storytelling may support students' engagement in meaning making through externalising their understanding of matter. Meaning making as a process involves critical thinking, sharing of ideas and negotiation of understanding. To this aim, two digital stories were created. The first one, SEeDS, presents the story scenes in an order that is not predefined, and the second one, Narration, in a predefined order. This research is informed by a socio-constructivist approach to learning and focuses on meaning making through cooperative learning settings. In doing so, it seeks to answer the following research questions of this thesis:

RQ1: Whether, and, if so, how do the SEeDS and Narration activities support learners in each of the two contexts to access, reflect upon on, and apply prior science learning?

1.1.   Whether, and, if so, how does the SEeDS activity support learners in the Greek context to access, reflect upon, and apply prior science learning?

1.2.   Whether, and, if so, how does the 'Narrative' activity support learners in the Greek context to access, reflect upon, and apply prior science learning?

1.3.   Whether, and, if so, how does the 'SEeDS activity' support learners in the English context to access, reflect upon, and apply prior science learning?

1.4.   Whether, and, if so, how does the 'Narrative activity' support learners in the English context to access, reflect upon, and apply prior science learning?

RQ2: Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?

2.1   Whether, and, if so, how does the SEeDS activity facilitate the types of peer talk that research suggests can support science learning in the Greek context?

2.2   Whether, and, if so, how does the 'Narrative' activity facilitate the types of peer talk that research suggests can support science learning in the Greek context?

2.3   Whether, and, if so, how does the SEeDS activity facilitate the types of peer talk that research suggests can support science learning in the English context?

2.4   Whether, and, if so, how does the 'Narrative' activity facilitate the types of peer talk that research suggests can support science learning in the English context?

RQ3: Whether, and, if so, how do the SEeDS and Narration activities engage and challenge learners in the two contexts?

3.1   Whether, and, if so, how does the SEeDS activity engage and challenge learners in the Greek context?

3.2   Whether, and, if so, how does the Narration activity engage and challenge learners in the Greek context?

3.3   Whether, and, if so, how does the SEeDS activity engage and challenge learners in the English context?

3.4   Whether, and, if so, how does the Narration activity engage and challenge learners in the English context?

The importance of this research lies in the fact that it focuses on meaning making in science learning and uses contemporary digital tools to design a socio-constructivist learning activity based on story-sequencing. The choice of a socio-constructivist approach as the framework of the design is based on the use of talk as a dialogic process (Mortimer and Scott, 2003) and the notion of problem-based and cooperative learning in the negotiation of meaning (Chang-Wells and Wells 1993). Exploring the use of digital storytelling in science can help to develop a teaching/learning model that will engage students in the process of meaning making, guide future research and inform teaching practice in the science classroom and beyond.

1.4 Thesis Overview

This thesis is divided into eight chapters. The first chapter is the introduction of the thesis, in which the structure of the research study is presented.

The second chapter, *Learning as a meaning making process*, focuses on the importance of meaning making in developing knowledge and indicates how the sequencing of events in a digital story can best achieve it. Chapter 2 is divided into three sections. The first section discusses meaning making in learning as framed within a socio-constructivist approach to learning, drawing on the pedagogical models of problem-based and cooperative learning. The second section connects meaning making to storytelling and highlights the importance of sequencing the story events in engaging students in meaning making. The last part of this chapter discusses the role of mobile technology in support of digital storytelling and acknowledges the differences between digital story-making and story-retelling.

The third chapter, *School science and tricky topics*, critically examines science as a school subject across the educational backgrounds of Greece and England. Then it makes reference to the notions of Troublesome knowledge, Threshold Concepts and Tricky Topics and how they link to the science topic of matter. Finally, it places under scrutiny a considerable body of research investigating students' alternative ideas about matter, seeking to identify any practical gaps in tackling it.

The fourth chapter, *The Method of Creating the Two Digital Storytelling Activities,* describes the methodological procedure followed from the design to the implementation of the two digital storytelling activities.

The fifth chapter, *Research Methodology*, sets out the methodological approach used to achieve this research's objectives. The methodology, including the design and methods used to implement both the pilot and the main studies, is discussed in detail, along with issues of sampling and data collection tools. This chapter also presents the coding and analysis of this research's findings through qualitative research analysis.

The sixth chapter, *Presentation of Findings,* presents data from implementing the two digital storytelling activities in one Greek primary school in Athens and one English secondary school in Northamptonshire. The chapter presents episodes of team discussions from the two digital storytelling approaches. It also shares extracts from students' digital stories to exemplify students' engagement in the two activities.

Chapter 7, *Discussion of Findings*, discusses the insights gained from Chapter 6 and connects findings to the relevant literature to address the research's three driving questions.

Chapter 8, *Implications and Conclusions*, summarises the main findings concerning the objectives and the procedures followed during this research. Furthermore, it underlines the implications of the results, both for research and practice. This chapter also points out the research's limitations regarding the technical and other procedural and contextual difficulties that have occurred during its implementation. Finally, the closing section is concerned with recommendations for future research and final comments concluding the work done in this research.

CHAPTER 2: LEARNING AS A MEANING MAKING PROCESS

2.1 Introduction

This chapter concerns itself with the areas of theory and research related to the main focus of this research, thus, setting its literature background. The literature review aims to critically examine and discuss the key themes that form the basis of the research focus. More specifically, it starts with an overview of meaning making in learning, dwelling on a socio-constructivist point of view. Then it continues with the construction of meaning through stories before emphasising the value of the sequencing and ordering of story events in the meaning making process. Next, it examines the role of storytelling in education. Finally, it shifts the focus from storytelling to digital storytelling, discussing technology's role in supporting stories. This chapter is discussed according to four themes. The first theme defines meaning making and acknowledges its importance in students' learning. It particularly pays attention to the socio-constructivist approach to learning, which focuses on learning, not performance, viewing students as co-constructors of knowledge in a social realm (Adams, 2006b). Then, it links meaning making to problem-based learning, acknowledging its role as a learning and teaching approach. The second theme makes reference to storytelling, highlighting the significant role that the sequence of story events plays in externalising students' understanding of the learning material. Lastly, in the third theme, the focus shifts to digital storytelling and the use of technology and reviews how digital storytelling can be used in the (science) classroom.

2.2 Definitions of learning

To learn something means to come to know or acquire knowledge about something or do something (Moon, 2004) through study, teaching, instruction, or experience (Clark, 2018). Sometimes this is defined as *knowing that* and *knowing how* and relates to the notion of skills, that is, the ability to do something (Moon, 2004) – for instance, the ability to use an iPad to read an article, to plant a flower, to write an essay, to boil an egg. Learning starts long before children attend school. Therefore, any learning they encounter in school has a

previous history (Vygotsky, 1978). For instance, students begin to study science in school, but they become aware that flowers need water to grow long beforehand. And that hot running water in the bathroom coincides with the misting of the mirror. Therefore, when students come to the classroom, they have already formed preconceptions about how the world works. "If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom" (Bransford *et al.,* 2000, p. 14).

Learning starts in the pre-school years when children learn speech from adults (Bransford *et al.,* 2000) and ask questions about the things around them. In this period, children learn the names of objects in their environment, but the words children use in their speech correspond with the adult's words in their "object relatedness but not in their meaning" (Vygotksy, 1987, p. 163). That means that children in the pre-school years learn and speak about the things around them, but the words they attribute to objects do not have the concrete meaning that corresponds to the words. If, for instance, the child first learns the word *rose* before the word *flower*, the word may be used to refer to roses and all flowers. The older the child gets, the better understanding they develop of new words, argued Vygotsky (1987, pp. 171-172):

> "The path from the child's first encounter with a new concept to the moment when the word and concept are made the child's own is a complex internal mental process. This process includes the gradual development of understanding of the new word, a process that begins with only the vaguest representation, including the child's first use of the word. His actual mastery of the word is only the final link in this process ".

The above quote shows that the conceptualisation and understanding of a new word are gradually developed through a complex internal mental process. The developmental process is completed when the child is finally able to assimilate the meaning of a word. Such mastery provides the basis for the subsequent development of a variety of highly complex internal processes in children's thinking (Vygotsky, 1978). This is especially important for the development of scientific and everyday concepts in school-age children, on which this chapter will dwell in later chapters. The idea that children own the conceptualisation and understanding of new words is part of the learner's meaning making process. It has a valuable

place in this research that seeks to develop students' active meaning making. The extent to which children understand something allows them to devise their way of representing it and dealing with it, even when circumstances change (Halford, 2014).

By the time children reach primary school, they are already equipped with the ability to think in abstract terms, make sense of the world by creating intuitive models or theories, and experiment to develop their ideas (Duschl and Hamilton, 2011). Cognitive psychologists suggest that young children not only have a surprising capacity and prior knowledge in select domains, but they are also capable of reasoning about the natural and social world (Duschl and Hamilton, 2011). Children become more adept at acquiring new ideas using their existing network of ideas and prior experiences. There may be occurrences in which the learning material does not just accumulate as knowledge. Still, the new material itself can change what is already known or understood or change itself under the influence of what is already known (Moon, 2004). In other words, children from a young age can use their existing knowledge base and prior experiences to acquire further information, make inferences, develop problem-solving strategies, organise memory, and enhance their learning (Halford, 2014). As individuals begin to see learning as making sense of ideas by relating them to their previous knowledge and experience, information becomes transformed into personal meaning (Entwistle and Peterson, 2004). Meaning making is both an individual and a social process enabled by the exchange of words and plays a vital role in learning. Before unfolding it in more detail, it is worth looking at the definition of understanding and its links to the meaning making process.

2.2.1 Learning theories: socio-constructivism

Educational theorists held different beliefs about how individuals acquire, retain, and recall knowledge, which led to multiple learning theories (Clark, 2018). Learning theories cast light on the complex process of learning and offer a conceptual framework around which instructional approaches can be structured to optimise learning (Arghode, Brieger and McLean, 2017). Learning theories are divided into three main categories: behaviourism, cognitivism, and constructivism. Despite their overlapping features across these categories,

their differences are often highlighted to help educators select principles and conceptions that best fit their teaching contexts (Ertmer and Newby, 2013).

Learning in the context of behaviourism can be defined as the acquisition of new behaviour or modification of an existing one due to teaching, training, or tutoring (Woollard, 2010). Behaviourists view learning as a measurable change in behaviour in response to certain external stimuli (conditioning). Behaviourism discounts thinking or other mental activities as part of the learning process because these variables are not observable behaviours (Clark, 2018). Although behaviourists fail to consider any mental activity, other educationalists consider these processes as fundamental elements of learning and cognition. In consequence, further learning theories, among which cognitivism, were developed. Unlike behaviourism, the theory of cognitivism values the role of mental activities – thinking, remembering, perceiving, interpreting, reasoning and problem solving – in the learning process (Clark, 2018). Cognitivism emphasises the acquisition of knowledge using internal mental processes that stress information storage, processes, and retrieval (Arghode *et al.*, 2017; Ertmer and Newby, 2013). The cognitivist learning perspective embraces the notion of *schemata* – a unit of knowledge, understanding and skill, stored in long-term memory – that the individual uses points of reference when encountering new phenomena or experiences (Clark, 2018). One similarity that both behavioural and cognitive theories share is to consider the world as external to the learner and, thus, "the goal of instruction is to map the structure of the world onto the learner" (Ertmer and Newby, 2013, p. 54).

On the contrary, the theory of constructivism does not concur that knowledge is independent of the learner. Learners actively construct their understanding of the world based on their existing knowledge, experiences, and interactions with the environment. As such, meaning is *constructed* instead of *acquired*, and there is not one but multiple understandings of the world. Constructivism sees learning as meaning making, not as a direct outcome of the teacher transmitting the knowledge. As Wells (1995) argues, someone reading a science text brings his existing knowledge to link with the new information and construct the meaning. Constructivist approaches to learning seek to understand how students build their knowledge and what this means for understanding influences on thought processes (Adams, 2006b). In other words, in a constructivist designed learning environment, students must make sense of

the learning material based on the active interpretations of ideas they encounter in many sources, such as teachers' lessons, books, television and the Internet (Osborne and Dillon, 2010). That is not always possible in practice because if students fail to understand or inadequately synthesise previous information, they will not interpret new knowledge sufficiently. Therefore, it is important that teachers both understand and accept that each learner constructs knowledge differently and that these differences stem from the various ways in which individuals acquire, select, interpret, and organise information (Adams, 2006a). This constructivist perspective holds a valuable place in this research, informing the design of its proposed activities.

While constructivism promotes a more learner-centred approach, the socio-cultural learning theory (Vygotsky, 1962) views the construction of knowledge as achieved through social interaction. Language and discourse play a fundamental role in shaping meanings (Alexopoulou and Driver, 1996). At the heart of Vygotsky's perspective on development and learning is that learning originates in social situations, where ideas are rehearsed between people mainly through talk (Mortimer and Scott, 2003). Student talk plays a vital role in facilitating learning because it offers interlocutors the opportunity to construct new ways of understanding through a collaborative negotiation of shared ideas and opinions (Ertmer and Newby, 2013; Simons *et al*., 2000). Studies investigating the social processes of knowledge construction in group settings reveal that when peers negotiate meaning about a topic, they concurrently negotiate their interaction on the social plane (Simons et al., 2000; Howe *et al*., 1990). That, in turn, involves students' attitudes and behaviours that depend on a variety of social and contextual factors that operate in school classrooms (Myles, 2013). This research will not concern itself further with these factors, as it does not aim to take a sociological stance by examining students' socio-cultural backgrounds.

Vygotsky's (1987) socio-cultural theory also highlights the importance of context in relation to learning. Context, also known as an "approach setting, provides the medium in which students discover meaning through social encounter; these encounters enable students to become familiar with the nuances of their contexts and gain assistance with problems beyond their competence" (McDrury and Alterio, 2003, p. 28). The emphasis that Vygotsky places on the social context of thinking stresses how the contexts in which individuals operate or

connect impacts their learning potential (McDrury and Alterio, 2003) significantly. Through the social process, learners co-define and co-create knowledge of the community that is context/domain-specifically meaningful and connected with their experience (Mahnaz, Hung and Dabbagh, 2019). Learning is, thus, an experience-meaning construction process.

Social constructivism includes elements from the constructivist and sociocultural approaches and views knowledge construction as the product of social interaction, interpretation and understanding (Vygotsky, 1962). Some of the work most closely tied to social constructivism comes from Vygotsky (1978) and Bruner (1986). Their work suggests that knowledge creation is inseparable from the social environment in which it is formed. Learning, therefore, is considered a process of active knowledge construction (Woolfolk, 1993) within and from social forms and procedures. That means that learners first encounter ideas in the social environment, mainly in the language (Osborne and Dillon, 2010). Due to the mediatory features of the language and other forms of communication, knowledge is first formed on the interpersonal (social) and then the intrapersonal (individual) level (Vygotsky,1978). The role of knowledgeable others, such as teachers or more capable peers, becomes one of guiding learning experiences through questions and stimulating discussion (Osborne and Dillon, 2010). Such guidance is defined as *scaffolding* (Wood *et al.*, 1976).

> "Teachers should observe and listen to how students describe their work and their reasoning through the use of suitably phrased, open-ended questions, and set tasks that require students to use skills and apply ideas which employ a variety of communicative methods... What all this provides for are spaces and instances of and for active co-construction of meaning and understanding. The mutually reinforcing nature of open-ended, 'exploratory' talk provides mechanisms and opportunities for individual reflexivity within a context that actively desires and operates to mediate knowledge construction into the social space. The most obvious reform required then is the devising of more open-ended tasks that require students to think critically, solve complex problems and apply their knowledge in and to their own world …"
> (Adams, 2006b, p. 74)

This cited quote indicates the principles of teaching practice in a socio-constructivist learning setting. Students' reasoning and discussion with teachers and peers provide the means for constructing meaning and understanding. At the same time, exploratory talk promotes critical

thinking and the sharing of knowledge in the social space. Critical thinking requires students to interact vigorously and critically with the content (Entwistle, 2018; Entwistle and Ramsden, 1983). Students need to employ, thus, a deep approach to learning that shifts away from the requirements of test and exam questions found in superficial and rote learning. At the same time, teaching must not be merely concerned with prescribed performance targets that supplant cognitive development.

In the social constructivist learning environment, teachers shift their focus beyond performance and test results and concentrate on what should be at the heart of the educational process: learning and learner. Assessment is framed within the norms of current teaching, and it "seeks to consider how and why student positions do not successfully mediate into the social domain; that is, how and why student responses do not fit with current socially agreed interpretations" (Adams, 2006b, p.252). Therefore, instead of measuring students' performance in terms of absolute rightness and success or failure in a test situation, assessment should be based on improving students' interpretation of the learning material. As Silcock (2003) states, students learn through their efforts, and all teachers can ever do is arrange opportunities for students to engage profitably with curricula. Despite the promising character of the socio-constructivist approach to learning, its practical application in teaching and learning environments is limited (Adams, 2006 a,b). Most schoolteachers continue to judge performance by test results, focusing thus on the assessment of learning than on learning. This research differentiates itself from traditional teaching approaches that appear to be student-centred but are teacher-driven. It proposes a novel approach that engages students in active co-construction of meaning and critical thinking. It will also provide teachers with the opportunity to use assessment as a dynamic process of uncovering and acknowledging shared understanding (Adams, 2006b).

2.2.2 Learning as a meaning making process

In a socio-constructivist learning environment, learning becomes "the development of personal meaning more able to predict socially agreeable interpretations" (Adams, 2006b, p. 246). As such, it is inseparable from the social exchange process. That is, the meanings of any signs and operations, such as language, gestures, symbols and so on, result from an

interactive process that an individual and others mutually experience, understand, agree upon, and eventually establish (Vygotsky, 1978). In this social interaction process, knowledge construction occurs through negotiating meaning and observing others in this social group (Mahnaz *et al.,* 2019). The collective understanding about a topic is then internalised into individuals' knowledge base (Mahnaz *et al.,* 2019). That is, learners make meaning on an individual level by relating the new learning material to their current cognitive structure (Pardoe, 2000).

Interpreting and negotiating information while sharing it with others is an essential element of meaning making. Meaning is constructed instead of acquired, resulting in multiple understandings of the world. It is socially constructed through the moment-to-moment actions and interactions of the actors (Osborne, Erduran and Simon, 2004) and takes place at two levels, individual and collective. "At the collective level, meaning making shapes and is shaped by the ways individual children make sense of ideas and engage in transactions with each other and the teacher. During these transactions, the discourse that unfolds is a critical semiotic tool for meaning making" (Varelas *et al.*, 2007, p. 68).

How meanings are constructed in school science, differ from how other communities create meaning (Young and Nguyen, 2002). Meaning-making in science is about understanding core scientific values (Taber, 2008) and being able to use the strategies it offers for thinking about the world (Richmond and Striley, 1996) and for applying them in practical contexts. Engaging in the process of meaning making entails an exchange of ideas between students while they work cooperatively. Therefore, students need to have the opportunity to collaboratively make sense of the topic and exchange different interpretations and perspectives of the topic (Mahnaz *et al.*, 2019). That can lead to explicit or implicit cognitive conflict, whose resolution results in constructing higher forms of reasoning (Bearison, 1982, p. 203). One way of engaging in meaning-making in science is through problem-based learning, described next.

2.2.3 Problem-based learning

The socio-constructivist perspective emphasises the student-centred learning process, in which the teacher acts only as a guide, as the focal point of contemporary education systems

(Akinoğlu and Tandoğan, 2007). This learning process becomes a personalised process, as the learner takes responsibility for their learning. Here, the skills of problem-solving, critical thinking and learning to learn are developed (Akinoğlu and Tandoğan, 2007). One way of helping students to utilise their knowledge from various sources and develop their reasoning skills within a discipline area is problem-based learning (Peterson and Treagust, 1998).

Problem-based learning shares the same acronym (PBL) as project-based learning, but PBL only refers to problem-based learning in this thesis. The two instructional methods are frequently confused as they share the same learning principles, like learning by doing, student-centred learning (Gong, 2017), achieving a shared goal through collaboration and social interaction (Kokotsaki, Menzies and Wiggins, 2016). They are sometimes practised in combination (Gong, 2017; Gao, 2012). Nevertheless, their differences are not negligible. PBL, as the name suggests, typically starts with a problem and ends with a corresponding solution (Gao, 2012). By contrast, project-based is mainly task-oriented, provided through authentic questions and problems within real-world practices (Al-Balushi and Al-Aamri, 2014) and aims to construct an end product, a 'concrete artefact' (Helle *et al.*, 2006). In other words, project-based learning needs to culminate in an end product (Kokotsaki, Menzies and Wiggins, 2016) instead of PBL, which primarily focuses on the process of learning.

Problem-based learning is rooted in Dewey's "learning by doing and experiencing" principle (Dewey, 1938). Dewey's work on education focused on understanding learning as an experiential process that connects with one's lived experience; this is what is often referred to as "learning by doing" (Mahnaz, Hung and Dabbagh, 2019). Experiential learning, for Dewey, needs to be triggered by a problem, understood as an unclear situation or phenomenon in need of an explanation (Dewey, 1933). The word *problem* derives from the Greek *problēma,* which means obstacle. From a cognitive perspective, the problem is considered *a question to be resolved* (Jonassen, 2011). As used in this thesis, the word problem refers to an issue that is uncertain and so must be examined and solved. When a problem is ill-structured, students have to develop the ability to identify the problem and set parameters for developing a solution (Mahnaz, Hung and Dabbagh, 2019).

On the other hand, argue the authors, learners are less motivated and less invested in developing a solution when a problem is well-structured. However, learners may have a

different view in practice, favouring well-structured problems with a single answer, requiring less thinking. This tendency reflects surface teaching approaches based on the transmission of knowledge rather than nurturing students' critical thinking and problem-solving skills (Adams, 2006b).

Problem-based learning (PBL) represents a paradigm shift in how learners view knowledge, learning, and instruction (Mahnaz, Hung and Dabbagh, 2019) through facilitated problem solving (Hmelo-Silver, 2004). The ultimate goal is to change learners' mindsets beyond the surface level. As Ovens *et al.* (2011) point out, there is a prevalent view that learning depends largely on the effectiveness of the instructors' transmission, and it is the instructors' responsibility to deliver the information in better ways. When presented with ill-structured problem scenarios, which enclose vague goals, insufficient information and various constraints (Jonassen, 1997), learners often feel lost or helpless. That is because they have been so used to being spoon-fed through lectures and note-taking, as they have experienced in traditional learning environments" (Mahnaz, Hung and Dabbagh, 2019, p. 370). The problems used in PBL instructional approaches tend to be complex, challenging, and open-ended and have both multiple solutions and multiple paths or procedures to follow (Ertmer *et al.*, 2009). Their solution depends on how deeply learners engage in choice-driven inquiry (Barell, 2007), autonomous decision-making, and higher-order thinking.

PBL is mainly applied in medical and postsecondary education, aiming to develop learners' abilities to apply their knowledge in real-world settings by working collaboratively on meaningful problems (Merritt *et al.*, 2017). Although PBL methods have been used in primary and secondary learning (Song, 2018; Siew *et al.*, 2017; Leuchter, Saalbach, and Hardy, 2014; Chen and Chen, 2012; Potvin *et al.*, 2011), more research is needed to determine the impact of PBL on student learning in educational settings (Rico and Ertmer, 2015) (see next section 2.2.3.1).

In PBL, teachers and tutors act as facilitators of the learning process rather than as providers of knowledge (Hmelo-Silver, Bridges and Mckeown, 2019). They are responsible for facilitating students' learning and promoting effective group functioning by encouraging active participation of all members, monitoring the quality of learning and intervening where

necessary (Mahnaz, Hung and Dabbagh, 2019). Teachers are also expected to have an active role in the scaffolding of student learning by providing a framework that students can use to construct knowledge on their own (Mahnaz, Hung and Dabbagh, 2019). The roles of the teachers as facilitators in the PBL instruction often involves distributing worksheets, leading discussions, or helping students determine how to search necessary information (Leuchter, Saalbach, and Hardy, 2014; Inel and Balim, 2010). For instance, in the study of Leuchter *et al*. (2014) with lower elementary students, teachers were encouraged to provide verbal support and ask questions to advance observation, comparison, and the interpretation of data, as well as the deduction and verification of hypotheses and arguments (Merritt *et al*., 2017). That is not the case in this research, as participants will be initially guided through the technicalities of the problem-based activity by their teacher before they take full responsibility for solving the problem. Teachers need to act more as facilitators than guiders throughout the learning process in the PBL instruction so that students take ownership of the process and learn from it.

Table 1 below summarises the characteristic features of Problem-based Learning, as they are discussed thus far.

Parameters	PBL pedagogical model
1) **Role of instructor**	i) Tutor presents and sets the problem situation ii) Tutor facilitates the problem-solving process iii) Tutor models and demands evidence of metacognitive thinking iv) Tutor does not provide information related to content/problem v) Tutor facilitates a comprehensive assessment of learner content knowledge and the learning process
2) **Role of the learner**	i) Small groups of learners ii) Self-directed learning is required iii) Teamwork and collaboration are required
3) **Strategies for implementation**	i) Problems are disciplinary specific or ii) interdisciplinary developed by expert faculty to address curricular goals iii) Problems are the driving force for learning and generate a need to know that motivates students to conduct research and gather relevant information related to the problem situation. iv) Problems are ill-structured and authentic
4) **Availability/ access to resources**	i) Learners have access to all available data and information ii) Direct instruction on relevant information may be scheduled to coincide with learner needs within specific problems
5) **Assessment of intended learning outcomes**	i) Both knowledge-based and process-based ii) Conducted after each problem exercise iii) Standardized tests specific to the profession determine learner and program success

Table 1: Summary of the defining features of PBL (Mahnaz, Hung, and Dabbagh, 2019, pp. 88)

Problem-based learning (PBL) is linked to meaningful, experiential learning (Hmelo-Silver, 2004). It is a constructivist, student-focused approach that promotes reflection, skills in communication and collaboration (Yelland, Cope and Kalantzis, 2008). PBL is well-suited to helping learners develop strategies and construct knowledge (Hmelo-Silver, 2004). The general pattern for instruction within PBL starts with a small group of students presented with a problem (in the content domain and aligned with the larger curricular goals); this problem is complex and does not have a single correct answer; students work collaboratively in small teams to identify what they need to learn to solve the problem; students take responsibility

for the path or procedure followed to research answers to the learning issues; students report back to the group on their research results and apply their new knowledge to the problem; the student teams develop and present their proposed solution to the problem, and conclude the activity by reflecting on what they learned and the effectiveness of the strategies employed (Mahnaz, Hung and Dabbagh, 2019). This research situates itself in the tradition of PBL as the elements of ill-structured problems, collaborative work and students' being responsible for owning the learning process fit well the purpose of meaning making in a socio-constructivist learning setting.

2.2.3.1 Problem-based learning in science

Drawing on the socio-constructivist perspective, the PBL model helps students engage in a meaning-making process while promoting reflection and communication and collaboration skills (Yelland, Cope and Kalantzis, 2008). Problem-based learning places students in the centre of the teaching approach that involves solving unclear but genuine problems – including story problems (see section 2.2.3.1). Science involves natural phenomena, such as a thunderstorm or a skier's movement over a mountain slope, that are represented as problems or as puzzles because they are not easy to relate, are counterintuitive, or may hide an element of surprise (Mahnaz *et al.*, 2019). Students work on such problems in small groups, discuss them using their prior knowledge and try to construct a tentative theory that explains the phenomena or events described in the problem-at-hand in terms of its underlying principles or mechanisms (Mahnaz *et al.*, 2019). During this first analysis of the problem, students propose hypotheses that may be inaccurate, superficial, or mistaken. Still, they represent the conceptions that students hold—or even collaboratively construct—about the world (Mahnaz *et al.*, 2019). Teachers need to allow students' misconceptions to be expressed because this has facilitated remediation through the confrontation with new, more accurate conceptions (Dole and Sinatra, 1998; Chinn and Brewer, 1993).

In PBL settings, students are confronted with real-life scenarios or other contextualised problems that require a solution. These problems are "often ill-defined and messy, so there is no clear path or procedure to follow" (Etherington, 2011, p. 54). A number of studies examining problem-based activities in science learning have shown an improvement

in students' inquiry learning skills (Chen and Chen, 2012), problem-solving competency (Song 2018), scientific creativity (Siew, Chin and Sombuling, 2017), scientific reasoning (Leuchter, Saalbach and Hardy, 2014), collaboration skills (Song, 2018; Potvin, Mercier, Charland, and Riopel, 2012; Inel and Balim, 2010) in comparison to traditional teaching methods.

For instance, Song (2018) used a mixed research method (pre- and post-tests, student focus groups, students' reflections, and group artefacts) to examine fifty-three upper primary students' (12 – 13 years old) collaborative problem-solving competency in a project-based science learning with productive failure (PF) instructional design using iPads and laptops. Findings from the study showed an improvement in students' understanding of conceptual knowledge, production of better-quality group artefacts, a positive attitude towards the challenges from the project-based learning process, and a sense of ownership of student learning. The outcomes from Song's (2018) study imply that PF instructional design is beneficial to developing primary students' collaborative solving competency in science learning in a seamless learning environment. The current research borrows the idea of primary students' collaboration in science learning using iPads. Still, it does not limit itself to assessing students' problem-solving competency through a matrix of collaborative problem-solving skills. It neither aims to evaluate students' improvement of conceptual knowledge through standardised tests before and after the intervention. This research differentiates itself in that it aims to explore students' engagement in a problem-based science learning activity without focusing exclusively on the amount of scientific reasoning that students produce. Doing so aims to identify students' understanding (or misunderstanding or lack) of existing knowledge as they interact in a collaborative setting.

Another example comes from the study of Siew, Chin and Sombuling (2017), who used quasi-experimental pre-test and post-test control group design to explore the effects of PBL with cooperative learning method on two hundred and sixteen six-year-old preschoolers five trait dimensions (Fluency, Originality, Elaboration, Abstractness of title, and Resistance to premature closure) of scientific creativity. Findings from their study suggested that the combination of PBL with the cooperative learning method had a significantly positive impact on fostering preschoolers' trait dimensions of scientific creativity as opposed to two other methods, the PBL and Hands-on. The contribution of Siew, Chin and Sombuling's (2017) study

is valuable to the design of this research, which also relies on the use of the PBL with cooperative learning method to explore students' understanding of scientific concepts. However, the study has some limitations, as it focuses on preschoolers' solutions to a set of six real-world problems by evaluating their answers in tests before and after the intervention. That leaves a gap in examining older students' solutions to problems related to scientific concepts. Also, the quantitative methodologies used in the study do not provide a thorough insight into the cooperative engagement of students. This research seeks to address these limitations by first exploring primary and early secondary students' problem-solving in science learning, and providing a qualitative analysis of students' interaction whilst working cooperatively to implement a science activity.

Leuchter, Saalbach and Hardy (2014) used pre-test and post-test instructional design to examine two hundred and forty-four primary students' (4 – 9 years old) conceptual understanding of scientific concepts (*floating* and *sinking*) and scientific reasoning in a problem-based context. The study aimed to provide adequate support for conceptual development and facilitate processes of scientific reasoning by providing a learning environment that contained scaffolds in terms of(a) task features (e.g. sequencing, comparisons) and (b) a problem-based learning context. For example, each student could work on the task by being encouraged to do experiments with the given materials, using a worksheet as an experimental protocol. The results revealed a decrease in students' misconceptions from pre-test to post-test and the production of significantly more correct reasoning about the processes of *floating* and *sinking* of solids and hollow bodies. Although the study highlights the valuable role that scaffolding plays in improving young students' understanding of scientific concepts and their scientific reasoning, it has some serious limitations. First, it uses measurable methodologies to assess students' understanding of scientific concepts in terms of success or failure, failing to acknowledge the former's interpretation of the learning material. Second, the use of continuous scaffolding does not provide many opportunities for students to scaffold their understanding through the immediacy of shared interrogation both with and by peers (Adams, 2006a). Seeking to address these gaps, this research will primarily use a qualitative approach to explore students' interpretation and externalisation of understanding; then, it will provide any scaffolding to

students, giving them time to think independently and interact actively with their peers to shape their understanding.

Chen and Chen (2012) offered technology-based PBL instruction to ninety-six 7th graders (12 years old) through an instructional website including news, resources, courseware, simulation, and evaluation. The purpose of their experimental study (pre-test and post-test) was to determine the impact of instruction on learner performance, attitude toward science, and inquiry ability. To do so, students were required to gather necessary information from the material presented and collaboratively solve the problem as given by following a step-by-step problem-solving procedure (e.g., representation of problem(s), development of solutions, and monitoring and evaluation of a plan of action) (Chen and Chen, 2012). The results reported no statistical difference in the science performance of the treatment groups. Students had more positive attitudes toward learning science, and their inquiry abilities were higher than those in the control group. While the study of Chen and Chen (2012) offers valuable evidence in support of PBL learning settings, their methodological approach focuses on judging performance by test results. That leaves a gap for more in-depth research that focuses on assessment for learning, not of learning, which this research will aim to address.

Potvin, Mercier, Charland, and Riopel (2012) examined eight hundred and seventy-five thirteen-year-old students' conceptual development in a PBL learning environment. In an experimental design of pre-test and post-test type, students were required to solve twenty tasks about electricity after being given video instructions about how to plug the source, link up wires, and avoid short-circuits. The study's outcome revealed that students from the experimental group performed significantly better in the tests than their peers from the control group. They also benefited more from the interaction with their peers, especially hearing about the latter's conceptions, regardless of those being right or wrong (Potvin *et al*., 2012). That study highlighted the importance of peer interaction in constructing shared understanding, a perspective that the current research shares. However, it failed to explore the exchange of ideas during students' interaction and how that might affect students' understanding of electricity. This research seeks to emphasise how students' collaborative interaction can shape their understanding of scientific concepts.

Inel and Balim (2010) investigated the impact of the problem-based learning approach in science and technology teaching upon upper primary school students' construction levels for science concepts. Forty-one 7th grade students participated in the semi-experimental design study, completing pre-tests and post-tests. The results revealed a significant difference in favour of the experimental group on students' scores on the academic achievement test and concept construction levels. The study enriched evidence supporting the PBL approach in improving students' understanding of science concepts. Still, it failed to examine how students' collaborative interaction might have impacted their construction of science concepts. The current research aims to address this gap using a qualitative methodology to investigate students' collaborative interaction.

While the studies mentioned above provide rich empirical evidence about the impact of PBL learning environments on students' performance in and improvement of science knowledge, they share one major limitation: they focus on examining test scores before and after an intervention but fail to investigate students' collaborative interaction, during which students share, negotiate, and interpret existing and sometimes contrasting information (Vygotksy, 1987).

Additionally, in many studies (Song, 2018; Chen and Chen, 2012; Potvin *et al.*, 2012, Inel and Balim, 2010), participants were 12 years old and above. In one (Leucther *et al.*, 2014), they were between four to nine years old and in another one (Siew *et al.*, 2017) they were pre-schoolers - under the age of 6 years old. That leaves a gap for research examining 10- to 12-year-olds' collaborative interaction to implement a science task in a PBL setting. Although there might be some doubt about the ability of primary students to engage in PBL, considerable research has shown their potential to solve ill-structured mathematics problems (Lesh, English, Riggs, and Sevis, 2013), suggesting the feasibility of applying PBL at these levels. Aiming to address the limitation, this research focuses on the upper two grades of primary school students (ages 10 -12), using an in-depth approach through qualitative methods.

Also, few of the studies identified here (Potvin *et al.*, 2011; Inel and Balim, 2010) indicated that PBL had a positive impact on older primary students' development of reasoning and application skills as well as on their understanding of scientific concepts. What they did not

account for, however, was the explanatory process in peer talk that underpinned students' reasoning, which means that students' understanding of scientific concepts can be found in their reasoning for their answers and not the answers themselves (Driver, 1983). That highlights again the need for more qualitative research, which will provide insight into the discursive process of primary students as they engage in problem-solving activities.

Despite the number of studies identified above showing the effectiveness of PBL in science learning, there is not enough empirical evidence to support storytelling in problem-based contexts (see next section 2.2.3.2). This research will design a story problem to help students externalise their understanding of science concepts to address this issue. It also aims to guide teachers on how to implement PBL activities involving story tasks in the actual science classroom.

2.2.3.2 Problem-based stories (story problems)

Story problems are the most common problems students encounter in formal education and the most extensively researched (Jonassen, 2011). Students start solving story problems in early elementary school and frequently encounter them through graduate school (Jonassen, 2011). From mathematical calculations ("How many apples does Mary have?") to literary analysis ("What does the author imply?") to scientific experiments ("Why and how does this happen?") to historical investigation ("What took place, and why did it occur that way?"), students learn how to answer questions and solve problems (Delisle, 1997).

Classrooms are places where stories are told either through textbooks or through teachers that tell stories about the subject matter they teach. These stories organize the curriculum material, and teachers tell them as explanations or illustrations of a larger idea (Gudmundsdottir, 1991). Teachers often use stories in their classrooms to solve a usual teachers' problem: how to translate 'knowing into telling' (Whyte, 1981). Stories result from a narrative way of knowing, suggests Gudmundsdottir (1991). According to Bruner (1986), there are two fundamental ways of knowing. One is the *'paradigmatic'* way, the search for universal truth conditions, which is primarily the natural and physical sciences domain. The paradigmatic mode is, in its nature, logic, scientific, and based on reasoning (Murmann and

Avraamidou, 2014). The other fundamental way to perceive and know about the world, as Bruner (1986) proposes, is the *'narrative'*, which looks for connections between events. The narrative mode is sequential, action-oriented, detail-driven, and influenced by feelings and emotions (Murmann and Avraamidou, 2014), and it is the default mode of thinking (Bruner, 1986). "Narrative ordering makes individual events comprehensible by identifying the whole to which they contribute and the effect one has on another" (Bruner, 1986, p. 13).

To solve story problems, learners must demonstrate a conceptual understanding of the problem types by constructing a conceptual model and applying solution plans based on that model (Jonassen, 2011). Conceptual models, also known as problem schemas, are defined as mental representations of the pattern of information represented in the problem (Riley and Greeno, 1988).

Problem schemas contain "semantic information and situational information about the problem associated with the procedures for solving that type of problem" (Jonassen, 2011, p. 242). There is a dearth of research examining the use of story problems and storytelling in PBL instruction. Specifically, the nature of problems provided in many studies includes scenario- or case-based problems, according to the grade level it targets. For example, in Araz and Sungur's (2007) study, students had to deal with case-based, ill-structured problems by brainstorming and generating ideas related to the problems to identify issues involved in the cases. Teachers gave students guidelines for approaching the case problem and took responsibility for what they learned and how (Araz and Sungur, 2007). In the study of Leuchter, Saalbach, and Hardy (2014), described previously, participants were given structured and clear access to the problem by doing experiments with available materials. None of these studies involved story problems, despite the similarities that can be found between case or scenario-based and story problems. Both story and case/scenario-based problems involve a given scenario [plot] which contains critical pieces of information needed to solve the case or problem. Both approaches require the learner to analyse and evaluate the evidence provided, determine the accuracy of the given information, seek additional information to validate or refute or extend that information, and then deliver a written or oral response to the questions posed by the instructor that articulates clearly their thinking about the problem (Mahnaz, Hung and Dabbagh, 2019).

Where the two approaches differ is in the learning setting adopted – the case or scenario-based learning is more teacher-centred than the story-based one, which is student-centred. Specifically, when learners work on a case or scenario, either alone or in groups, they have to apply what they previously learned to the specific circumstances as delimited by the information provided in the case (Mahnaz, Hung and Dabbagh, 2019). By narrowing "the scope of the information provided and specifying the questions to be answered, the designer of the case is intentionally leading the learners to arrive at a predetermined solution" (Mahnaz, Hung and Dabbagh, 2019, p. 89). On the contrary, with story-based problems, learners have to use and apply their existing knowledge to synthesise a story of their own while providing a solution to its problem, demonstrating thus their understanding of the acquired information. In sum, cases or scenarios present complex yet well-structured problem situations that contrast with the ill-structured problems that drive the learning process in story-based approaches. This research will concern itself with ill-structured story problems.

Overall, stories and story problems are used in everyday lives and serve to communicate understandings, experiences, and events (Avraamidou and Osborne, 2009). In recent years, stories have gradually gained increasing interest as a means for communicating science, with many researchers proposing their use as learning tools in science education (Murmann and Avraamidou, 2014). This issue will be discussed extensively in upcoming sections.

2.2.4 Collaborative Learning

The most broadly used definition of collaborative learning is a construction of shared understanding through interaction with others. The participants are committed to or engaged in shared goals and problem-solving (Dillenbourg, 1999; Littleton and Häkkinen, 1999; Roschelle and Teasley, 1995). In addition to the construction of shared understanding, collaborative learning commonly refers to the co-construction of knowledge (Baker, 2002), negotiation of shared meaning (Pea, 1993), construction of common knowledge (Crook, 2002), exploratory talk (Mercer, 1996) and many more. Collaborative learning is mainly characterised by mutual goals, division of labour, role interdependence, and group rewards (Johnson and Johnson, 1983). It can take a variety of formats, depending on the degree of

coordination among the group members (Arvaja and Häkkinen, 2010). For example, students may have shared task alignment, in which the activity is organised around joint problem-solving efforts (Barron, 2003), such as in the case of this research. That involves sharing and expanding each other's ideas instead of individual solutions until a common ground is reached (Barron, 2003; Clark, 1996). Azmitia (2000) found that collaborative learning settings relying on problem-solving tasks that had one correct solution or could be solved through systematic hypothesis testing resulted in a smooth collaboration emphasising cognitive development. However, collaboration was more stressful in more open-ended and ill-defined problems because there was no clear script on how to proceed Azmitia (2000). As it appears, collaborators' interaction and their personalities and relationships play an important role in managing collaboration (Arvaja and Häkkinen, 2010). This research will concern itself with the interaction among collaborators working through an open-ended and ill-structured problem.

Collaborative learning environments promote "active involvement in learning and reciprocal interaction among students" (Nastasi and Clements, 1991, p. 112). When students work together to solve complex tasks with an ill-defined problem, they are more likely to exchange ideas and information (Arvaja and Häkkinen, 2010). They can also use higher-level reasoning strategies, such as category search and retrieval and formulation of equations from story problems (Nastasi and Clements, 1991). Thus, students take responsibility for every step of the task, selecting the steps for its solution. Ill-structured problems that do not have a single correct answer can be featured as group tasks (Clark, 1994). They elicit knowledge from a wide subject domain and increase the possibility of many participants contributing to the discourse (Arvaja and Häkkinen, 2010). By contrast, single individuals can often accomplish problems with one identifiable correct answer (Chizhik, 2001). The interaction will naturally be more like helping each other understand concepts without a need for deeper-level discourse (Arvaja and Häkkinen, 2010).

Working together in ill-structured problem-based tasks provides students with opportunities to think about new ideas (Linn and Eylon, 2006); resolve opposing views (Amigues, 1988); explain one's thinking (Webb *et al.*, 1995); receive explanations, and make critique (Chi, 2008). In such collaborative settings, engage students in constructing meaning because participants bring along their existing ideas to meet the new ideas presented in the talk

(Mortimer and Scott, 2003). There can often be occasions when there is no tension between existing and new ideas and learning progress smoothly for the individual. At other times, conflicts may arise that need to be resolved if new and existing ideas are integrated. In either case, the collaborative benefits students gain from being grouped varies according to their attainment level. For example, studies about short-term collaboration show that group work leads to better problem-solving and learning outcomes (Barron, 2003; Webb and Palincar, 1996) and improved performance (Azmitia, 2000). Other studies in collaborative learning suggest that students learn better in groups of similar than asymmetrical attainment levels (Light, 1993). And there are those pointing out that mixed-attainment groups are better because the low-attainers benefit the most from the interaction with the high attainers (Zohar, 2008).

On the other hand, middle-attainment students appear to learn better in homogenous or narrow-range heterogeneous groups (i.e., either with low- or high- attainers, not both) (Nastasi and Clements, 1991). Hogan *et al.* (1999) propose that groups must be heterogeneous in existing knowledge and thinking skills. The more peers talk about conceptual issues in their groups, the higher reasoning levels they reach. That suggests that elaborating on each other's ideas relates to sophisticated reasoning. However, it is important to note that students' working together does not necessarily imply that all group members benefit the same by the end of the task. Hatano and Inagaki (1991) pointed out that the information team members use to solve a given problem does not coordinate into a new piece of knowledge in each member's head. Sampson and Clark (2008) also argued that group outcomes are not merely the sum of individual abilities but group interaction processes. Thus, the implementation of collaborative learning involves more than having students work in groups. Students must learn from each other, utilise each other's skillsets and resources, and share experiences that may benefit the entire group. However, these approaches (Sampson and Clark, 2008) have not been fully translated into effective teaching processes – an issue that this research seeks to address.

2.2.5 Thinking together – types of student talk during collaboration

According to Vygotsky (1962) and the notion of socio-constructivism, language has three essential functions: as a cognitive tool for knowledge processing; as a social or cultural tool for sharing knowledge amongst people; and as a pedagogic tool for intellectual guidance between individuals (Mercer *et al*., 1999). Among peers and adult guidance, the social experience of language use shapes individual cognition and thinking (Mercer *et al*., 1999). In essence, language is the tool for mediating thought. It is only through shared actions and communication with others that students can internalise practices and discourse features (Vygotsky, 1978) and transform them into aiding learning tools. One type of language that promotes learning is what Mercer (1996) states as exploratory talk. This talk represents "a joint, coordinated form of co-reasoning in language, with speakers sharing knowledge, challenging ideas, evaluating evidence and considering options in a reasoned and equitable way" (Mercer and Howe, 2012, p. 16).

The work of Mercer, Wegerif and Dawes (1999) focused on training students how to use language to respect all group members and ensure that everyone speaks and explains their thoughts. Their findings reveal that when learners receive this sort of exploratory talk, they perform better on science tests. With the focus on how teachers can train students to use exploratory talk, the Mercer *et al*. (1999) study overlooks students' instinctive use of such talk. When students work together to implement an assigned science task, their discussions can often include constructive arguments and critical thinking – key features of exploratory talk. There is limited empirical evidence supporting that, and this thesis' research seeks to address it. This focus on working with learners within a social environment provides fruitful information about how to instil learners with the language of science through discussion (Osborne and Dillon, 2010).

To capture the richness of students' talk when working together in groups, Mercer and his colleagues (Mercer and Littleton, 2007; Mercer *et al.,* 1999) devised a three-part typology of talk, as shown in *Table 2.*

Type of talk	Definition
Exploratory talk	Speakers engage critically but constructively with each other's ideas. Statements and suggestions are sought and offered for joint consideration. These may be challenged and counter-challenged, but challenges are justified, and alternative hypotheses are offered. In exploratory talk, knowledge is made publicly accountable, and reasoning is visible in the talk (Mercer *et al.,* 1999, p. 97)
Disputational talk	Speakers engage in a competitive interaction, disagreement, and individualised decision-making, including cycles of assertion and counter-assertion
Cumulative talk	Speakers share and build information in a positive but uncritical way, accumulating 'common knowledge'

Table 2: Definitions of students' talk in the science classroom (adapted from Mercer and Littleton, 2007; Mercer *et al.,* 1999)

Mercer and his colleagues are among the first who investigated the validity of exploring students' use of talk as a tool for reasoning and carrying out a collaborative approach in the study of mathematics and science (Mercer and Sams, 2006; Mercer *et al.,* 2004; Mercer *et al.,* 1999). Given that these studies were conducted in British primary schools, the three types of talk defined in their framework are based on the use of the English language in science/maths classrooms. This thesis' research includes British students as a participating population so that a fair comparison can be made. Findings from studies in science classes (Mercer *et al*., 2004; Mercer *et al*., 1999) suggest that social interaction has a developmental influence on individual thinking. As such, students in primary schools can work together more effectively, improve their language and reasoning skills, and reach higher attainment levels in their science courses.

Nevertheless, according to the researchers, primary students' talk can often be fairly simplistic and minimal (Mercer *et al.,* 2004), which is quite expected because of their young age. Findings from the work of Mercer and his colleagues apply to this thesis, which aims to

take its research a step further by relating these types of talk with meaning making during storytelling. On the other hand, now, these studies pay great significance to the teacher's role in guiding students during collaborative work and helping them to use exploratory talk, which will not be further explored in this research as it does not fit its purpose.

2.3 Stories and storytelling in education

The focus of educational research has been on stories over the last twenty years as a medium of data representation, guiding the development of methodologies (Hadzigeorgiou, 2016). Stories, along with drawings and narratives, have been found to have a mediatory role in constructing meaning (Pantidos, 2017). The technique of stories can be used to organise events, facts, characters, ideas, and so forth into meaningful units (Hadzigeorgiou, 2016). In the process of engaging with stories, meaning is constructed. A story takes the audience through a set of events, all the way from problem to solution and critical engagement with the solution (Polkinghorne, 1996), provoking thus active thinking and supporting meaning construction (Dettori and Paiva, 2009). Polkinghorne (1996) argues that the meaning of a story is created by noting that something is a part of a whole and that something is a cause of something else. In the classroom context, this means that the learner moves from a cognitive understanding of a concept to relate it to their own experience (Clark and Rossiter, 2008). That does not imply merely plucking an example of this concept from a collection of personal experiences. It suggests that the learner manages to connect the two, and it is in the making of this connection that new learning occurs (Clark and Rossiter, 2008).

In this context, telling stories is recognised as a valuable strategy to advance understanding and make sense of events, as it enables both its teller and the audience to create meaning, to understand what happens and to prepare for what may happen in the future (McDrury and Alterio, 2001). Storytelling is a traditional method of teaching (Pedersen, 1995). It is a simple yet powerful method that helps students make sense of the complex and unordered world of experience by crafting storylines (Gils 2005; Bruner 1990). Storytelling describes a set of characters that experience a series of events and work towards an acceptable outcome (McDrury and Alterio, 2003). Through the characters' experiences, one attempts to construct meaning, understand what happens, and prepare for what may happen (McDrury and Alterio,

2001). Storytelling plays an important role in classrooms because educators can use it to stimulate students' critical thinking skills (McDrury and Alterio, 2003, p. 8), and help them to develop a variety of skills in communication, search, collaboration and task completion (Di Blas *et al.*, 2009; Σεραφείμ και Φεσάκης, 2005). The process of debate, discussion, and reflection that students engage in as they work together to storyboard, shoot, and edit their digital stories are critical to the learning process (Standley, 2003). When students get involved in creating a story, it helps them make sense of a cognitive domain (Alexander, 2017).

Storytelling can be used as a learning tool for understanding complex subjects. The official curriculum guidance for storytelling in the classroom focuses on established story scripts that encourage students to recount or retell and rewrite an existing story (Kucirkova, 2018). Such an approach is useful in assessing children's writing skills and their ability to comprehend a story, remember it and follow a specific storytelling style (Kucirkova, 2018). For this research, the storytelling activities will be based on an established story script that students need to remake and retell, seeking to evaluate students' understanding of specific content.

2.3.1 Sequence of events in stories

One of the principal properties of stories is their inherent sequentiality (or sequence) of events (Bruner, 1990, p. 43). A story is a composition of a unique sequence of events, mental states, happenings involving human beings as characters or actors. However, merely reciting a series of events does not constitute one (Cobley, 2001) because events do not have a life or meaning of their own. Events' "place in the overall configuration of the sequence as a whole – its plot or Fabula" (Bruner, 1990. p.43) gives them meaning. It is the presence of connections and relationships among the story elements that determine its overall configuration or plot (Dettori and Paiva, 2009).

Norris and his colleagues (2005) state that stories typically have an opening situation, complications that involve action, and a resolution in the end, which may be either a success or failure. Stories go somewhere with some resolution or conclusion provided at the end (Norris *et al.*, 2005). Other authors suggest that stories can be a series of connected events whose sequence has meaning when the motives and choices of the characters create

causative links between events (Coffin, 2004, Klassen, 2006). That is, stories can be viewed in terms of change-of-state and event sequences that produce the sense of flow in the story (Klassen, 2006; Coffin, 2004). A way of representing such sequences is by a number of "minimal stories" that represent "initial state → event → (as a result) final state" (Klassen, 2006); this is the approach taken in this research. Regardless of the sequence representation, one should "temporally and causally organise a story into a sequence that is meaningful" to themselves and their audience (Shapiro and Hudson, 1991, p. 960). In that way, the audience understands the context of the sequence decisions.

Having to decide about the sequence and presentation of a story depends on selecting one or more beneficial or satisfying options from a larger set of options (Jonassen, 2011). These options may involve requirements, strategies, events, predictions, and opportunities. Still, the decision always requires "a commitment to a course of action that will yield results that are satisfying for specified individuals" (Yates, 2003, p. 24). These decisions are part of learners' strategies to construct a coherent story (Nicolocopoulou, 2008). Decision making is an explanation-based process because the decision-maker must make sense of the collected evidence to aid the selection process (Jonassen, 2011). Decision making depends on how people argue for and against each option based on their knowledge and combine those arguments to reach a decision (Jonassen, 2011). The final decision results from the process of supporting or rejecting alternative claims/decisions and contains causal accounts of the evidence (Jonassen, 2011). In other words, decision making is evidenced in how the story elements convincingly and satisfyingly hung together.

Typically, primary-school children (6–10 years old) know how to create stories that include initiating events, goal-directed actions, and consequences. Children's stories trend towards reduced ambiguity, increased referential adequacy, and effective temporal and causal connectives (Pinto *et al*. 2016; 2015). By the age of five, children can sequence events chronologically and gradually order multiple events if their culture values this type of discourse (Peterson and McCabe, 1983). Experience and context influence a child's ability to construct stories (Silva *et al.* 2014). As children get older, they become more able to produce complete episodes that are coherent, hierarchically organised and causally related (Stamouli, 2012). From the age of 12 onward, students are more capable of sequencing events and

creating a story plot, revealed findings analysing young students' construction of coherent narration of events (Trabasso and Nickels, 1992).

Over the last two decades, a considerable body of research has examined children's strategies to create coherent stories. Although these studies yield valuable evidence supporting children's narrative skills, their main focus is on the development of language, vocabulary and/or literacy skills with pre-school children (Nicolopoulou, 2019; 2016; 2008; Nicolopoulou and Trapp, 2018). Other studies investigating children's construction of stories cast light on young children's involvement in the production of personal stories and the value that such involvement had in terms of authorship, autonomy, authenticity (Kucirkova, 2019; 2018). A noticeable limitation occurring from the studies just mentioned is that they solely capture the narrative skills regarding the use of language with very young children. That leaves a gap in examining older (school-level) children's creation of coherent stories that help them to externalise their understanding of a troublesome topic. This research will address this gap by proposing a problem-based story that requires students to engage in decision making to determine its plot.

2.3.2 Hierarchical sequencing

Considering that a story requires, at its most basic, an account of a sequence of events (Cobley, 2001), merely reciting a series of events does not constitute a coherent story. Sequencing the story events can include other relationships, such as *hierarchical sequencing* (Gagnè, 1968). Robert Gagné (1968) developed the term *hierarchical sequence* to teach "intellectual skills" in the cognitive domain. *Hierarchical sequencing* is based on the observation that learning a skill starts with the simpler "component skills" before moving on to the complex skill they are part of. For example, in the science topic of matter, one must first learn that matter consists of three states – solids, liquids and gases – before they learn how substances change conditions (state changes). However, a *hierarchical sequencing* could go on seemingly forever, and one needs to be careful about using it. Deciding about the right order highly depends on the interpretation of specific knowledge. For instance, certain concepts need to be learned before others because, without the first, the latter will not be understood. It depends on the classroom teacher to decide upon this, based on the

curriculum requirements and his/her students' existing knowledge. The purpose of hierarchical sequencing, thus, is to identify the prerequisite skills that need to be taught and the order of the prerequisite relationships among them. Although Gagné's (1968) proposed teaching strategy is outdated, hierarchical sequencing is the most common teaching sequence presented in the curriculum.

2.3.3 Science stories

Science stories are slightly different from stories in the humanities because of their purpose and the role of their audience (Klassen, 2009). That is problematic, as it is not easy to accomplish the explanatory purpose in narratives (Norris *et al.,* 2005). In particular, the main purpose of a science story is to facilitate the teaching and learning of science and not just to entertain or communicate a message, as it happens with a story in the humanities. Although "the primary use of narrative in science is to provide a forensic analysis not only of what we know but how we know", another function of narrative is to provide "a celebration of the wonder and awe of the scientific account of the material world" (Avraamidou and Osborne, 2009, p.1692). That is also to understand the natural world. Unlike stories in humanities, science stories are appropriate for describing one's understanding of the world (Hadzigeorgiou, 2016), according to research based on the constructive nature of human sense- and meaning making (Egan, 1999). In other words, science provides causal explanations about the material world, and science stories translate that knowing into telling (Avraamidou and Osborne, 2009) – and this is how this research will use science stories.

A science story is expected to entertain and engage learners emotionally, as it happens with the stories in humanities, and help them to understand the science content (Klassen, 2009). The narrative perspective on science is based on the fact that scientific theories are fundamentally story-like because they rely on metaphors, analogies, and conceptual frameworks (Hadzigeorgiou, 2018). Stories are a conceptual tool for providing coherence, continuity, and meaning to their contents (Hadzigeorgiou, 2016). They are also considered a means of translating knowing into telling (Avraamidou and Osborne, 2009), making them a valuable instructional tool, especially in the context of science education, where abstract knowledge needs to be presented in a way that makes sense to the students. There are,

however, limitations regarding the use of stories in science education, according to Hadzigeorgiou (2018; 2016). One limitation is that it is difficult to create stories for all phenomena and science concepts because of the need to use deductive-nomological explanations.

Also, the author argues that scientific ideas, such as concepts or laws, need to be applied in various situations to be understood. Another limitation is that descriptive explanations, as presented in a narrative form (through the use of anthropomorphism), are more suitable for young children (Hadzigeorgiou (2018). This thesis accepts the truth found in the first two limitations. Indeed, science is based on the paradigmatic (logico-mathematical) mode of thinking, which involves testing concepts using evidence, arguments, and so on.

Contrary to that line of thinking, this thesis believes that science stories should not be considered a tool for testing concepts or explaining phenomena through experimentation and material evidence. Science is about developing causal explanations of the material world, for instance, what is causing global warming or what causes a rainbow – physical behaviours brought out by scientific laws (Avraamidou and Osborne, 2009). The purpose of a science story is to describe such natural phenomena and physical behaviours through a set of sequenced events to help its audience makes sense of what happens – what precedes, what happens and what follows/how it ends. Furthermore, this thesis concurs with Hadzigeorgiou's (2018) view that there is limited research examining the use of stories in science, described next, a limitation that this research seeks to address.

Empirical data shows that science stories can improve students' understanding of the nature of science (Erten, Kiray, and SenGumus, 2013); attitudes toward science (Hadzigeorgiou, 2006); scientific inquiry practices (Kokkotas *et al.*, 2010); or the learning of science concepts (Hu, Gordon, Yang and Ren, 2021; Kerby, DeKorver and Cantor, 2018). Hu, Gordon, Yang and Ren (2021) used personification storytelling that attributes personal characteristics to cosmic bodies with metaphors relating to children's lives to examine preschool (aged four to five) children's understanding of abstract astronomy concepts. Drawing on evidence from the analysis of pre- and post-intervention interviews, educators' documentations, and children's hands-on activities and free drawing, their results showed a significant improvement in children's understanding of abstract astronomy concepts that are generally considered unsuitable to them.

Kerby, DeKorver and Cantor (2018) developed a demonstration show at a science museum to evaluate young students, aged five to eleven, concept knowledge using pre- and post-assessment. Findings from their study showed that the deconstruction, modification, and reassembly of story elements promoted conceptual understanding, interest, enthusiasm for learning, and self-efficacy in the audience (Kerby *et al.,* 2018).

Morais (2015) investigated qualitatively how primary children aged eight to ten responded to and experienced storytelling involving chemistry and related hands-on activities. The researcher used a content analysis of students' drawings after the hands-on activities and answers to a series of questions related to the story. The results showed that using carefully chosen appropriate stories in combination with hands-on activities could be an effective instructional strategy to stimulate interest in science and support the learning of concepts.

Hadzigeorgiou, Klassen and Froese Klassen (2012) conducted an empirical study to determine the effect of romantic understanding in science learning (alternating current). Grade 9 students who were taught about electricity based on a story about Nikola Tesla were compared to those students (experimental group) who were taught using traditional lecture techniques (control group). Using quantitative and qualitative analyses of journal entries, they found that the experimental group had higher scores on the summative assessment and was more involved with the content and the context of the story than the control group.

Kokkotas, Rizaki, and Malamitsa (2010) employed bibliographical research to examine how storytelling, as a teaching strategy, might engage primary students in science and develop their understanding of electricity and electromagnetism. Their study indicated that the teaching intervention using storytelling helped primary students make connections to their existing knowledge and contextualised gaps in students' knowledge, developing thus their understanding (Kokkotas *et al.,* 2010). Furthermore, the researchers emphasised that the story was appropriate and developed students' inquiry skills, such as hypothesis exploration, formulation, interpretation, and metacognitive skills, such as comprehension of new knowledge.

Banister and Ryan (2001) used an anthropomorphic story to teach Year 4 children, aged nine to ten, about the water cycle and documented students' increased retention of concepts through a series of open-ended questions, rewriting of the story and semi-structured interviews. The authors concluded that storytelling as a form of explanation helped primary children to prune some of their old ideas and widen others to varying degrees.

While the studies described above offer valuable insight into the use of stories in teaching science concepts, they share some important drawbacks. First, they use stories as part of demonstration shows at museums (Kerby *et al.,* 2018); or as an introduction to an expository text, hands-on activity, or subsequent lesson (Hu *et al*., 2021; Morais, 2015; Hadzigeorgiou *et al*., 2012; Kokkotas *et al*., 2010; Banister and Ryan, 2001). That requires additional pedagogical techniques to complete the intervention. Second, they evaluate students' conceptual knowledge on an individual level through drawings (Hu *et al.,* 2021; Morais, 2015) or questionnaires (Kerby *et al*., 2018; Hadjigeorgiou *et al*., 2012; Banister and Ryan, 2001), failing to examine students' collaborative interaction and shared understanding. Considering everything, this research aims to create science stories that schoolteachers can use to promote science education and help students externalise their understanding of science concepts on the social level and identify the latter's knowledge gaps in a specific science topic.

2.3.4 From storytelling to digital storytelling

A significant number of recent changes in the presentation and delivery of stories is made possible by emerging technologies (Chen *et al*., 2003). The rapid development of technology, alongside the advent of relatively inexpensive (Davis, 2004) digital tools, shifts the focus from traditional types of storytelling to a new form of more technologically aided storytelling: digital storytelling. Digital storytelling is not a new idea, despite the existing emphasis on multimedia technology. Joe Lambert and the late Dana Atchley contributed to creating the digital storytelling movement in the late 1980s as cofounders of the Centre for Digital Storytelling (CDS), a non-profit community arts organization in Berkeley, California. At its core, digital storytelling enables computer users to become creative storytellers following the traditional process of selecting a topic, conducting some research, writing a script and developing an interesting story (Robin, 2016; 2008).

Like all storytelling, digital storytelling is a form of narrative expression. It combines an original script with visual imagery, soundtracks, animations and most importantly, narration in the author's voice (Weis *et al.*, 2002). It is usually shorter than a typical oral presentation – between 2 and 10 minutes long – but it "makes up in content what it forgoes in length" (Frazel, 2010, p. 10). Digital storytelling content usually consists of computer-based graphics, (recorded) audio, computer-generated text, video clips, animation, and music. In this research, digital storytelling combines animated cartoons with students' commentaries (in written format). In addition, the digital storytelling activities are created on iPads, for the following reasons: first, they allow for control with touch screen operations (e.g., there is a touch-sensitive keyboard); second, they provide a variety of apps that suit the needs of students with various abilities and different learning activities (Kucirkova *et al.*, 2014); lastly, they facilitate the creation of content-related strategies by providing an easy-to-use system which allows for several operations, such as audio-recording or photography, to take place at one location (Kucirkova *et al.*, 2014).

A digital story can also be presented in numerous ways. For example, it can be typed up as text, be performed and videoed, be narrated and audio-recorded, be based on students' drawings and photographs, or combine various modes (Kucirkova, 2018). Authoring or editing a digital story does not necessarily require a new story. Students can also be story editors that make changes to the text or illustrations of existing stories, such as in the case of this research, in which students will edit a predefined digital story. The physicality of manipulating and methodically arranging digital images, audio and text "makes students slow down and think about their work in new ways" (CNDS) and leads to reflective meaning making. The process of digital storytelling can be seen as a constructivist learning approach, as it allows students to make connections between their creation and their sense of learning (Alexander, 2017).

Choo, Abdullah and Nawi (2020) conducted a critical analysis of empirical studies using digital storytelling in teaching and learning. They concluded that digital storytelling is beneficial in developing the teachers' content, pedagogical and technological knowledge and enhancing student learning as it increases their understanding of content and caters for their multiple intelligence. Similarly, in the systematic review of de Jager, Fogarty, Tewson, Lenette, and

Boydell (2017), results indicated that digital storytelling in research was especially appropriate and mainly used with marginalised groups.

Using a qualitative methodology, Schmoelz (2018) studied lower and upper secondary students' interaction in classroom activities that use digital storytelling to enable co-creativity. Drawing on evidence from interviews and group discussions with students and teachers, field notes and videography of classroom activities, the study documented that students engaged in action through giving, taking, sharing, or limiting control in the digital story-writing phase. In the digital story-producing phase, students experienced co-creative flow as they shared enjoyment and fun, from which control and rationality were absent. The current research uses the element of co-creativity, as students will work collaboratively to implement the digital storytelling activities. It also expands existing research by looking into students' collaborative interaction, highlighting how they construct a shared understanding of the learning content.

In their study, O'Byrne, Stone and White (2018) examined the mentoring and modelling of storytelling and digital storytelling in early-years (aged four to six) students' motivation for writing and digital content construction. The researchers conducted a qualitative analysis of students' work products (i.e., sketches, illustrations), video-recorded observations of students in the classroom, and researcher notes. They found that students developed enhanced communication skills by learning to organise their ideas, ask questions, express opinions, and construct stories while interacting with others and the computers to create digital stories. This research differentiates itself by examining how students construct arguments and provide explanations while working collaboratively to create digital stories on iPads.

Campbell (2018) conducted action research to investigate primary (Grade 5 and 6) students' engagement in writing and the motivation and ability to create higher quality writing. The researcher analysed evidence from observations, interviews, a writer self-perception scale, print and digital writing samples, and writing evaluations. He concluded that effective teaching combined with technology could significantly improve students' writing skills and engagement in the project, including improved writer self-perception and confidence. While

Campbell's (2018) study emphasised scaffolding by teachers, this research takes a different stance acknowledging the importance of student-centred settings in allowing students to take full responsibility for sharing and (re)constructing their knowledge.

Smeda, Dakich and Sharda (2014) investigated the pedagogical aspects of digital storytelling and its impact on primary and secondary students' learning, using innovative learning experiences based on digital storytelling. Employing qualitative (interviews and observation) and quantitative (an evaluation rubric) methods, the study findings indicated that digital storytelling was a powerful tool to integrate instructional messages with learning activities to create more engaging and exciting learning environments. This research also uses innovative learning experiences based on digital storytelling. It steps beyond Smeda *et al.'s* study (2014) and examines students' creation of the story content (plot), aiming to highlight students' understanding.

Barrett (2006) stressed that digital storytelling could facilitate the convergence of four student-centred learning strategies: student engagement, reflection for deep learning; project-based learning; and the effective integration of technology into instruction. This research seeks to cover most of these learning strategies. It will engage students in the learning process, give them space to achieve deep learning, and evenly integrate technology into instruction.

Robin and Pierson (2005) examined how graduate students and undergraduate teacher-education students visioned, designed, and created digital stories about a real-world problem. They found that digital storytelling could capture the imagination of both students and teachers because the act of crafting meaningful stories elevates the experience for students and teachers. Lastly, the benefits of using digital storytelling in this research align with Gils (2005) proposition on the many advantages of using digital storytelling in education, such as to provide more variety than traditional methods in current practice; to personalise the learning experience; to make explanation or the practising of certain topics more compelling; to create real-life situations easily and more cheaply; and to improve the involvement of students in the process of learning. Digital storytelling is "not an inherently superior teaching strategy, and the tools are not a panacea; educators need to keep an eye

on the prize of substantive, reflective, course- and programme- appropriate learning" (Matthews-DeNatale, 2013, p. 200).

2.3.5 Digital storytelling in science education

While digital storytelling spans the curriculum, covering many subjects, it is most often associated with the arts and humanities (Sadik, 2008). Research, however, indicates that technological advances can support the teaching of science (Isman *et al.,* 2007). Various studies emphasise the significance of technology-integrated science education to construct links between scientific knowledge, to develop advanced understanding, to improve problem-solving skills, to enhance students' interest in science, to establish more positive attitudes towards science, and to increase student motivation (Serin *et al.,* 2009; Avraamidou, 2008).

For example, Dewi, Magfiroh, Nurkhalisa, and Dwijayanti (2019) used interviews and pre- and post-tests to examine whether the use of contextual-based digital storytelling in science teaching could improve seventh-grade students' critical thinking. Similarly, Dewi, Savitri, Taufiq and Khusniati (2018) used pre- and post-assessment to evaluate the use of science digital storytelling in improving seventh-grade students' cognitive ability. The two studies found a statistical improvement in critical thinking (Dewi *et al.,* 2019) and cognitive ability (Dewi *et al.,* 2018) of students in the experimental than the control group. One limitation found in these studies is that they used standardised tests to assess students' critical thinking (Dewi *et al.,* 2019) and cognitive ability (Dewi *et al.,* 2018) on an individual level, ignoring the role that social interaction can play when students implement together a science activity. This research acknowledges the importance of social interaction in students' science learning and aims to explore it in depth.

Cheng and Chuang (2018) examined fourth-grade students' learning processes of scientific imagination in a marine science digital storytelling project. Analysed data from students' completed worksheets, digital storyboards, final digital storytelling products, and interviews revealed that students with low performance were not proficient in describing the relationships among scientific concepts and creating science stories based on their science knowledge. The authors suggested that interactive learning environments and fluent digital

literacy are essential in improving students' ability to explore and connect different ideas in the development of scientific imagination. The current research takes a further step from Cheng and Chuang (2018), seeking to explore how a collaborative learning setting may help students to use their existing scientific knowledge to create stories about scientific concepts.

Tan, Lee and Hung (2014) investigated the use of 'edu-tainment' storytelling in a Grade 5 science classroom, asking students to design a digital story about a scientific concept (the water cycle). Deriving evidence from (video) recorded class interaction and teacher talk, students' generated artefacts and focus groups, the authors concluded that the creation of digital stories (in which there is a purposeful integration between the narrative context and the knowledge content) depended upon the type of knowledge – whether it was hierarchical or horizontal – that the students needed to acquire through instruction. This research seeks to enrich evidence about the hierarchical structure of knowledge presented through the curriculum.

Using a quasi-experimental study, Hung, Hwang and Huang (2012) examined Grade 5 students' learning performance in science through a project-based digital storytelling activity. Students had to collect data on the Internet while being guided by the teachers asking questions and then create movies for storytelling based on the collected data. The experimental results showed that project-based learning with digital storytelling had effectively enhanced students' science learning motivation, problem-solving competence, and learning achievement. In Hung *et al.'s* (2012) study, teachers played an important role in guiding students' data collection, an approach this research opposes, as it adopts a more student-centred strategy that allows students to work autonomously, without guidance (related to the learning material), to create a digital story.

Sadik's (2008) study evaluated the effectiveness of digital storytelling in learning and the extent to which students aged thirteen to fifteen were engaged in authentic learning tasks. Students were encouraged to produce their own digital stories and then present, publish and share them with their classmates. Using quantitative (digital story evaluation rubric) and qualitative (classroom observation and interviews) analysis of students' produced stories revealed that overall, students did well in their projects. Also, students' stories met many of

the pedagogical and technical attributes of digital stories. The current research does not aim to evaluate students' ability to construct standardised digital stories but to identify students' understanding (or lack) of the learning content through digital stories.

Solomon (2002) highlights the impact of pictures and cartoons in a science story because individuals have a much larger capacity for in-built attention to moving objects (as reported in the classic experiment on the cat's visual cortex by Hubel and Weisel, 1962). That suggests that video and acting can be doubly valuable. However, a lack of appropriate ready-for-use educational material hinders the use of the stories in education (Vrasidas *et al*., 2015). Finding a story relevant to the lessons being taught and knowing how to integrate the educational area into a classroom environment and keep the lesson relevant are two concerning issues for teachers, making the need for proper teacher training (Vrasidas *et al.,* 2015). Thus, there is a gap in creating suitable and relevant educational material that teachers can use to create, produce, or compose digital stories that will match their classroom's individual learning needs. To this end, this research proposes activities that include educational material (carefully selected and compiled from various sources available online) that afford students to freely order and sequence it based on their understanding of the domain knowledge.

2.4 The use of technology in digital storytelling

The technological setting for digital storytelling advanced rapidly after the start of the twenty-first century, with the advent of mobile devices as the ultimate digital storytelling device (Alexander, 2017). Mobile devices open new opportunities for individuals to view, read or listen to traditional forms of stories otherwise constructed and consumed on classic devices, such as laptops, game consoles and desktop computers (Alexander, 2017).

2.4.1 iPads and the "Our Story" application

In the last decade, the release of iPads in spring 2010 has supplemented mobile devices. iPads are significantly advanced compared to previous technology because they allow for control with touch screen operations (e.g., there is a touch-sensitive keyboard). They also provide a variety of apps that suit the needs of students with various abilities and different learning activities (Kucirkova *et al*., 2014). Furthermore, they facilitate the creation of content-related

strategies by providing an easy-to-use system that allows for several operations, such as audio-recording or taking pictures, to take place at one location (Kucirkova *et al.*, 2014). Since its release in 2010, Apple's iPad has been in the spotlight as an affordable and flexible learning tool for all levels of education (Falloon, 2015).

Some studies examine the multimodality of iPads with young students, focusing on how iPads can engage children in communication and literacy-related activities, such as story-sharing and story-creation (Kucirkova *et al.,* 2014; Kucirkova *et al.,* 2013). These studies provide valuable information about students' engagement and collaboration when using iPads, which apply to this research. For instance, in both studies, students use a storytelling app called Our Story, the same app that the participants of this research use. The first study (Kucirkova *et al.*, 2013) analyses collaborative talk and peer engagement with educational software using the concept of exploratory talk (Mercer, 1996; Mercer *et al.,*1999). The current research uses the same idea to analyse students' peer talk during collaboration. The present study differentiates itself in its purpose because it does not seek to evaluate how students can improve their literacy skills using iPads.

The "Our Story" app is a storytelling app for smartphones and tablets developed at the Open University in England. The app facilitates the creation of stories in three modes (audio, pictures, text) and offers the possibility of turning them into a customisable digital record (Kucirkova *et al.,* 2014). A unique feature of the "Our Story" app is that it enables users to select and sequence content. It gives the flexibility to move chunks of content, re-arrange them in the filmstrip and then play them as a complete story. That enables users to re-create their own story, view it finished and go back and re-order the content if they are not satisfied with the result (*Figure 1*). In addition, the app allows its user to replace still pictures with videos. Although videos cannot support editing features, they can still be used.
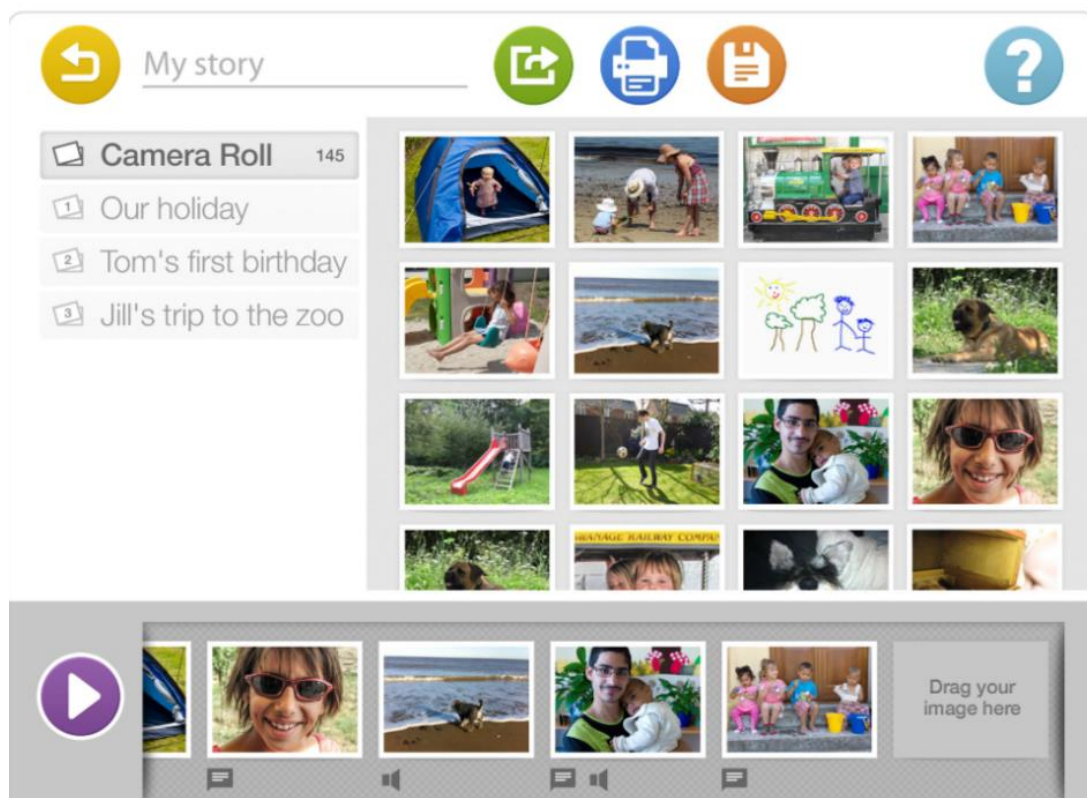
Figure 1: The filmstrip on the Our Story app that enables the selection and sequencing of content.

The contribution of both the iPad and "Our Story" app plays a significant role in the emerging research concerning mobile technologies. Yet, it goes beyond this research, which will not address it further. It can be, nonetheless, taken into consideration for future research.

2.4.2 Animations in digital stories

Animations can be defined as the conceptualisation of the act, process, or the result of imparting life, and it involves the illusion of movement on a screen (Barak *et al.*, 2011). Animations constantly require the reader to interpret their content actively and seamlessly blend metaphors and explanations without interrupting the flow of narration (Green and Brock, 2000). On the other hand, animations are a passive medium in which the receiver does not control the flow of information, and this may be a disadvantage from an educational perspective (Tversky, Morrison and Betrancourt, 2002).

In learning, animations are an effective way to visualise processes that cannot be seen or that are difficult to explain in class. There are two ways in which animations can contribute to a

better understanding of the learning material: First, they enable the creation of mental representations of concepts, phenomena, and processes. Second, they can replace challenging cognitive processes (such as abstraction, imagination, or creativity) that some learners are short of (Barak *et al.*, 2011). In other words, animations provide more external support for learners to construct their dynamic internal representations than static graphics (Lin and Atkinson, 2011). Considering that the scientific language is often difficult for students to understand, researchers believe that its vocabulary needs to be visualised so that abstract concepts become more concrete (McCartney and Samsonov, 2011). The researchers argue that animations help students first visualise individual concepts and the relationships between them to gain an idea of the whole. In this way, students manage to conceptually transform and adjust scientific knowledge into their mental shapes (Fensham *et al.*, 1994; Pike, 1994).

However, this dynamic and vibrant nature of videos and animations is likely to pose a threat to novice learners. The processing of visual materials requires "high levels of mental abstraction and synthesis of the procedures modelled, which may overload students' cognitive capacity, especially if students are novices in a domain and lack appropriate domain knowledge to guide their attention" (Moreno, 2007, p. 766). Also, "if the animation is ill-designed, and too much information is displayed in a short time, it may be cognitively overwhelming for students" (Barak *et al.,* 2011, p. 840). On the other hand, animations can be underwhelming and lead to excessively passive information processing. That, in turn, can prevent learners from performing effortful cognitive processes required for a deep understanding (Schnotz and Rasch, 2005). Thus, the teacher's competence in carefully designing and/or selecting the instructional use of animations in class is an essential determinant for successful science learning.

Numerous studies in the past decades have shown positive results that favour the use of instructional animations in (science) learning. For instance, Najjar (1998) examined the use of animation among learners and found that the more visualised means are used, the better the learning process becomes. The study showed that the best method for teaching dynamic processes was through the use of digital animation. Other studies showed that the use of animations and visualisations improved students' conceptual understanding (Barak and Dori, 2005), learning achievements (Dori *et al.*, 2003), spatial abilities (Kaberman and Dori, 2009;

Barnea and Dori, 2000), and motivation to learn science (Rosen, 2009). These findings illustrated how animations aided students in constructing mental pictures among students similar to the mental model of scientists. Barak, Ashkar and Dori's (2011) study also found that animation motivated students to learn science. Barak and his colleagues (2011), who investigated the effect of animated movies on students' learning and motivation in classroom practice, found that animation improved students' self-efficacy, interest, enjoyment, and connection to daily life better than traditional textbooks with still pictures. The studies just described concluded that animations are beneficial when they are directly connected to the curriculum or when they encourage active learning and collaboration among students while learning with animations (Barak *et al.*, 2011).

Although the use of quantitative analysis conducted in these studies was very effective for showing whether students' conceptual understanding of science has or has not improved after animation movies, it did not explain how and why this has happened. There is a gap in addressing how and why animations are beneficial in developing students' understanding of certain scientific concepts. To achieve that, a more qualitative research approach is required. Moreover, the studies described here investigated the use of short animated movies in educational websites that provide curriculum-based content and entertainingly explain hundreds of scientific concepts. A serious limitation of such websites is that they aim to engage students' interest in learning science in a fun and entertaining manner by satisfying new generation students' digital needs. There is no doubt that making science fun and enjoyable for students to learn is of utmost importance. Nevertheless, the material offered in educational websites often represents and presents the proposed curriculum teaching sequence in a digitalised form, which does not cater to the different needs of students' conceptual understanding of science. Seeking to address this gap, the animated activities proposed in this research afford students to sequence them in a meaningful manner.

2.4.3 The cognitive theory of multimedia learning (CTML)

The cognitive theory of multimedia learning (CTML) (Mayer 2014; 2005) provides valuable information on why learning with digital tools can be beneficial, based on three cognitive science principles of learning. The first one is the *dual-channel principle*, according to which

learners can organise information into two different cognitive structures, namely the visual/pictorial and the auditory/verbal channel. When information is presented to the eyes, for instance, illustrations, videos, or animations, it is being processed in the visual channel; when information is presented to the ears, like narration or nonverbal sounds, its processing takes place in the auditory channel (Mayer, 2005). The suggestion is that if learning environments can stimulate the activation of both channels, the visual and auditory channels, they will prevent a cognitive overload (Mayer, 2014; 2005). That is possible, for example, by presenting sound images or spoken texts in combination with written texts or visual images. Such a combination can help learners connect visual and verbal information while building cause-and-effect relations among the pieces of verbal information and visual information (Mayer, 1997). To test learners' cognitive capacity requires memory span tests (Simon, 1980) and draws on practices from cognitive psychology, which is beyond the purpose and scope of the current research, which will not analyse them in detail. Still, it is necessary to acknowledge that learners can only absorb and retain information that does not overload their mental capacity (Sweller, 2007). The reason is that short-term or working memory can only keep a certain amount of information simultaneously. When learners receive new information, this is transferred from short-term memory (STM) to long-term memory (LTM). Information kept in STM lasts for half a minute or more, whereas in LTM, it resides until senescence or death (Novak, 1988). The transfer of information from short-term to long-term memory takes a few seconds per chunk (Simon, 1974). Short term or working memory, as a kind of 'information gate' (Miller, 1956), can store or process only about seven 'chunks' of information at one time, and this depends on the kind of information – for instance, digits, letters or graphics – and on the learners' cognitive capacity that develops with age (Flavell, 1963). In either case, content needs to be broken up into chunks of information that do not exceed learners' cognitive load capacity (Sweller, 2007). The way these chucks are then ordered helps learners better understand the material under study (Reighlucth, 2007). Considering this, the content presented in the digital activities of this research will be broken down into short chunks of information, each lasting a few seconds, to prevent possible cognitive overload.

The second principle underlying the CTML is the *limited capacity* and views each channel as having limited capacity for processing at once (Mayer 2014). Information enters the human system through one channel, and if learners devote adequate cognitive resources to the task,

it can be represented in the other channel (Mayer, 2005). For example, an illustration of an object or event, such as lighting a match, may initially be processed in the visual channel. Still, the learner can mentally construct the corresponding verbal description in the auditory channel.

Conversely, a narration describing how to light a match is originally presented to the ears. Still, the learner may shape a corresponding mental image that is processed in the visual channel. For this transition to happen from one channel to the other, it presupposes that learners have the existing knowledge and past experiences to help them visualise or verbalise relevant information or build a new one (Anderson, 1983). Therefore, learners' prior knowledge affects the way they process new or existing information. That is often the case with storytelling tasks that require learners to produce a fictional story based on information presented to only one channel. For example, using a written prompt (Merritt and Liles, 1989), one picture (Coelho, 2002), several pictures (Hickmann and Hendricks, 1999), a wordless storybook (Botting 2002), a video (Eaton *et al.,* 1999), or something similar delivers information to the visual channel. Alternatively, in a story-retelling task, information is first processed to the auditory channel as learners have to listen to a story and retell it at some later point (Botting 2002; Merritt and Liles 1989). Both storytelling and story-retelling are the dominant eliciting methods (Roch *et al*., 2016; Lever and Sénéchal 2011) to assess students' narrative competence. Prompting students with a title, a picture or not prompting them at all (Spinillo and Pinto 1994) is a very common storytelling technique that schoolteachers use. It is also a very popular research method to assess children's narrative competence and task comprehension by asking them to tell a story (Gazella and Stockman 2003) based on a single prompt. Various tasks can be used to analyse students' stories, with studies showing that students' performance depends on the method (Pinto *et al.,* 2018) and the medium used – whether they are asked to tell or to write a story (Pinto *et al.* 2015) or produce a story with digital tools. This research uses the technique of single prompts to the visual or the auditory channel to evaluate students' domain knowledge through digital storytelling in a specific school subject.

The third principle underpinning the CTML theory is *active processing* which assumes that active learning entails carrying out a coordinated set of cognitive processes (Mayer, 2014;

2005). In simple words, learners need to engage actively with learning content to comprehend new information. That is likely to happen using interactive learning environments, in which the learner can actively and directly influence their learning processes (Hillmayr *et al.*, 2020). In other words, "the defining feature of interactivity is responsiveness to the learner's action during learning" (Moreno and Mayer, 2007, p. 310).

Such interactivity can occur in different ways. According to Hillmayr and his colleagues (2020), one way is when the learner receives additional information on-demand or feedback while entering solutions. Another way to occur is when the learner determines their learning pace or the preferred order of presentation. This research concerns itself with the latter by enabling participants to determine the preferred order of their story. The order of content presenation can "strongly influence what is learned … and sometimes even whether the material is learned at all" (Ritter and Nerb, 2007, p. 3). Langley (1995) defines order effects as differences in performance that arise from the same material being presented to learners in different orders.

Finally, the learner can interact with the learning environment by manipulating the presented information (Hillmayr *et al.*, 2020). That allows learners to "control aspects of the presentation, such as setting parameters before a simulation runs, zooming in or out, or moving objects around the screen" (Moreno and Mayer, 2007, p. 311). Contrary to other instruction methods that do not use interactive features — wherein the learner passively receives information— an interactive learning environment enables learners to act as sense-makers constructing their knowledge (Hillmayr *et al.*, 2020). Taking into account that "deep learning depends on cognitive activity" (Moreno and Mayer, 2007, p. 312), interactive tools offer these specific characteristics that can support student learning.

2.5 Limitations and gaps of the reviewed literature

Recent research has investigated the impact of PBL instruction on students' science learning in primary and secondary learning (Song, 2018; Siew, Chin and Sombuling, 2017; Leuchter, Saalbach and Hardy, 2014; Chen and Chen, 2012; Potvin, Mercer and Riopel, 2012; Inel and Balim, 2010; Araz and Sungur, 2007). Despite their valuable contribution to the field of PBL in

science education, these studies have primarily used experimental or quasi-experimental methods to assess students' academic achievement, knowledge retention, conceptual development, and collaboration before and after the PBL instruction. That leaves a gap in an in-depth exploration of a) students' interaction while working collaboratively to implement a problem-based activity; b) students' construction of shared understanding through the collaborative interaction; c) students' externalisation of understanding (and identification of knowledge gaps) while implementing a problem-based activity. This research values the importance of social interaction as a discursive process. It acknowledges that scientific concepts can be understood in the arguments and scientific explanations underpinning students' answers and not the answers themselves (Driver, 1983). Also, engaging in problem-based collaborative activities is a meaning making process. It includes features of intrinsic motivation and interest in the content of the task, a focus on understanding the learning material, an attempt to relate parts to each other, new ideas to previous knowledge, and concepts to everyday experiences (Entwistle, 2018; Entwistle and McCune, 2004).

Although the above studies enrich evidence about the practical application of PBL in science education, none of them examines the use of problem-based learning in combination with storytelling (see previous section 2.2.3). That is where the current research aims to make its contribution. As with problem-based tasks, solving story problems is based on implementing specific strategies, such as analysing and evaluating the evidence provided, determining the accuracy of the given information, and then delivering a solution to the problem (Mahnaz, Hung and Dabbagh, 2019). These strategies differ according to the type of the problem. Solving a problem-based story requires learners first to conceptualise the problem, organise and sequence all the relevant information and then apply a solution plan based on that conceptualisation. Meaning that when the story parts are sequenced, it helps learners to mentally organise the given information, make sense of its plot (Bruner, 1990) and understand its content and context. Existing research on strategies that learners use to create sequent stories has mainly examined the development of narrative, vocabulary and/or literacy skills (Nicolopoulou, 2019; 2016; 2008; Nicolopoulou and Trapp, 2018). There is, thus, a need for more research investigating how learners use sequence strategies to solve relevant story problems in school subjects, such as science.

The official curriculum guidance for using stories in the classroom focuses on established story scripts that encourage students to recount or retell and rewrite an existing story (Kucirkova, 2018). While stories may be used in the teaching and learning of science, they are often only used as introductions, 'attention grabbing' activities that prompt students to become aware of particular scientific events or phenomena (Tan, Lee and Hung, 2014). Existing research on the use of science stories has shown that they are mainly used as an introductory hook to follow-up hands-on activities or subsequent lessons (Hu *et al*., 2021; Morais, 2015; Hadzigeorgiou *et al*., 2012; Kokkotas *et al*., 2010; Banister and Ryan, 2001). That leaves a gap in using science stories to help learners reflect on and externalise their understanding of a science topic and identify possible knowledge gaps. Science stories are also used to assess individual students' concept knowledge through drawings (Hu *et al.,* 2021; Morais, 2015) or questionnaires (Kerby *et al*., 2018; Hadjigeorgiou *et al*., 2012; Banister and Ryan, 2001), failing to examine students' shared understanding through collaborative interaction.

Lastly, the last two decades have shifted from storytelling to digital storytelling due to the rapid development of (relatively inexpensive) technological tools (Davis, 2004). Digital storytelling helps teachers to develop pedagogical strategies and knowledge (Choo, Abdullah and Nawi, 2020); students to engage in the story creation process (Schmoeltz, 2018; Smeda, Dakich and Sharda, 2014; Barrett, 2006; Robin and Pierson, 2005) and enhance their writing and communication skills (Campbell, 2018; O'Byrne, Stone and White, 2018). Regarding science education, the use of digital storytelling has been assessed in improving students' critical skills (Dewi, Magfiroh, Nurkhalisa and Dwijayanti, 2019), cognitive ability (Dewi, Savitri, Taufiq and Khusniati, 2018); scientific imagination (Cheng and Chuang, 2018), learning performance (Tan, Lee and Hung, 2014; Hung, Hwang and Huang, 2012), and production of digital stories (Tan, Lee and Hung, 2014; Sadik, 2008). None of those mentioned studies has investigated the use of digital storytelling in helping learners to build a shared understanding of a science topic and its relevant concepts while working and interacting collaboratively.

Considering the above, it appears that there is limited research on the use of problem-based digital storytelling activities in the teaching and learning of science that can help students think about and externalise their understanding of a science topic while reflecting on and

identifying possible gaps in their prior knowledge. Thus, this research will seek to address the following two questions:

RQ1: Whether, and, if so, how do the SEeDS and Narration activities support learners in each of the two contexts to access, reflect upon on, and apply prior science learning?

RQ3: Whether, and, if so, how do the SEeDS and Narration activities engage and challenge learners in the two contexts?

At the same time, no known research has considered the type of talk that occurs naturally (without instruction) between students when working to implement problem-based stories in science. The work of Mercer and his colleagues on student group talk in science learning (Mercer and Littleton, 2007; Mercer *et al*., 1999; Mercer, 1994) focused on the trained use of a specific type of talk. There is a gap in exploring the use of naturally occurring language when groups of students work together on a story problem. Given this gap, this research explores the second research question.

RQ2: Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?

2.6 Chapter Summary

This chapter critically examined and discussed how problem-based digital storytelling activities could engage students in meaning making in science. Meaning making is explored through students' social interaction while working together in a collaborative learning environment. The socio-constructivist perspective acknowledges the significance of problem-based stories in (science) learning as they create a space for critical thinking and reasoning while fostering cognitive conflict and reflection. The following chapter, Chapter 3, examines the troublesome nature of school science and highlights the need for creating problem-based story activities.

CHAPTER 3: SCHOOL SCIENCE AND TRICKY TOPICS

3.1 Introduction

The previous chapter, Chapter 2, took a critical look at the socio-constructivist perspective of learning, which acknowledges the importance of social interaction in developing learners' understanding. When learners engage in the social process of sharing and negotiating information, they also engage in meaning making about the world around them. Socio-constructivism embraces the notions of problem-based learning and storytelling, which can be used in school classrooms to help students understand the learning material. In this chapter, the focus shifts to teaching and learning school science and how story problem-based story activities can engage students in meaning-making.

3.2 Science as a school subject

Teaching science is "a process of guiding learners to construct understandings of the world that match scientific models as well as possible – given that they will always be relying on their existing knowledge and understanding to interpret the teacher's presentation" (Taber, 2017, p. 121). In this line, much school level learning is built on the expectations of the world formed in early childhood, which are essential foundations for all later learning (Vygotsky, 1986). Learners rely on an existing set of models to make sense of the happenings around them. Teaching new knowledge can help to develop and readjust those models in the light of new experience; however, "once established, existing patterns of thought tend to dominate" (Taber, 2017, p. 120).

The process of teaching science at school is highly interactive as teachers seek to facilitate students' sense-making to shift current knowledge and understanding towards the proposed curriculum scientific knowledge (Taber, 2013). When planning and designing lessons, teachers need to consider what students already know, what their alternative ideas may be and how well they understand key concepts and present them so that it makes sense to students and will be interpreted as intended (Taber, 2017; 2013). The question is whether teachers are well prepared and equipped to identify students' knowledge needs before

teaching any science topic or if they have the time to do so, given the constant pressures and competitiveness of the school systems.

It is generally accepted that in many countries worldwide, primary schools use a generalist model for instruction, according to which a single teacher teaches all core academic subjects (US) (Reys and Fennell, 2003). A key argument made in favour of this model of instruction is that it provides better stability, and it forms closer connections when young children have only one teacher (Chan, Terry, and Bessette, 2009; Hood, 2009). By contrast, in Greece, primary school subjects are taught by one teacher and by a specialist teacher if it concerns a subject of specialisation, such as music, arts, physical education, ICT, English (Eurydice, 2019). The classroom teacher usually teaches science unless an experienced science teacher is appointed at the particular school (Π.Ι, 2011). In secondary schools, specialised teachers deliver their subject of specialisation – for instance, chemists teach chemistry, and physicists teach physics (Eurydice, 2019).

The vast majority (89%) of primary schools have classroom teachers delivering most science lessons in the UK. Regarding secondary education, science teachers in most schools in England and Wales are required to teach outside their specialism. That means that even though they usually train as scientists in one area of science (chemistry, physics or biology), there is a requirement for training that will help them gain expertise across all aspects of school science (Kind and Taber, 2005). That creates "a professional dilemma – on the one hand, science teachers are regarded and respected for their specialist skills, but, on the other hand, they are also expected to teach as experts throughout the whole science area" (Kind and Taber, 2005, p. 16).

Teachers' lack of knowledge, experience, and/or training in the domain of science may often result in a lack of confidence or a sense of being ill-prepared to teach science content (Osborne and Dillon, 2010; Weiss *et al.*, 2001). There is a need for teachers to have a deep understanding of the subject they teach to identify students' alternative ideas and support students in developing evidence-based explanations (Zangori, Forbes and Biggers, 2013; McNeill, 2009). Many countries, like England, provide teachers with the opportunity to attend subject knowledge enhancement courses or teacher training events to improve their

understanding of specific subjects (CFE, 2017). Similarly, in Greece, a variety of in-service training are offered for teachers across the country (ΥΠ.ΕΘ, 2018).

In addition to the non-specialist teacher tradition in most primary schools, one must also consider the regularity of science teaching weekly. Across UK schools, many year groups (Years 1-6) are taught science weekly. Standalone lessons are more prevalent for older year groups, with younger students more likely to receive cross-curricular work (CFE, 2017). On the other hand, Greek schools offer weekly standalone science lessons in Grades 5 and 6, while earlier Grades 1-4 receive *Environmental study* lessons. Regarding the weekly hours of delivery, science, in England, is taught for 1.4 hours a week for upper-year groups, with lower year groups receiving even fewer hours of weekly lessons (CFE, 2017). In Greece, *Environmental study* is taught for 4 hours a week in Grades 1 and 2, and 3 hours in Grades 3 and 4. Science is taught in upper Grades 5 and 6 for 3 hours a week (ΥΠ.ΕΘ, 2018). It is often the case that the actual hours spent on teaching science are even less than planned as teachers face pressures to focus on other subjects, such as mathematics and literacy, that are emphasised in educational accountability measures and teacher evaluation systems (Banilower *et al*., 2013; Century, Rudnick and Freeman, 2008).

Based on the factors just described – the non-specialism in science and the lack of the necessary preparation time and materials – it seems difficult for teachers to attend to students' alternative ideas about phenomena before the instruction that will enable them to elicit and respond to students' ideas during instruction (Oliveira, 2010). Aiming to address this gap, this research will use a novel tool (Tricky Topic Tool described in section 3.5) to help teachers (with much or less experience or knowledge in teaching science) identify students' alternative ideas and support them in the process of meaning making.

Science as a school subject has always been a challenge for teachers and students. It is a challenging task for students to understand science (content, inquiry and process skills). It involves a non-linear construction process, which is complex and iterative, taking time and effort (Hadzigeorgiou and Schulz, 2019). According to TIMSS 2015, students' performance and cognitive domains (knowing, applying, and reasoning) in the subject of science seemed to have increased from 2011 to 2015, with Asian countries – like Singapore and Korea – having

the highest scores as opposed to European countries like Finland or England (Martin *et al.,* 2016; Mullis *et al.*, 2016). The TIMSS 2015 report highlights that European countries, including England, were not as successful as Asian countries in improving students' (4th and 8th grades) science performance and cognitive domains in the four years. Meaning that teaching science is a challenging task for teachers as well.

Teachers have to provide students with opportunities to develop a scientific understanding and engage with the science content and its techniques, such as concepts, equations, laws, and laboratory skills (Hadzigeorgiou and Schulz, 2019). Hadzigeorgiou and Schulz (2019) stress that engagement does not necessarily involve, or result in, understanding, especially in the case of learning science; engaging students in science is a prerequisite for understanding. Teachers need to support learners in linking new material with prior learning to facilitate new meaningful learning and reinforce the previous one (Taber, 2008). Prior knowledge is a crucial determinant of students' learning from their science classes (Taber, 2015). Receiving new information will often stimulate reorganisation of the base as the student reflects on the incoming knowledge and sees how it puts the older knowledge in a different light (White and Gunstone, 1992). In meaningful learning, the process of acquiring information signifies a modification of both the newly acquired knowledge and of the specifically pertinent aspect of cognitive structure to which the new information is associated (Ausubel, 2000).

Generally, science appears to be a difficult subject to teach and learn because it involves a body of knowledge and a way of reasoning or thinking that differs from everyday knowledge and thinking (Hadzigeorgiou and Schulz, 2019). TIMSS provides evidence that most countries' educational systems fail to provide sufficient and substantive training, materials, and other resources to classroom teachers to better equip and support them in teaching exciting yet complex subjects such as science.

3.3 Students' conceptions about science

Learning science involves an introduction to the concepts, conventions, laws, theories, principles, and ways of working in science and an appreciation of the application of this knowledge to social, technological, and environmental issues (Mortimer and Scott, 2003).

However, the way science is taught at schools often appears to be disconnected from everyday life. Students find it difficult to conceptualise and understand the connections of science (concepts) to the natural world (Osborne *et al.,* 2004). The way students experience natural events is expressed through an "everyday or common-sense way of talking and thinking" about scientific phenomena (Leach and Scott, 2000). That happens because individuals are immersed in an everyday social language from birth. This language provides the means for daily communication with others and shapes a way of talking and thinking about the surroundings by drawing attention to certain features and representing those features in specific ways (Mortimer and Scott, 2003). For instance, how individuals routinely talk about the Sun 'rising and setting' helps develop a strong view of the Sun moving through space instead of the Earth spinning on its axis (Mortimer and Scott, 2003). Such informal or spontaneous concepts (Vygotsky 1987) are part of an everyday social language. They include many of these views referred to as alternative ideas or even misconceptions in the science education literature.

However, such alternative conceptions may occur from the scientific view itself, rather than the other way around, proposed Leach and Scott (2000). That happens because students learn or receive scientific concepts and conceptions in a completed form from the domain of adult thinking (Vygotksy, 1987, p. 169). Scientific concepts can be described as "systematic mental representations of the natural world that have a central place and role in science" (Kampourakis, 2018, p 591). They may include observable entities (e.g., "mammal" or "mountain") or unobservable entities (e.g., "atom" or "gene"). They can also be related to processes (e.g., "photosynthesis" or "adaptation") (Kampourakis, 2018). Therefore, any discourse about science involves concepts whose meaning needs to be clear among those participating in the discourse. Therefore, a problem with scientific concepts is that they are essentially developed and exhausted within the frames of teaching them to students and students learning them.

Nonetheless, these conceptions are often described as stable and hard to change even after students are systematically instructed in these subjects whatsoever (Driver *et al.*, 1985). For these alternative frameworks to be rectified, they need to be identified early. Their identification lies in students' reasoning for their answers and not the answers themselves (Driver, 1983), which is often the case in the science classroom. Everyday talking about

scientific issues influences students' learning, which is deeply linked to students' prior knowledge but is usually resistant to change (Driver, 1989).

Research into students' conceptual learning has a long history, from Piaget through to the student conceptions literature, focusing on the cognitive and conceptual aspects (Hubber *et al.*, 2010). Literature on student conceptions documents difficulties with students' learning of major scientific ideas across most topics, addressing the problem in terms of alternative ideas or frameworks (Duit 2002; Driver and Easley 1978), and the learning task in terms of conceptual change (Vosniadou 2008; Treagust and Duit 2008; Hubber and Tytler 2004). Considerable research into teaching strategies to support this "conceptual change approach has reported some success, but increasing criticism of this approach is also evident in a comprehensive amount of research demonstrating difficulties in changing students' naive ideas to more scientific conceptions" (Hubber *et al.*, 2010, p. 6). The processes that manage to successfully move students' thinking from a naïve to a scientific view appear to remain elusive; conceptualising, thus, how to support students' transition between naïve and scientific views remains a significant challenge (Hubber *et al.*, 2010). That is particularly evident in numerous studies investigating major conceptual areas such as changes to matter, force and motion, earth in space, and animal behaviour and adaptation (Duit 2002), which shall be discussed extensively in the upcoming sections of this chapter. This research considers the challenge of conceptually changing students' naïve ideas into scientific conceptions and proposes the following: teachers need first to diagnose the problem of misconceptions or alternative ideas to prepare proper interventions to tackle it. To do so, teachers need to acknowledge that the source of the problem is not merely a series of mislearned facts (Driver, 1983). They also need to accept that these problematic areas are resistant to change and cannot be easily corrected. This research aims to bridge this gap, help teachers and students to identify their knowledge gaps, and then tackle them through cooperative interaction. The choice of collaborative learning environments is built on the opportunities they provide students for active co-construction of meaning and understanding (Adams, 2006a).

3.4 Troublesome knowledge in science learning

The process of learning about science requires students to restructure their intuitive knowledge so that it conforms to the currently accepted scientific ideas (Vosniadou, 1991). Although this process of conceptual restructuring can be a long and difficult one, often engendering misconceptions (Osborne and Wittrock, 1983), it raises important questions about curricula and methods of instruction. What is the best sequence of concepts for students to develop knowledge in a domain? What are the best instructional methods in case a scientific concept fundamentally differs from the intuitive knowledge that already exists in the knowledge base?

To address these questions, teachers essentially turn to national curricula for guidance. The term curriculum materials refers to the resources designed for classroom teachers to guide their instruction (Stein *et al.,* 2007). They serve as a key conceptual tool for teaching approaches and decision making (Davis *et al.,* 2016). Science teachers have curriculum materials as a point of reference, based on which they "design experiences for classroom use" by crafting "a repertoire of teaching practices" (Davis *et al.*, 2016, p. 127). Curriculum materials are designed to support not just student learning but also teacher learning (Davis and Krajcik, 2005). For instance, in many countries, science textbooks include marginal notes for teachers about misconceptions students may hold regarding a particular idea or background about the lesson's content (Beyer *et al.,* 2009). Marginal notes may be more integrated (Davis *et al.,* 2014). In this light, teaching practices in science are guided by the nature of conceptual understanding, common misconceptions, and how to achieve conceptual change (Limon and Mason, 2002).

Teachers need to understand the conceptual barriers that learners may encounter towards the deep understanding of a concept (Adams and Clough, 2015). Evidence from various disciplines indicates that certain concepts often prove problematic or troublesome for learners (Meyer and Land, 2006; 2005; 2003; Perkins, 1999) and may cause them to fail or give up a subject altogether (Adams and Clough, 2015).

Troublesome concepts are found in all disciplines, but they are perhaps more frequently met in mathematics and science (Perkins, 1999). Understanding invert and multiply to divide fractions is a good example of troublesome knowledge in maths; or that heavier objects do fall faster (neglecting any air resistance), encountered in physics. There are many reasons causing conceptually difficult knowledge, encountered as troublesome, but the most persistent ones are: intuitive beliefs and interpretations that emerge from misimpressions from everyday experience (Osborne and Dillon, 2008; Perkins, 1999), reasonable but mistaken expectations (Perkins, 1999); the subject's difficult language (Evagorou and Osborne, 2010; Osborne and Collins, 2000), and the complexity of experts' views of the matter (Osborne and Dillon, 2008; Land and Meyer, 2006; Osborne *et al*., 2004; Perkins, 1999). Troublesome knowledge presents a barrier to students' understanding of new core concepts or Threshold Concepts (Meyer and Land 2006; 2003). Threshold concepts are seen "as conceptual gateways or portals that lead to a previously inaccessible, and initially perhaps troublesome, way of thinking about something" (Meyer and Land, 2006, p. 3). A threshold concept must be understood, but that does not necessarily lead to a qualitatively different view of the subject under study (Meyer and Land, 2003).

Troublesome knowledge takes different forms, and Perkins (1999, pp. 8-10) considers five of them:

- *Ritual knowledge:* has "a routine and a rather meaningless character", following a routine to get a particular result, such as invert and multiple to divide fractions.
- *Inert knowledge:* "sits in the mind's attic, unpacked only when specifically called for", for example, passive vocabulary – known words that are mainly unused.
- *Conceptually difficult knowledge:* a combination of misunderstandings and ritual knowledge that contrast intuitive beliefs and everyday interpretations in out-of-classroom contexts, such as understanding objects in motion.
- *Foreign or alien knowledge:* comes from a contradictory perspective to one's own. The learner often "does not even recognise the knowledge as foreign", for instance, Newton's second law states that force equals mass times acceleration.
- *Tacit knowledge:* refers to mainly personal and implicit (Polanyi, 1958), upon which one acts but is only superficially aware or utterly unconscious of it (Perkins, 2008), such as *equal temperament* in music (Manning, 2002).

Troublesome knowledge does not limit itself to only these categories. A concept can be troublesome not only because it "operates at a deep integrating way in a subject, but also because it is taken for granted by practitioners in a subject and therefore rarely made explicit" (Davies in Meyer and Land, 2006, p. 74). Troublesome knowledge proves difficult both to teach and learn, but once understood, it has an important transformative effect on students' understanding.

3.5 Tricky Topics in science

In the light of troublesome knowledge and concepts, academics and researchers from the OU and other European Universities shifted the focus from TCs in Economics to the STEM disciplines, including several troublesome concepts that students struggle to understand.

The JuxtaLearn Project at the OU (2012-2015)

The JuxtaLearn Project (JxL) goal was to enable students to overcome barriers to science and technology understanding through creative video performance, collaborative learning, and reflection. Researchers sought to engage student curiosity in difficult-to-learn science and technology subjects to this aim. JuxtaLearn's purpose was to support students along a creative process that would lead to a deep and thorough understanding of topics identified as particularly problematic – as in the case of this research. The JuxtaLearn Project reflected the incremental and flexible approach that teachers should take when teaching complex concepts.

The JxL Project, conducted at the OU in cooperation with six other European Universities, was designed to help students (from secondary to higher education) to overcome the troublesome knowledge that presented a barrier to their understanding of Threshold Concepts in science and technology (Clough *et al*., 2013). The goal was to encourage students to express their understanding through collaborative learning and creative performance (video story-making co-created with researchers). Using metaphor, analogy, students compared their digital stories with teachers' models (representation of a concept) and

identified their areas of misunderstanding (Clough and Adams, 2014). That creative comparison enabled them to re-construct a working model that corresponded more closely to the expert concepts being taught (Clough and Adams, 2014). Despite the creative nature of story-making, the JxL project had some serious limitations regarding students' ownership of the creative process. First, the researchers' participation in the video story-making did not allow students to own the story-making process, as they were under continuous guidance and instruction. Second, the analogy of comparing with experts' scientific models did not allow students to express their ideas and reason about them freely. That promoted the recalling and reproducing of scientific knowledge found in the science textbooks. Another issue that the JxL failed to address was the practical engagement of students in the classroom situation, which involved school schedules, busy teaching timetables and science teachers' expertise in coordinating such creative activities. A final limitation of the JxL work was that it was very time-consuming and resource-intensive. The long hours (all-day workshops) required to implement the story-making activities, along with the frequent lab/library re-arrangements to accommodate those workshops, were off-putting factors for both students and teachers to further engage in or commit to them. This research considers that some schools may not have the equipment nor the time in their timetable to engage in these activities. Therefore, more research is needed to evaluate the application of such story-making/telling activities in practice within regular school schedules and timeframes, using fewer intensive resources.

This research builds on the idea to help students externalise their understanding of problematic topics through story creation. However, it takes a different stance from JxL as it seeks to create storytelling activities that are simple enough in structure. Thus, students will be able to implement them during regular school hours, in their classroom, without spending much time or energy in re-arranging the setting. Moreover, this research will not compare teachers' models to challenge and promote students' understanding of complex topics. Instead, it will employ JxL's idea on collaborative learning and creative story-making but with a twist. It will allow students to make their own story by editing a set of prepared story clips and determining its story plot. This structured activity differs from the flexible one presented in JxL, as it allows students to work independently rather than being guided and directed by researchers. It also enables them to concentrate on overcoming troublesome knowledge

while inventing a suitable plot instead of creating everything from scratch (make characters out of plasticine, invent the plot, video-record the story, edit and share the finished story). The JuxtaLearn Taxonomy reflects the problems that children frequently encounter with a typical Threshold Concept, and these fell into one of four main categories (Clough *et al.,* 2013):

1. *Incomplete pre-knowledge:* children either lack an understanding of or have an incomplete or flawed understanding of underpinning topics, scientific methods, processes, or discourse.

2. *Essential Concepts*: information that children need to learn alongside the TC. They are smaller, distinctive 'sub-concepts' that a student shall understand to grasp the overall TC.

3. *Terminology*: everyday terms take a different meaning when used as part of scientific discourse, combined with new introduced scientific terms.

4. *Intuitive Beliefs*: informal, intuitive ways of thinking about the world, which are strongly biased toward causal explanations and counter-intuitive to scientific explanations.

The JuxtaLearn Taxonomy provides a framework that enables teachers to break down a Threshold Concept into a set of categories, named as Stumbling Blocks (SBs) in the JuxtaLearn Project (Clough and Adams, 2013). The Stumbling Blocks are based on examples of student misunderstandings that teachers encountered during their teaching practice. By locating student problems within the Taxonomy, teachers are then able to review their existing practice and try new methods to create interventions to tackle those problematic areas. The JxL team also decided to use the term Tricky Topics (TCs) to refer to teacher-identified problematic concepts. These are supplemented with Threshold Concepts drawn from the literature (Clough and Adams, 2015). The new term, Tricky Topics, is used in this thesis and concerns science learning and teaching while using the JxL taxonomy to identify troublesome topics.

Considering that the notion of Tricky Topics is quite novel, there is still limited research investigating its practical application with young students in primary or early secondary school. In this line, there is restricted evidence regarding the use of digital storytelling to help

students overcome tricky topics and understand better troublesome concepts. This research seeks to address the above gaps and enrich the literature on tricky primary and early secondary education topics. The next section presents the Tricky Topic Guide that progressed from the JuxtaLearn project, as it guides how to identify, capture, and assess tricky topics in all levels of education.

3.6 The Tricky Topic Guide

Following on from this work, the OU, in collaboration with the Oxford University, the Teaching Tricky Topics (TTTs) guide was developed to help teachers overcome SBs by developing targeted interventions.

The TTTs guide consists of three stages that allow teachers to *identify, capture* and *assess* difficult knowledge that causes barriers to their learners' understanding (https://www.open.edu/openlearn/ocw/mod/oucontent/view.php?id=72094), as *Figure 2* shows:
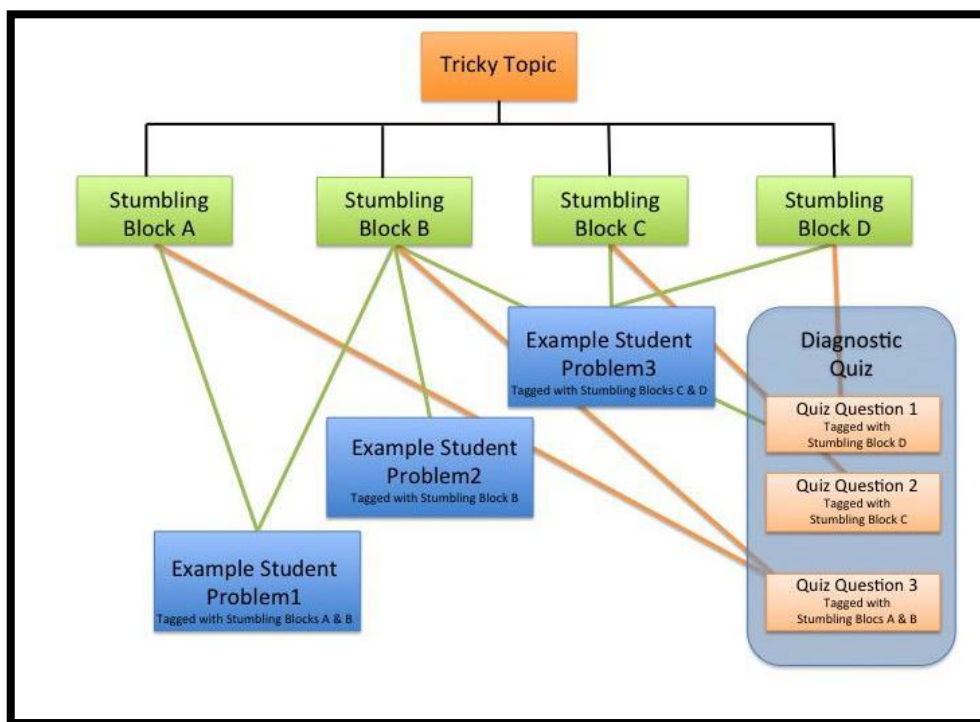
Figure 2: The Tricky Topic Guide (from Adams and Clough, 2015)

In the first stage, teachers *identify* the topics students find tricky and break these topics down into assessable parts (or stumbling blocks). Then, in the next stage, they *capture* results from stage 1 into the Tricky Topic tool, which helps them to understand why students find these topics tricky. Finally, in the last stage, they can use the online tool for guidance to develop questions that thoroughly assess student understanding. Teachers can design interventions to enhance students' deeper learning and use the questions to evaluate the research at this final stage. Visualisation of the results provides detail of students' depth of learning of individual stumbling blocks. Some examples of Tricky Topics identified during the JxL project are *the division of fractions* in maths; *matter* in chemistry; *optics and ray diagrams* in physics; *photosynthesis* in biology; *magnetism* in physics; *microbes and diseases* in biology; *electricity* in physics; *moles* in chemistry. The TTTs guide furnishes the design of this research, as described in the next chapter.

3.7 Identification of *matter* as a tricky topic

Research with teachers during the JxL project highlighted that the same student problems with *matter* repeatedly recurred from one year group to the next. These findings were augmented from the literature on Threshold Concepts (Meyer and Land, 2006; 2003) and students' conceptual problems across different age groups over time (Hadenfeldt, Liu and Neumann, 2014; Stefani and Tsaparlis, 2009; Talanquer, 2009; Mortimer and Scott, 2003; Harrison and Treagust, 2002; Johnson, 1998; Driver *et al.*, 1985) (for a critical examination of matter see next *section 3.7.1).* After the systematic identification of this topic area in terms of theoretical underpinning, followed its identification in practice through the science teachers and the curriculum material (for a cross-age and -context coverage of the topic, see later in this section). Through the Tricky Topic Process (TTP) (see *section 4.2.1* for a detailed description of the three stages of the Tricky Topic Process), a schoolteacher helped to identify matter as a problematic topic across students in the upper two grades of primary school. With the help of the JuxtaLearn Taxonomy, the teacher specified the Stumbling Blocks for this Threshold Concept and broke each Stumbling Block down into its specific problem areas (e.g. underpinning concepts or re-use of everyday terminology leading to confusion). In other words, identifying matter as a tricky topic drew on empirical and theoretical evidence from

the notion of TTs and TCs. Finally, to make this identification more rigorous, this research enquired into the availability of supporting resources that would improve students' understanding of matter. To the best of the author's knowledge, there was a scarcity of resources available online or otherwise supported by technology that could address the troublesome nature of matter. This research considered everything and sought to practically address the tricky topic of matter and inform teaching practices.

Understanding the structure and properties of matter is a key element of everyday worldview (Harrison and Treagust, 2002). Developing students' understanding of matter is fundamental to constructing scientific ideas. Yet, existing research has repeatedly and consistently shown that students fail to gain a deep understanding of the particulate nature of matter (Stefani and Tsaparlis, 2009; Talanquer, 2009). Students' difficulties in understanding matter occur from students' intuitive views of the structure of matter (Talanquer, 2009) and the fact that they cannot directly observe certain phenomena (Vosniadou and Brewer, 1992). Nevertheless, researchers also relate students' poor understandings of the particulate nature of matter with ineffective instruction (Johnson, 1998), its misrepresentation in the science textbooks (Adbo and Taber 2009), and teachers' lack of understanding (Gabel, 1993). It appears that the topic of matter continues to be problematic, which makes it a tricky topic, according to findings from the JuxtaLearn Project. The difficulties in learning matter are not limited to a particular point in schooling but develop across grades (Johnson, 1998). This research will focus on this topic, which contains troublesome knowledge, seeking to address it in practice. It will review its application in two pre-high school contexts (UK and Greece) to show an international perspective on the teaching of matter.

3.7.1 The educational backgrounds in Greece and England

It is important to initially describe the educational background (school years and phases of compulsory education) in Greece and England for contextual purposes. Unlike Greece, England and Wales differ from Scotland and Northern Ireland in their secondary schools regarding the type of school and age of transition between phases (Kind and Taber, 2005). For this research, though, reference is only made to England.

Country	Age of students		
	(Compulsory)		(Non-compulsory)
	Primary school	Gymnasium	Lyceum
Greece	Grade 1: 6 – 7 years old Grade 2: 7 – 8 Grade 3: 8 – 9 Grade 4: 9 – 10 Grade 5: 10 – 11 Grade 6: 11 – 12	13 – 15 years old	15 – 18 years old
	Primary school	Secondary school	Secondary school/ Sixth form
England	Key Stage 1: 5 – 7 Key Stage 2: 7 - 11	Key Stage 3: 11 – 14 Key Stage 4: 14 – 16	16 – 18

Table 3: Structure of the national education systems in Greece and in England

Table 4 summarises the compulsory and non-compulsory education structure in both Greece and England. There are minor differences regarding compulsory education between the two countries.

In Greece, the term *primary* refers to education between ages 6 and 12, *secondary* to education between 13 and 18 and *higher* for post-18-year-olds. The school year in Greece runs from early September to mid-June. Children begin compulsory education at the age of five in pre-primary schools, and at the age of six, they enrol in the first grade (Eurydice, 2019). Attendance at primary school is for six years and includes first, second, third, fourth, fifth and sixth grades (corresponding to the Greek letters *Α΄, Β΄, Γ΄, Δ΄, Ε΄* and *ΣΤ΄).* The Ministry of Education and Religious Affairs is responsible for supervising the organisation and operation of primary education (including state/public and special education schools funded from public money – and private schools funded from private sources and tuition fees).

Secondary education starts at the age of 12 up to the age of 18 and is divided into two cycles: compulsory secondary education and non-compulsory secondary education (Eurydice, 2019). Compulsory secondary education is provided for students aged 12 to 15 and is offered through a three-year cycle, called Gymnasium. The non-compulsory secondary education is

divided into a three-year cycle, provided through the General Lyceums (GEL) or High Schools, and the Vocational High Schools (EPAL).

In England, the term *primary* applies to education between ages 5 and 11, *secondary* to education between 11 and 18 and *tertiary* to education for post-18-year-olds (Eurydice, 2019). The school year in England generally runs from the beginning of September to mid- or late July (Kind and Taber, 2005). Children begin compulsory education at five (Kind and Taber, 2005). Most children attend a publicly funded primary school, which can be a maintained school funded via the local authority (LA or an academy with a direct funding agreement with the government (Eurydice, 2019). Most students transfer from primary to secondary schools at age 11, where full-time education is compulsory until 16. In some cases, though, children attend a middle school from the age of 8/9 and transfer to secondary at 12, 13 or 14 (Kind and Taber, 2005). Secondary schools cater to pupils from age 11 to either 16 or 18/19 (Eurydice report, 2019).

The following section discusses the national curricula set out for the primary and secondary levels of compulsory education regarding the teaching/learning of science.The National Curriculum or National Curricula[1] state the content that must be taught to children in compulsory education, that is, aged 6 – 15 in Greece, or 5 to 16 in England.

3.7.2 The National Curriculum for science – Greece

The current primary education National Curricula in Greece is modelled based on **the Cross-Thematic/Interdisciplinary Curriculum Framework for Compulsory Education,** as redefined in 2011 **(ΥΠ.Ε.Θ, 2018**). The curricula applied in primary education are prepared by the Institute of Educational Policy (IEP), which also guides the programmes of study, textbooks, and other teaching aids (Π.Ι, 2011). There are different analytic programmes of study (APS) for each school subject, which are configured in six levels (each of which corresponds to one of the six grades of primary school or in fewer levels depending on the subject) (Eurydice, 2019). The APS refer to the content and distribution of teaching/learning material and records

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[1] In Greece, the term *curriculum* is used interchangeably with *analytic programmes of study* or *syllabus*. The term analytic programmes of study (APS) will be used for comparative purposes with the corresponding English ones.

the aims of each school subject; the educational goals; the thematic units and proposes indicative activities and interdisciplinary work plans (ΥΠ.Ε.Θ, 2018). The choice of teaching methods to achieve the goals is left to the discretion of teachers based on the social, cultural, learning characteristics of students and their interests and needs (Eurydice, 2019).

Fourteen subjects are taught in primary school, all of which are compulsory[2]. Physical sciences are taught in the fifth and sixth grades and Environmental study at the four lower grades. The rest of the subjects include the Arts, Physical Education, Music, Geography, Religious Education and more. Particular emphasis is given to integrating ICT in the educational process across all grades and promoting the laboratory teaching of science (in the upper grades) (Eurydice, 2019). To offer extra support to the lab teaching of physical sciences, laboratory centres of physical sciences (EKFE) operate (Eurydice, 2019).

Teachers are obliged to implement the APS and achieve the proposed educational goals, considering their students' educational needs. To help teachers implement the APS and guide them through the teaching process, there is provision for the following: teaching instructions based on the APS of each subject by the Institute of Educational Policy; teacher books for each subject; and collaboration with school coordinators (Eurydice, 2019). The Institute of Educational Policy is responsible for preparing the school textbooks (for both teachers and students). At the same time, the Ministry of Education and Religious Affairs caters for their selection and approval.

Finally, the analytic programmes of study guide the assessment of student's performance, which concerns not only the acquired knowledge but also the acquisition of skills and the development of attitudes, values and behaviours (ΥΠ.Ε.Θ, 2018). A summative assessment – in the form of written tests and essays – is carried out at the end of an instructional unit, based on the learning objectives for each subject (Eurydice, 2019). The promotion of students from one grade to the next is based on this type of summative assessment carried out

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[2] There are no official records dividing the 14 subjects into core and secondary subjects. Anecdotal evidence, however, shows there is a common practice among teachers and schools to consider mathematics, literacy, history and science as core subjects and the rest of them as secondary.

throughout the year. Students are not required to sit exams to get promoted to the next grade.

3.7.3 The National Curriculum for science - England

A National Curriculum (NC) was introduced under the Education Reform Act 1988, entitling students to a broad and balanced curriculum and setting standards for attainment. Re-enacted by the Education Act 2002, and last revised in 2014, the National Curriculum specifies compulsory subjects, programmes of study and entitlement areas for ages 5 to 16. However, it does not prescribe teaching hours (Eurydice, 2019). It sits alongside requirements for religious education, relationships, sex and health education, and careers education. The NC is compulsory for maintained schools, but academies generally adhere to the same key stage structure for organising the curriculum (DfES, 2014; 2013).

In England, the National Curriculum document divides compulsory education into four Key Stages; at the end of each, children take tests (Kind and Taber, 2005). According to the Education Act 2002, which determines key stages, Primary education consists of Key Stages 1, for students aged 5 to 7 (Years 1 to 2); and Key Stage 2, for students aged 7 to 11 (Years 3 to 6). Lower secondary education is also divided into two key stages – Key Stage 3, for students aged 11 to 14 (Years 7 to 9); and Key Stage 4, for students aged 14 to 16 (Years 10 to 11).

The NC outlines the core knowledge and attainment targets around which teachers can develop their lessons to promote the development of students' knowledge, understanding and skills as part of the wider school curriculum (DfE, 2014). All schools must publish their school curriculum by subject and academic year online. The NC includes twelve subjects classified in legal terms as core (English, mathematics and science) and other foundation subjects, including sex and relationship education for secondary education (DfE, 2014). All schools must also provide religious education at all key stages (Eurydice, 2019). The Secretary of State for Education is required to publish programmes of study for each national curriculum subject, setting out the matters, skills and processes that must be taught at each key stage

(DfE, 2014; 2013). Schools are free to choose how they organise their school day, as long as the content of the national curriculum programmes of study is taught to all pupils.

3.7.4 The science programmes of study in Greece

In recent years, there has been a systematic effort to restructure and rationalise the curriculum in primary school (Eurydice, 2019). The current view on the teaching of science places great emphasis on understanding the nature and methodology of science to prepare students to become informed citizens (Σκουμιός, 2015). By adopting a cross-thematic approach, the new curriculum proposes interdisciplinary topics that embrace the idea of problem-based and inquiry learning (Π.Ι, 2011). These topics seek to involve students in solving real problems that have a personal meaning for themselves (think globally, act locally); to emphasise collaboration, planning and argumentation; to take advantage of the use of ICT in science; and develop students' scientific literacy. The new curriculum seeks to engage students in developing evidence-based models, arguments, and explanations, which are vital in enhancing and demonstrating understanding of an accepted scientific viewpoint.

It is also the purpose of the new curriculum to make science more relevant to student interests, promoting a student-centred and cooperative-based teaching model of science that uses less the school textbook and more on the "minds-on" and "hands-on" approaches (Π.Ι, 2011). Therefore, it proposes the research-developing teaching model by Schmidkunz and Lindeman (1992) to aid the teaching-learning sequence.

The research-developing teaching model derives elements from the discovery learning theory (Bruner, 1961), a method of inquiry-based instruction. This popular theory encourages learners to solve problems by first inventing procedures (Roll *et al.* 2011); discovering critical features of the problem (Kamii and DeClark, 1985); formulating initial models of the situation (Gravemeijer, 1999); or analysing their peers' work (Kapur, 2010), and then receiving explicit instruction, whether from teachers or technology-enabled automated supports (Chase and Abrahamson, 2015). In the research-developing teaching model, there is a structure that helps teachers to design, plan, execute and evaluate the key elements of a course (Schmidkunz, 1992 in Π.Ι, 2011). This model encourages students to solve problems of scientific nature, systematise their research according to the methodological models of

physical sciences; question their daily observations; formulate hypotheses; test these hypotheses through experimentation; and reach valid conclusions (Π.Ι, 2011). Problem-solving and experimentation hold a valuable place in the research-developing model and add to the design of the teaching sequence. This model consists of four stages (Π.Ι, 2011, pp. 38-40) and applies in the teaching of physical sciences in both the fifth and sixth grades of primary school[3] (see *Appendix 2*).

The science textbook is a primary instrument used to implement the research-developing teaching model. It is extensively used in science teaching, as it is the main instrument for meeting the curriculum criteria and achieving the attainment goals (Lemoni, Stamou and Stamou, 2011). The textbook guides the teaching practice, proposes lesson planning, breaks down the learning objectives into attainment goals, analyses the teaching sequence steps, helping to reduce the preparation time. At the same time, it relies on current scientific, pedagogical methods (Holmeier and Schaffter, 2017).

Apart from the teacher's book, the Pedagogical Institute also proposes two student books: the textbook and the activity book. The student textbook provides theoretical information about the scientific phenomena, while the activity book includes worksheets (about the experiments) that help students to practice their scientific skills (Π.Ι, 2011). The activity book with its worksheets is the basic instrument that supports the experimentation process at school, and the student textbook is supplementary (Π.Ι, 2011). The activity book promotes and engages students in scientific practices through activities and experiments. Its structure is based on the research-developing teaching model (discussed earlier in this section), and it is presented through the experimentation worksheets. Both the activity book and textbook help students to become familiar with the scientific approach of phenomena (Μαραβέλης, Κουλαϊδης και Δημόπουλος, 2014).

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[3] The description of the proposed research-developing teaching model is included in Section 1.7: Teaching models (orig. Ενότητα 1.7: Διδακτικά Μοντέλα), pp. 33-41 and is the same in the Teacher Books for the fifth grade (http://ebooks.edu.gr/ebooks/v2/classcoursespdf.jsp?classcode=K05) and for the sixth grade (http://ebooks.edu.gr/ebooks/v2/classcoursespdf.jsp?classcode=K06) .

Thematic units/topics of teaching: matter

Considering the purposes of the new curriculum, the Greek science programme of study sets learning objectives that enhance students' content knowledge and develop their skills in scientific literacy (Π.Ι, 2011). It is designed around specific fields that meet the basic learning objectives of physical sciences: matter and transformations; motion and stability, forces and interactions; energy; waves and their applications in technology for information transfer (NRC, 2012). It also aims to offer a deeper interdisciplinary understanding of the fundamental crosscutting concepts, such as: (a) patterns, (b) cause and effect: mechanism and explanation, (c) scale, proportion and quantity, (d) systems and system models, (e) energy and matter: flow, cycles and conservation, (f) structure and function; and (g) stability and change (NRC, 2012).

In the Greek primary context, the science study programme is structured around nine thematic units, which have a functional continuity and coherence across all primary grades and continue to high school. The thematic sections are the following: *life around us; energy; electrical and magnetic phenomena; sound; machines and dynamic interactions; thermal phenomena; light; chemical phenomena.* The science programme of study for the fifth grade includes four broad units and their sub-units; the sixth grade contains five units with their sub-units (see *Appendix 1*).

Many chapters in the fifth and sixth grades science textbooks involve experiments. All sub-units refer to learning objectives – what students are expected to learn by the end of the instructional unit. Similarly, all chapters match specific attainment goals – what students should be able to or learn to do by the end of the chapter. In the fifth grade, matter is taught through *Chapter 1: Materials* and *Chapter 5: Heat.* In the sixth grade, matter is taught in *Chapter 2: Heat and Energy.* This research concerns itself with the teaching of matter in the fifth grade, and so the discussion following entails only the related information. Thus, the focus of this research is on the first two units and certain sub-units, including matter as it was identified through the Tricky Topic Process (discussed in the upcoming chapter 4, section 4.2.1). These units and sub-units correspond to specific chapters in the science textbook (for both teachers and students).

Thematic Units - Sub-units	Chapters in the textbook	Learning objectives	Worksheets (in activity book) - Attainment goals
UNIT 1: MATTER SUB-UNIT 1.2: Materials and technological objects around us – Raw materials	1: Materials (pp. 12-17) 1.1 Structure of matter 1.2 Properties of materials	Students are expected to: - gather information from different sources about the properties of technological objects. - evaluate the correctness of the above information based on existing knowledge, their own research, and discussions between them. - draw conclusions from the observations, classifications, and measurements they make and announce them to the class. - classify materials based on their physical properties. - use the correct terminology to describe basic everyday materials and their properties. - understand that the production of technological objects is based on the properties of certain materials, which derive from raw materials. - use and / or build models to describe the production of technological objects.	This sub-unit does not include any experimentation worksheets from the student activity book. Instead, it proposes educational websites about the structure of matter, such as - http://pals.sri.com/tasks/tasks5-8.html - http://pals.sri.com/standards/nses5-8.html - http://ekdidyma.web.uowm.gr/?q=physics/innovations/ms

		- become aware of the nature and role of these models.	
UNIT 2: HEAT IN OUR LIVES **SUB-UNIT 2.2: Temperature measurement**	5: Heat (pp. 40-54) 5.1 Heat and Temperature: two different concepts	Students are expected to use instruments and scales to measure temperature and to develop experimentation skills.	**WorkSheet1: The thermometer (pp. 70-73)** **Attainment Goals:** Students should be able to: - mention that measuring temperature with our senses is subjective - describe the production of both mercury and alcohol thermometers as well as their purpose and use - use the alcohol thermometer to measure the temperature of certain bodies - experimentally measure the temperature of water at melting point and boiling point - describe the scientific process of Celsius work in defining its scale - calibrate an uncalibrated thermometer
SUB-UNIT 2.3: The effect of thermal interaction - Thermal conductivity of material	5.1 Heat and Temperature: two different concepts	Students are expected to use the model "Higher temperature body - Lower temperature body", to interpret and predict the phenomenon of thermal interaction.	**WS2: Heat and Temperature: two different concepts (pp. 74-78)** **Attainment Goals:** Students should be able to: - mention different ways in which they can increase the temperature of a substance - observe experimentally that when a substance absorbs energy, its temperature increases

			they should observe experimentally that heat flows from a hot to a cold body
SUB-UNIT 2.4: Changing the condition of materials	5.2 Melting and Freezing	Students are expected to: - distinguish and control the variables that determine heat transfer, contraction, expansion as well as the change in the states of matter - and find the relationships between them	**WS3: Melting and Freezing (pp. 78-81)** **Attainment Goals:** Students should be able to: - observe experimentally that ice melts at certain temperature - observe experimentally that as ice melts, the temperature does not change - define as *melting* the change of state from a solid to a liquid - mention that for a body to change from a solid to a liquid it needs to absorb energy - observe experimentally that water solidifies at certain temperature - observe experimentally that as water solidifies, the temperature does not change - define as *freezing* the change of state from a liquid to a solid - observe experimentally that a body's temperature of freezing is equal to its temperature of melting

	5.3 Evaporation, boiling and condensation		**WS4: Evaporation and Condensation (pp. 82-83)** **Attainment Goals:** Students should be able to: - define as *evaporation* the change from the natural state of a liquid to a gas, that happens only from the liquid's surface - mention that during evaporation the liquid absorbs energy - define as *condensation or liquification* the change of the natural state of a gas into a liquid - mention that during condensation the gas releases energy **WS5: Boiling (pp. 84-86)** **Attainment Goals:** Students should be able to: - define as *boiling* the change from the natural state of a liquid to a gas, that happens to the whole body of a liquid - observe experimentally the temperature at boiling point is standard - observe experimentally that as water boils, the temperature does not change - mention that the temperature of boiling is distinct for each substance - discern the phenomenon of evaporation from that the phenomenon of boiling

	5.4 Contraction and expansion		WS6: Heating and cooling solids (pp. 87-91) **Attainment Goals:** Students should be able to: - observe experimentally that solids expand when they are heated - observe experimentally that solids contract when they cool down WS7: Heating and cooling liquids (p. 89) **Attainment Goals:** Students should be able to: - observe experimentally that liquids expand when they are heated - observe experimentally that liquids contract when they cool down WS8: Heating and cooling gases (p. 91) **Attainment Goals:** Students should be able to: - observe experimentally that gases expand when they are heated - observe experimentally that gases contract when they cool down

Table 4: The chapters in the science textbook with their related objectives and goals

It is evident from *Table 5* that the units and sub-units from the Science Programme of Study correspond to different chapters in the school textbooks; this is because of the cross-thematic and interdisciplinary notion that underpins the structure of the new curriculum (see the previous section). In this line, the teaching of matter involves *Chapter 1: Materials* which refers to the structure of matter (1.1) and properties of materials (1.2), and *Chapter 5: Heat* that includes heat and temperature: two different concepts (5.1), melting and freezing (5.2), evaporation and condensation (5.3) and contraction and expansion (5.4). As it appears, the proposing teaching strategy for the topic of matter follows a hierarchical sequence (see earlier section 2.4.4) and first presents the structure of matter and then continues with phase changes in temperature measurement. Given the freedom that teachers have to organise and present the instructional units according to their teaching approach, Chapters 1 and 5 can be presented in a row or follow the recommended-by-the-curriculum sequence. In the case of this research, the Greek teachers adopt the first strategy of teaching-related chapters one after the other.

Also, *Table 5* outlines the *sub-unit 1.2: Materials and technological objects around us – Raw materials. Chapter 1: Materials* does not include any worksheets, which means that students are not expected to carry out experiments to learn about the properties of technological objects. Instead, it is suggested to gather information from different sources, such as the educational websites mentioned. The rest of the sub-units, such as *1.3: Density of the materials around us, 1.4: Mixtures, solutions, air, water* and *1.5: Acids, bases, salts,* shown in *Table 6* involve experimentation and worksheets, accordingly, yet they do match the purpose of this research and will not be further discussed.

The science curriculum for the upper two grades of primary school does not recommend any scientific model to help students understand the particulate nature of matter. Scientific models are simplified depictions that contain a theory, concepts and/or the laws that define the object, phenomenon or procedure under study (Βραγοτέρης και Ψύλλος, 2017). They help students to understand and predict how an object works, how a process takes place or how a phenomenon evolves, and they are valuable research tools for hypothesis testing (Petridou 2008; Schwarz and White 2005). However, there is no formal provision for the use of scientific models in the teaching of matter at primary school, according to science

programmes of study for the fifth and sixth grade (ΥΠ.Ε.Θ, 2018; Π.Ι, 2011). Helping students understand the general nature of scientific models is an essential goal of the middle/secondary and high school science curriculum (Harrison and Treagust, 2000).

As for sub-units *2.2: Temperature measurement; 2.3: The effect of thermal interaction - Thermal conductivity of materials; 2.4: Changing the condition of materials* which correspond to *Chapter 5: Heat in our lives,* which involve worksheets and thus experiments, the teaching sequence followed is the one supported by the research-developing teaching model (see Appendix 2).

To conclude this section, the science content teachers have to teach is mandatory for the two upper grades (and all grades) of the Greek primary school. Still, teachers have the flexibility to organise the teaching sequence by introducing content earlier or later than set out in the programme of study. Similar conditions apply to the teaching of science in England, as presented next.

3.7.5. The science programmes of study in England – UK

In the UK, students usually start to experience formal science lessons at the age of five years, even though they have already formed a scientific vocabulary by the time they get to first discussing matter. Since the introduction of a National Curriculum for England and Wales, primary school students are now required to study Experimental and Investigative Science, which includes Life Processes and Living Things, Materials and their Properties, and Physical Processes (headings taken from the Key Stage 1 Programme of research). Therefore, primary science lessons include the effects of physical forces like pushing and pulling, how plants and humans grow, and how various objects sink, float or balance. These are concepts that students have previously experienced in some form in their daily lives (Pine *et al.,* 2016). The national curriculum for science aims to ensure that all students (DfES, 2014, 2013).

- Develop scientific knowledge and conceptual understanding through the specific disciplines of biology, chemistry, and physics

- Develop an understanding of the nature, processes, and methods of science through different types of scientific inquiry that help them to answer scientific questions about the world around them
- Are equipped with the scientific knowledge required to understand the uses and implications of science today and for the future

The science study programs are set out year by year for Key Stages 1 and 2. Year 6 students (aged 10-11) are in the final year of Key Stage 2, and Year 7 students (aged 11-12) are in the first year of Key Stage 3.

Thematic units/topics of teaching: matter

According to science programmes of study for Key stages 1 and 2 in England (DfES, 2013), students get introduced to the *states of matter* for the first time in Year 4 (8-9 years old), and they need to learn how to:

- compare and group materials together, according to whether they are solids, liquids or gases
- observe that some materials change state when they are heated or cooled, and measure or research the temperature at which this happens in degrees Celsius (°C)
- identify the part played by evaporation and condensation in the water cycle and associate the rate of evaporation with temperature

At upper Key Stage 2, students explore various scientific phenomena and systematically analyse functions, relationships, and interactions. In Year 5, students learn how to use practical scientific methods, processes, and skills, including planning scientific inquiries, taking measurements using a range of equipment, recording data and results, using results to make predictions, reporting and presenting their findings, and identifying scientific evidence to support or refute ideas or arguments (DfES, 2013). The content areas and main curriculum elements include *Living Things and Their Habitats; Animals, Including Humans; Properties and Changes of Materials; Earth and Space; and Forces*.

With regards to the teaching of *Properties and Changes of Materials*, students should be taught to (DfES, 2013, p. 28):

- compare and group everyday materials based on their properties, including their hardness, solubility, transparency, conductivity (electrical and thermal), and response to magnets

- know that some materials will dissolve in liquid to form a solution, and describe how to recover a substance from a solution

- use knowledge of solids, liquids and gases to decide how they can separate mixtures, including through filtering, sieving and evaporating

- give reasons, based on evidence from comparative and fair tests, for the particular uses of everyday materials, including metals, wood and plastic

- demonstrate that dissolving, mixing and changes of state are reversible changes

- explain that some changes are irreversible and result in the formation of new materials, including changes associated with burning and the action of acid on bicarbonate of soda

The NC also provides additional notes and guidance (non-statutory) for each content area. In the case of *Properties and Changes of Materials,* students must develop a more systematic understanding of materials by exploring and comparing the properties of a broad range of materials. They must also explore reversible changes, including evaporating, filtering, sieving, melting and dissolving, recognising that melting and dissolving are different processes. Students need to explore changes that are difficult to reverse, such as burning, rusting, and other reactions, such as vinegar with bicarbonate of soda. A scientific approach to this content area involves students carrying out tests to answer questions, such as, "*Which materials would be the most effective for making a warm jacket, for wrapping ice cream to stop it melting, or for making blackout curtains?*" They can observe and compare the changes, such as when burning different materials or baking bread or cakes. Finally, students may research and discuss how chemical changes impact their daily lives, for example, cooking, and discuss the creative use of new materials such as polymers, super-sticky and super-thin materials (DfES, 2014 pp. 28-29).

During Year 6, students must be taught to use practical scientific methods, processes, and skills by teaching the programme of study content. Nonetheless, matter is not taught in Year 6 as it is not included in the content areas and main curriculum elements: *Living Things and Their Habitats; Animals, Including Humans; Evolution and Inheritance; Light;* and *Electricity*.

Regarding Key Stage 3, there is a single science program of study. Its key focus is to develop a deeper understanding of a range of scientific ideas in the subject disciplines of biology, chemistry, and physics. Students must start seeing the connections between the subject areas and become aware of the big ideas underpinning scientific knowledge and understanding, such as the links between structure and function in living organisms; the particulate model as the key to understanding the properties and interactions of matter; and the resources and means of energy transfer as key determinants to all these interactions. They also need to relate scientific explanations to phenomena in the world around them and use modelling and abstract ideas to develop and evaluate explanations (DfES, 2014).

During Key Stage 3, students must understand that science is about working objectively and modifying explanations to account for new evidence and ideas. It is also about subjecting results to peer review, deciding on appropriate types of scientific inquiry, evaluating results, identifying further questions arising from their results and developing a deeper understanding of important factors in collecting, recording, and processing data (TIMSS 2015 Encyclopaedia). Ultimately, they must use scientific vocabulary, including nomenclature, units, and mathematical representations (DfES, 2014). Students need to engage in *'working scientifically'* by developing the skills and attitudes of the scientific community – for example, scientific attitudes, experimental skills and investigations, analysis and evaluation and measurement. Teachers can help students do so by freely choosing examples that serve various purposes, from showing how scientific ideas have developed historically to reflecting modern developments in science (DfES, 2014).

The science curriculum at Key Stage 3 includes biology, chemistry, and physics content areas. In biology, the subject content includes *the Structure and function of living organisms; Material cycles and energy; Interactions and interdependencies; Genetics and evolution.* In chemistry, the content areas are *The particulate nature of matter; Atoms, elements, compounds; Pure and impure substances; Chemical reactions; Energetics; The periodic table; Materials; Earth and the atmosphere.* Finally, physics involve *Energy; Motion and Forces; Waves; Electricity and electromagnetism; Matter*, and *Space Physics.* Considering that the focus of this research is on matter, only the relevant areas in chemistry and physics will be presented (DfES, 2014).

Chemistry	Physics
Students should be taught:	Students should be taught:
The particulate nature of matter - the properties of the different states of matter (solid, liquid and gas) in terms of the particle model, including gas pressure - changes of state in terms of the particle model.	**Matter** **Physical changes** - conservation of material and of mass, and reversibility, in melting, freezing, evaporation, sublimation, condensation, dissolving - similarities and differences, including density differences, between solids, liquids, and gases - Brownian motion in gases - diffusion in liquids and gases driven by differences in concentration - the difference between chemical and physical changes. **Particle model** - the differences in arrangements, in motion and in closeness of particles explaining changes of state, shape and density, the anomaly of ice-water transition - atoms and molecules as particles. **Energy in matter** - changes with temperature in motion and spacing of particles - internal energy stored in materials

Table 5: The content area of matter as taught in chemistry and physics in the Key Stage 3 science programme of study for England.

As *Table 6* shows, in Key Stage 3, students are taught matter through the disciplines of chemistry and physics, which seek to provide an advanced understanding of the specific content area. In chemistry, *the particulate nature of matter* introduces the three states of

matter, their properties and their changes. In physics, matter is divided into three different units: its *physical changes, the particle model,* and *energy.* As it appears, when students enter Key Stage 3, they are formally introduced to one of the most central models in modern science—the particulate model of matter. Thus, teaching about this model is an ideal opportunity to help students understand the nature of models in the context of learning a central scientific concept (Snir, Smith and Raz, 2003). At this point, it is vital to note that the NC allows for variations in teaching. Different schools can teach science in different times and ways, and there is no right or wrong timing. It is impossible, thus, for a prescribed teaching sequence to matter to in all schools across the country. Any attempt to research a particular science topic needs to go through the individual teaching approach that a specific teacher within a specific school holds for their science class. For example, the English secondary school that participated in the current study noted that the course content for science in Year 7 included the following modules: *Cells and Human Body, Particles, Space, Forces and Energy, Reproduction and Evolution, Materials, and Waves.* Nevertheless, it is beyond the scope of this research to deepen into KS3 science, and thus it will not discuss it further.

3.7.6 Summarising the differences in the teaching of matter in Greece and England

It is evident from the discussion so far that the Greek and English science programmes of study share more similarities than differences in the proposed content areas, teaching sequence and learning objectives. In other words, both programmes of study describe a similar teaching sequence of knowledge and concepts. The main difference between the two contexts is in their educational systems' structure, regarding the various times and methods of teaching science in different schools. This research acknowledges the above and decides to research the two contexts for two reasons. First, to make a comparable reference of findings beyond one country, avoid prejudgments. Second, to evaluate whether or not the use of novel digital storytelling activities can fit within the teaching approaches (storytelling was identified as a common practice among the English and Greek teachers) of the two contexts.

The national curricula for both countries seek to develop students' scientific literacy. To do so, they set out learning objectives and attainment targets that help teachers design, plan,

and execute their lessons to engage students in working scientifically and learning to use the correct scientific vocabulary. The process of planning to teach is similar in both countries, starting from the curriculum document and moves through stages (Kind and Taber, 2005) or grades, respectively. Effective planning requires teachers to consider the time available, the total amount of material to be taught and then develop an overall outline plan for the course (Kind and Taber, 2005). Both countries allow teachers to freely decide on the teaching sequence of science, meaning that they can teach each science topic at different times and in various ways across each country's schools.

Finally, teaching science – as in most subjects – aims to help students progress in specific content areas. Yet, it is also vitally important that students develop a secure understanding of each key block of knowledge and concepts to progress to the next stage or grade. Unstable or superficial understanding will not allow genuine progression. Students may struggle at key transition points (such as between primary and secondary school), build up serious misconceptions, and/or have significant difficulties understanding higher-order content (DfES 2014; Π.Ι, 2011).

The following section considers the teaching sequence for matter across the two countries' educational contexts. It examines students' understanding of matter over the years.

3.7.7 Students' conceptions about *matter*

There is extensive research concerning young children's understanding of matter (Liu and Lesniak, 2005), undertaken in the past decades. Their findings are pretty informative because they can aid the design of a more effective curriculum and teaching strategy (Novak, 1977). Andersson (1990), who carried out a systematic review of that research, found that students' conceptions about matter could be grouped into two main categories: (a) conceptions about the particulate nature of matter (including conceptions about atoms, molecules and particle systems) and (b) everyday conceptions about matter and its transformations (including conceptions about chemical reactions, physical states and their changes and conservation of matter). Based on his review, Andersson (1990) concluded that most of the studies sought to identify and describe students' (mis)conceptions about individual aspects of the matter

concept, yet that there was a lack of studies investigating how students' understanding of matter developed with respect to both categories.

A considerable amount of research, conducted with students from as young as five up to sixteen years old, revealed students' common alternative ideas on the following major aspects of the concept of matter: physical properties and change (Lee *et al.,* 1993; Osborne and Cosgrove, 1983), the particulate nature of solids, liquids and gases (Driver *et al*; 1985; Stavy and Stachel, 1985; Séré, 1985), heat and temperature (Hitt and Townsend, 2015; Baser, 2006; Harrison *et al.,* 1999; Vosniadou, 1994; Erickson, 1985), evaporation (Bar and Galili, 1994; Russell *et al*., 1989) and condensation (Johnson, 2000; 1998). This large body of research covered grade levels from elementary to university and diverse cultural backgrounds.

In the early 2000s, Liu and Lesniak's (2005) carried out a comprehensive review of research on students' understanding of matter and identified four categories: structure and composition; physical properties and change; chemical properties and change; and conservation of matter (p. 436). Their conclusion was that there was still little known about how students develop understanding of the four aspects of matter and how to foster students' progression in understanding matter as a core idea.

Research that followed up, within the last decade, moved significantly forward towards investigating students' understanding of matter, taking into account how students conceptualised matter, to what extent students were able to explain everyday phenomena or how students developed an understanding of matter over time (Hadenfeldt, Liu and Neumann, 2014). Recent research focused on learning progressions for the concept of matter, taking into account different aspects of matter to investigate students' progression in understanding (CPRE, 2011; Stevens *et al*., 2010; Smith *et al*., 2006;). The systematic overview that Hadenfeldt and his colleagues (2014) provided valuable evidence supporting students' understanding of matter as it advanced through the years. Their findings revealed that a 'skeleton' model could describe students' progression in the understanding matter, regarding four aspects (as identified by Liu and Lesniak's (2005). Nevertheless, Hadenfeldt, Liu and Neumann (2014) did not propose any instructional activities or assessments that could help students understand matter, which the research will seek to address. There is still a gap

in "the development of proper assessment tools that allow researchers and teachers a valid interpretation of a student's test scores before using this model as background" (Hadenfeldt, Liu and Neumann (2014, p. 197). The current research considers that limitation and research's shift from categorising students' conceptions to analysing students' progression in the understanding of matter. Thus, it proposes an activity that considers how students understand matter and externalise and reflect on it. The aim is to engage students in the social construction of meaning, which is associated with the development of understanding. Doing so will provide practical guidance to teachers about the use of specific instructional activities. It is not the purpose of this research to assess students' progression of understanding – with or without reference to the skeleton model of Hadenfeldt, Liu and Neumann (2014).

Students' conceptual progression on matter has been the centre of review by Krnel, Watson and Glazar (1998) on the development of the understanding of matter. Their findings suggested that students' understanding of matter originated from their primitive actions, such as holding, breaking, pouring, blowing and so on. The researchers argued that such primitive actions on particular substances led to categorisation in the form of a concept or a prototype. For example, there was the prototype/concept *water*, in which young students tended to categorise all clear liquids, could be poured and wet surfaces.

After the beginning of formal education, there continues to be a key obstacle to learning about matter and its different forms. That seems to be "the relationship between the theoretical sub-microscopic (atomic/subatomic) level and the familiar macroscopic world" (Adbo and Taber, 2009, p. 759), or as Liu and Lesniak (2005) described it, the existing forms and the properties of matter. Students seem to hold naïve or common-sense views about matter, its structure, and its changes, even after receiving formal instruction (Talanquer, 2009), which may vary even within the same grade level. A conclusion drawn is that the difference between matter and its forms are difficult concepts to grasp at all levels and ages, from children to adolescents (Adbo and Taber, 2009) and across different countries (Hatzinikita *et al.*, 2005). In this context, the following sub-sections critically examine students' (mis) conceptions about the particulate nature of matter and its changes, based on research conducted in the past twenty years.

3.7.7.1. Solids and liquids

Empirical evidence about the structure of matter and its behaviour reveals that the physical appearance of objects, substances, and materials influence children, when they examine them in isolation or before and after a change (Talanquer, 2009) and through their actions on the world (Krnel, Glažar and Watson, 2005; 2003). Conducting interviews with 84 children aged 3-13 in Slovenia, Krnel and his colleagues (2005; 2003) investigated the development of the concept of matter. Their findings revealed that younger children (under nine years old) tended to classify objects and matter using a mixture of extensive properties (mass and volume) and intensive properties (colour and density). In comparison, older children (above nine years old) used intensive properties most of the time. Intensive properties characterise matter and do not change with the size, shape, or quantity of objects; extensive properties characterise objects and are changed when objects are divided or crushed or if the number of objects is changed (Holum, 1994). For instance, children used different actions to describe hard rigid pieces of solid substance, granular or powdery solids or soft elastic solids, argued Krnel, Glažar and Watson (2005; 2003). Nine-year-old children, classified frequently by colour (all white substances together), less frequently by substance (water and glycerine = water, balloon, and a bubble = air), followed by grouping according to the state of the substance (liquids and granular matter together) or by action (pouring, running, blowing) or shape (balloon and a bubble). Eleven-year-old children grouped solids in various ways, sometimes depending on whether they were soft-paste solids or powdery solids. Thirteen-year-olds applied the substance criterion (e.g. balloon and bubble or wood and cotton), followed by the state of matter (liquids and solids), by action (balloon and bubble, liquids, solids) and by shape (balloon and bubble) (Krnel *et al.,* 2003).

Krnel, Glažar and Watson (2005; 2003) concluded that school-age children had difficulties recognising powders as the same substance as larger pieces, so they used different actions to identify the substances. That was because "the intensive property of hardness of the substances appeared to be affected when the substances were in powdered form" (Krnel *et al.*, 2003, p. 635). For instance, children could easily hold lumps in their hands while powders flow through their fingers. According to Krnel and his colleagues (2003), this confusion between the intensive properties of single grains and larger amounts of powder made it more

difficult for children to recognise that the different forms were made of the same substance. Another problem their participants had with powders was their tendency to treat them as objects and group powders together because they were held in similar containers (Krnel *et al.*, 2003).

Similar were the findings from Stavy and Stachel's (1985) study on understanding solid and liquid materials with two hundred Israeli students aged five to twelve years old. Their work reported that children had more difficulty classifying solids than liquids. Children of all ages classified correctly rigid solids; only half the participants classified correctly non-rigid solids, while the rest referred to non-rigid solids as a separate, intermediate group. Powders were usually unsuccessfully classified – only sixth and seventh graders did slightly better, yet many children classified them as liquids because they poured or as an intermediate group (Stavy and Stachel, 1985). What can be inferred from the findings is that children understood as solids only the rigid materials (the shape of which is difficult to change), and they did not include non-rigid solids in this category (Stavy and Stachel, 1985).

Liquids, on the other, followed a different pattern, claimed the researchers. Their study showed that children from an early age could successfully classify liquids. Children considered all liquids to be made of water (water was used as a prototype for liquids) - any wet, runny material that could be poured as a liquid was defined as water (Stavy and Stachel, 1985). When a substance is used as a prototype, a limited number of similarities is used for comparison (Krnel *et al.,* 2003). So, when children described a liquid as being like water, they made connections between the liquid and water by recognising similarities in how the two substances responded to certain actions (Krnel *et al.,* 2003). Children also considered the liquid form of material as weighing less than the same mass of its solid form and weighing more than the same mass of its gaseous form (Stavy and Stachel, 1985). The researchers concluded that children of all ages judged materials according to their appearance and behaviour (solidity with hardness, strength, and non-malleability) and not type. They neither provided any definitions or explanations using terms from the particulate theory (Stavy and Stachel, 1985). These findings enhanced previous research by Shepherd and Renner (1982), which found that American high school students did not develop an understanding of matter and the underpinning theory of particles, despite having received formal instruction.

Similarly, Jones, Lynch and Reesink's (1989) study in Australia showed that students aged seven to twelve tended to categorise solids and liquids based on how "hard/soft, rigid/bendable, hollow/solid, space-filling/non-space-filling" they were (p. 426). Students learned the word liquid early and used it spontaneously while identifying any unknown colourless liquid like water (Krnel *et al.*, 1998). Liquids were defined as substances that run, pour, and resemble the prototype for liquids, water. Similarly, Lee *et al.* (1993) found that twelve-year-old students in the USA defined liquids as wet substances that run. However, students had problems with sticky liquids in which pouring was slower than with water (Jones 1984). Jones, Lynch and Reesink's (1989) also found that students encountered difficulties accepting ice as a solid because it could be changed into water. As it appeared, rigidity was considered an intrinsic and thus unchangeable enduring property; if a substance lost its rigidity, it could not be a solid (Jones *et al.*, 1989). The studies just mentioned aimed at investigating how students understood matter as a concept, failing to identify practical interventions that could help students develop a better understanding of matter. Despite enriching the literature on students' alternative ideas about matter, the studies mentioned above do not inform teachers "whether finding out what students know should involve searching for their correct notions about the topic or actively probing for misconceptions" (Pine *et al.,* 2016, p. 92). Teachers already use various methods to find out what students know about matter. Yet the above studies do not provide any practical guidance on how such information can be reflected in the teaching process. The research in this thesis seeks to address that gap in practice. It seems that matter continues to be a basic topic of interest in primary schools across different cultural groups. Despite the different purposes and methods that studies use to research the topic, reported data reveals some common patterns.

3.7.7.2 Gases

Children appear to have greater difficulty in conceptualising gases, which are perceived as harder to detect and identify than liquids (Krnel *et al.*, 1998). One feels the air, for instance, when the wind blows (Krnel *et al.*, 1998). Studies have shown that children are often unaware that the air and other gases possess material character and do not consider gas as having weight or mass (Brook *et al.,* 1989; Stavy, 1988; Séré, 1985; 1986). Children at age nine and eleven are found to use air as a prototype for gases (Krnel *et al.*, 2003), although gases and

air are considered as different substances (Krnel *et al.*, 2005). Leboutet-Barrell (1976) based that on children's experience with rising or floating material gases.

Andersson (1990) stressed how students at primary and lower secondary levels rarely thought of the air as an example of gas, as they considered them to be two separate things. In informal English and Greek, gas was first encountered as the substance used for domestic heating and cooking, which can probably explain their resistance to accepting air, as an example of gas. Andersson found that younger students associated gas with something poisonous, injurious or flammable, whereas air was related to breathing and life. Similarly, older students did not have any clear idea that gas is a superordinate concept to air and a mixture of different gases (Andersson, 1990). As Driver and her colleagues argued (1993), many students thought of air and gas as having "contrasting affective connotations: the air was 'good', and was used for breathing and life; gas is 'bad' because it may be poisonous, dangerous or inflammable" (p. 72). These studies provided rich theoretical evidence for students' ideas about gases. They lacked practical implications on how teachers could use students' alternative ideas as the starting point to design experiments that could address false beliefs. The research in this thesis seeks to address this gap with its proposed activities.

Similar were the results from studies with French-speaking students at eleven years of age, in the first year of secondary education (Séré 1986; 1985). Data collected from individual interviews and questionnaires showed that students' perception of air stemmed from blowing and flowing wind ideas. Students also interpreted dreams, thinking, and memory according to the notion of air. Generally, they tended to involve air in what seemed immaterial or unexplained (Piaget, 1969). Séré concluded that young students' thinking about air and gases mainly depended on their perceptions before being influenced by stereotypical views, such as "air is everywhere, or hot air rises" (1986, p. 424). Such existing knowledge is often utilised and can lead students to hold mistaken views. As with the previous research, Séré's (1986; 1985) studies indicated some of the reasoning behind students' explanations about the gaseous state of matter.

Nonetheless, her studies and the other studies mentioned here were fundamentally based on students' answers to predefined questions in either the interviews or the questionnaires. These studies did not provide any information on how teachers could practically help students

tackle these difficulties or resolve their misconceptions. The activities reviewed in this thesis seek to help teachers apply that in practice.

Overall, students distinguish more kinds of matter in solids because of the bigger variety of easily perceptible properties (Krnel *et al.,* 2003). Students often believe that matter only exists when there is evidence of its existence; when evidence disappears, it ceases to exist (Stavy, 1990). Piaget's (1969) findings regarding the existence of air likewise suggest that young students believe in the existence of air only when it moves, a fact that proves its existence. When it does not move, it does not exist, or its existence is not permanent. Finally, "the low incidence of classification of various substances by the state of matter indicates that the superior concepts of solid, liquid, and gas are not naturally derived categories but more results of schooling and science education" (Krnel *et al*., 2003, p. 636).

3.7.7.3 Heat and temperature

According to the science curriculum (in Greece and the UK) (see earlier section 3.7), the introduction of the three states of matter precedes matter's physical and chemical transformations due to temperature changes. Many students, especially young ones, face difficulties in understanding the concepts of heat and temperature because they view a) heat as an entity that flows out of objects; b) "cold" and "heat" as separate entities that are not part of a continuum; (3) heat and temperature as synonymous (Driver *et al*., 1994; Driver *et al*., 1993).

At this point, it is useful to define the concepts of temperature and heat briefly from a scientific perspective, before examining studies about students' ideas, according to Driver and her colleagues (1985):

> "*Temperature* is one of the parameters that describes the state of a system. Knowledge of temperatures (along with other parameters) is essential information for predicting the changes which will occur in one system when it interacts with another system. Temperature is a macroscopic property which expresses the state of agitation or disordered motion of particles; it is therefore related to the kinetic energy of these particles (p. 53).

Heat is a parameter that describes the interactions between systems; more precisely, it is one process of energy transfer. It is the difference of temperatures between two systems which determines whether heat transfer will occur. For example, when a mass of water is heated by a gas flame, there is a difference of temperature between the flame (temperature of combustion) and the water. So, heat is transferred from one system (gas + air) to the other system (water)." (p. 54).

These definitions of temperature and heat indicate that the two concepts can play a fundamental role in understanding particle movement and changes of states. For instance, solids need to have heat added to change into liquids (melting), and reversely, liquids need to have heat removed to turn back into a solid (freezing)[4]. During this process, heat is transferred from one system to another. The object's temperature may change, but at the melting/freezing point, heat is added to melt or removed to freeze without any temperature change. To the best of the author's knowledge, existing scientific studies review heat and temperature in isolation from other concepts related to matter – an issue that this research aims to address this issue.

Students have already constructed numerous simple explanations about everyday encounters involving heat and temperature before formal schooling (Driver *et al.,* 1985). These explanations may subsequently be integrated into the student's explanatory framework when they are faced with similar sorts of problems in a school setting. Part of the confusion that surrounds students' use of the term heat may also occur from everyday usage of the term (Driver *et al.,* 1985). It is often the case to hear expressions such as "close the window" and "keep the heat in" or equally to "keep the cold out". Such expressions tend to imply that heat is substantive (that it resides in objects) and can make objects hotter; can be stored in objects and transferred from one object to another; and can travel from one location in an object to another (Driver *et al.,* 1985). That kind of predisposition stemming from everyday interpretations of heat as something substantial may be one of the most important conceptual barriers students must overcome to embrace the current scientific way of thinking

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[4] Although it is acknowledged that not all solids melt, for example a cricket bat or a pencil, for the purposes of this research reference is only made to the basic principles underpinning matter, according to the science program of study of the countries referenced.

(Erickson and Tiberghien, 1985). Science textbooks sometimes reinforce that (Thomaz *et al.,* 1995).

Students have great difficulty in distinguishing between the concepts of heat and temperature because they tend "to view temperature as the mixture of heat and cold inside an object, or simply as a measure of the amount of heat possessed by that object, with no distinction between the intensity of heat and the amount of heat possessed" (Driver *et al.,* 1993, p. 126). Many students think that the temperature of a body is related to its size, volume or the amount of stuff present (Tiberghien, 1985). Students also think of temperature as a material property and a measure of heat. Their daily experience of touching objects supports the idea that some substances are naturally warmer or colder than others (Driver *et al.*, 1993). They also think that different sensations mean different temperatures (Thomaz *et al.*, 1995).

This everyday usage of the term also leads students to believe that heat and temperature are synonymous (Arnold and Millar, 1996). They can hardly differentiate between heat and temperature because they regard hotness and coldness as two distinct properties of physical objects, which can transfer to other objects by direct contact (Vosniadou, 1994). The terms *heat* and *hot* are found in children's vocabulary from the early age of two to three and are used to describe aspects of children's everyday encounters with hot objects (Erickson, 1985). It is not until they are eight or nine years old that they refer to heat as a 'state of hotness' of a body and a continuum from cold to warm to hot (Erickson, 1985). Likewise, students recognise the word temperature from frequent discussions about the weather, especially at five to seven years. But, unlike heat, they do not seem to use the term spontaneously in conversation (Erickson, 1985). Anecdotal evidence shows that, in informal English, when someone suffers from a cold, is said to 'have a temperature' (meaning hotness), referring to body temperature as being higher than normal. That is also evident in the Greek vocabulary for science, according to which both heat *[thermoteeta, gr]* and temperature *[thermokraseea, gr]* are produced from the same root, *thermōs [adj.]*, which means warm, hot. It is thus very common for Greek students, regardless of age, to use the terms *heat* and *temperature* interchangeably to denote the hotness of a material.

Students' alternative views of heat and temperature have been widely examined in several empirical studies that used constructivist and/or conceptual-change teaching strategies to promote students' conceptual understanding and transform their alternative views (Luera *et al.*, 2005; Thomaz, 1995; Stavy and Berkovits, 1980). For example, Stavy and Berkovits (1980) developed a conflict-producing technique, which aimed to advance students' understanding of the concept of temperature. Their findings suggested that conflict in training can improve knowledge of temperature in individual- and classroom-training situations. The success of this technique used by Stavy and Berkovits was based on the correct answers that students gave to different temperature tasks depicted on cards. Although this card-presentation method is common in science classrooms, it does not allow students to justify their thinking for the correct or wrong answers. It is like many current classroom tests teachers use to assess students' knowledge of science topics and concepts. If students do well in the tests, teachers mistakenly perceive it as an indication of successful understanding.

In later years, Thomaz *et al.* (1995) used a constructivist teaching approach to teach heat and temperature at an introductory level. The results showed a positive impact on promoting students' understanding of heat and temperature. Their research (Thomaz *et al.*, 1995) differed from the previous one. It asked students to provide scientific reasoning in responses to a questionnaire, with the purpose to apply them in practice and developing and testing a teaching model. Although Thomaz *et al. 's* (1995) proposed teaching model was based on the constructivist perspective that views learners as active constructors of knowledge, their activities were limited to the standard science experiments followed by a discussion between the teacher and students. In a similar line, Harrison *et al.* (1999) explored grade 11 students' conceptions about heat and temperature, using an inquiry approach that did not consider students' alternative ideas as wrong but limited. Findings indicated improved students' conceptual understanding of heat and temperature and better use of scientifically correct language. As before, the study of Harrison *et al.* (1999) framed itself in the traditional teaching-science model, emphasising students' reasoning through guided teacher-student discourse. There is a need for further research in this area that evaluates content knowledge and the learning process itself. The research in this thesis seeks to address the gap and advance knowledge of teaching models in a science classroom while offering students authorship and ownership of the learning process.

3.7.7.4 Evaporation and condensation

The concepts/phenomena of evaporation and condensation are linked to the understanding of the concept of heat are the concepts/phenomena of evaporation and condensation. Taking into consideration that young students' "thinking is perception bound, the process of boiling is more easily understood than the processes of evaporation and condensation. The reason is the direct perceptual evidence available to students" (Hadzigeorgiou, 2015, p. 74). Studies suggest that students face more problems with the concept of condensation than evaporation (Johnson, 1998). According to Bar and Travis (1991), this perceptual evidence affects mainly age levels younger than 12 years. In the case of condensation, students appear to have difficulty accepting the idea that water in its vapour state can be present in the air. The air is perceived as a "conduit for the water (formed), but there is no sense that the water can be in the air as a vapour" (Bar and Travis (1991, p. 704).

Explanations of the process of evaporation reveal two problems: first, students "rely heavily on perceptible cues and so believe that liquids simply disappear or go somewhere else during evaporation, and second, when they realise that a gas is formed, they think that air, as the archetype for gases, is formed" (Talanquer, 2009, p. 272). Even after formal instruction, students five to seven years old believe that water disappears during evaporation. In contrast, older ones, eight to eleven years old, mainly conceptualise the phenomenon as displacement – that nothing happens to water during evaporation (Talanquer, 2009).

Osborne and Cosgrove's (1983) study showed that students from New Zealand, across the ages of eight to seventeen, were able to associate the correct technical term with the processes of evaporation and condensation. Still, their understanding of these scientific terms was, most of the time, superficial. That implies that students could use labels like evaporation and condensation precisely, but scientific explanations do not underpin their understanding of these terms. For instance, despite formal teaching, students continue to think that air (rather than water vapour) is in bubbles of boiling water (Osborne and Cosgrove, 1983). There is currently limited research investigating the application of novel teaching approaches in practice to help change these misconceptions in science learning. This research seeks to address this gap by closely scrutinising its application in the primary science classroom.

Bar and Travis (1991) also explored Israeli children's views on the phase change from liquid to gas by employing multiple-choice questionnaires. Their findings revealed that although students at the age of ten to fourteen knew that (water) vapour could change to (liquid) water, applying that knowledge appeared to cause some difficulty. Their results confirmed those of Osborne and Cosgrove (1983) with older students, although there are some important differences in detail. Bar and Travis identified growing confidence in students in the age group of six to thirteen years regarding the relationship between (liquid) water and (water) vapour and the existence of vapour in the air. Bar and Travis claimed that "students from a young age have an almost correct view about boiling. They understand that the liquid changes into gas" (p. 378). Nonetheless, these studies failed to relate this to teaching practice, which this thesis aims to review.

Johnson (1998) questioned the claims made by Bar and Travis by arguing that the authors were not fully informed of what students understood by the gaseous state. The authors did not seem to value the ways in which language was used and accepted statements such as water disappears (during boiling) at face value. It could be that students used the term to mean it could no longer be seen, or that air was used by students in the same sense adults understand it (Tytler, 2000; Johnson, 1998). As Johnson (1998) pointed out, most children at the age of eleven were aware that there was something called air all around us (Russell *et al*. 1991; Sere 1985). They often referred to it as gas, but, at the same time, they also loosely regarded sprays, mist, steam, flames and smoke as gases (Russell *et al*. 1991), using the terms interchangeably.

As with previous research, these studies outline what students know about evaporation and condensation. However, what they lack is an activity that seeks to address students' misconceptions and alternative conceptions, which will not be restricted to the standard science experiments and follow-up classroom discussions. The research documented in this thesis proposes such an activity, which will be discussed in more detail in the next chapter.

To conclude this section, research findings show that there continue to be common firmly held (mis)conceptions about matter, including not only the properties of the three states (solid, liquid, gas) but also their changes (e.g. evaporation and condensation). Students' explanations of states' changes are often based on perceptible cues that occur from their observations and, as a result, are unable to extend explanations of the phenomenon to other substances (Harrison and Treagust, 2002; Krnel et al., 1998). However, of great importance here is that existing data reveal the persistence of students' false ideas even after formal teaching instruction. Given the "robust nature of misconceptions in science" (Pine *et al.*, 2016, p. 91) and the fact that research participants are mostly students across different grades of formal schooling, this can also reflect teachers' difficulties in teaching specific science topics.

One way of changing students' misconceptions or alternative ideas suggests knowledge restructuring, which can occur at two or more levels (Harrison *et al.*, 1999). As the authors explained, the first level, weak restructuring, refers to the addition of new facts and the generation of new relations between existing concepts. Assimilation and conceptual capture are considered examples of weak restructuring because students capture or add new information to their previous conceptions (Harrison *et al.*, 1999). That is similar to superficial or surface learning, which refers to understandings that syllabus constructors, teachers and examiners have in mind when setting out the curriculum to be studied (Entwistle *et al.,* 2002). The second level is radical (or strong) restructuring, implicating changes to core concepts, conceptual structure, and the phenomena can be explained by the new theory (Vosniadou and Brewer, 19). This level can be associated with deep learning that involves the range of understandings that students achieve personally. Accommodation and conceptual exchange are examples of this level of conceptual change, during which students change the way they view a phenomenon. For instance, they transform their view of heat as a material fluid to energy flow (Chi *et al.,* 1994). This research seeks to review the practice-based application of activities that engage students in science learning.

3.8 Limitations and gaps of the reviewed literature

A careful examination of the literature on school science revealed that specific topics are considered tricky for teachers and students, finding them hard to teach and learn accordingly. Drawing on empirical and theoretical evidence from research on Troublesome Knowledge (Perkins, 2008; 1999) and Tricky Topics (Clough and Adams, 2014; Clough *et al*., 2013) helped to identify matter as a tricky topic in school science. Considering the proposed teaching sequence of matter, pre-high school, in Greece and England and the scarcity of available resources to support its tricky nature, this research focuses on the topic of matter. Aiming to address this gap, the research in this thesis will seek to enrich evidence regarding its first two questions:

RQ1: Whether, and, if so, how do the SEeDS and Narration activities support learners in each of the two contexts to access, reflect upon on, and apply prior science learning?

RQ2: Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?

3.9 Chapter Summary

This chapter has reviewed research on school science and dwelled on the topic of matter due to its troublesome and tricky nature. The existence of distinct phases of matter is considered a threshold concept, which once understood opens up portals to previously inaccessible and initially perhaps a troublesome way of thinking about something. Many studies investigating students' alternative ideas about matter were placed under scrutiny, bringing to the surface practical gaps (for primary science teachers) that might occur from translating these findings. Identifying those gaps leads to the development of specific activities, as documented next in Chapter 4, that seek to provide practical guidance on tackling potential difficulties in the learning and teaching of matter.

CHAPTER 4: THE METHOD OF CREATING THE TWO DIGITAL STORYTELLING ACTIVITIES

4.1 Introduction

The previous three chapters closely scrutinised the theoretical underpinnings of meaning making (Chapter 2) and acknowledged its importance in science learning (Chapter 3). Chapter 3 also dwelled on the science topic of matter, which was identified as a tricky topic worth of focus through systematic analysis and practice-based examination. This research designed and constructed two digital storytelling activities to address the limitations and gaps of the reviewed literature. The first one, named SEeDS (Sequencing of Events enabling Digital Storytelling), presents story scenes not in a predefined order. The second one, Narration, presents story scenes in a predefined order. The creation of the two digital storytelling activities followed the three stages of the Tricky Topic Process: *identify* a tricky topic, *capture* student difficulties, create and *assess* interventions to tackle all or some problematic parts of the tricky topic.

4.2 Preparing for the two digital storytelling activities, SEeDS (Sequencing of Events enabling Digital Storytelling) and Narration

As a product of social interaction, the meaning making process is considered highly valuable in science learning and teaching because it can help to unfold students' (scientific or not) thinking. Students can engage in the process of meaning making when they create and tell stories. Acknowledging the importance of digital storytelling in science learning and seeking to address the existing gap in developing ideal interventions, this research created two digital storytelling activities, namely SEeDS and Narration. This research is informed by existing literature on troublesome knowledge and tricky topics and seeks to identify tricky topics in practice. As such, it follows the methodology of the Tricky Topic process to identify possible barriers in students' understanding of matter. This chapter documents the practical identification of a tricky topic across Greece and England and presents the method of creating the SEeDS and the Narration activities.

4.2.1 The Tricky Topic Process (TTP)

The two digital storytelling activities were designed as interventions for teaching and learning tricky topics, and they were created in the third stage of the Tricky Topic Process (TTP) (https://www.open.edu/openlearn/ocw/mod/oucontent/view.php?id=72094). The choice of the tricky topic process is based on teachers' perceptions of student barriers to understanding and helps to provide a practice-based focus on misunderstandings. There are other approaches to this identification, but this approach was identified as the most appropriate application to address this research's practice-based questions. In what follows, the three stages of the TTP, *identify, capture and assess,* are discussed.

Step 1: Identify

The first stage of the Tricky Topic Process (TTP) involves collaborative group activities. Teachers are encouraged to think of a Tricky Topic (content producing barriers to learners understanding) and break it down into assessable components and how these different components are linked together to produce misconceptions in understanding. A pilot scoping workshop was conducted in England with three secondary science teachers to establish tricky topics in general. The participants were teachers, two chemists and one biologist, and the workshop took place in the science lab of their sixth form school in Buckinghamshire. The first topic they identified as the most problematic topic between Year 6 and Year 7 students was the particulate nature of matter (see *Appendix* 3), with the biology teacher, Ben[5], explicitly stating that there was "*a really hot topic we could really look into: the particle theory of liquids, solids and gases... they don't understand that".* Among the reasons that teachers gave were that the specific topic *"actually has a lot of misconceptions in and that builds on through the key stages"* (Mary, chemistry teacher) and that its *"concepts are difficult"* (Cathy, chemistry teacher). They argued that students tend to "*look things in isolation rather than putting everything together…they are remembering things than understanding the relationships between them... we've got that the misconceptions they develop very young, and then we can't correct them because they do it too often…"* (Cathy, chemistry teacher). As an example, teachers identified liquids as a key stumbling block, *"because they [students] assume that the*

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[5] All the participating teachers' original names are not disclosed, and pseudonyms are used instead

liquid molecules are just here and there ... miles away from each other, just rather than sliding over each other, and they think that there is lots of space between them" (Mary, chemistry teacher). Among other problems, they mentioned students' difficulties in *"understanding things like density ... evaporation as well..."* (Cathy, chemistry teacher) or *"conduction not linking to convection… because they [students] could actually describe conduction quite well, and then they really struggle with describing convection"* (Mary, chemistry teacher). So, through the tricky topic process teachers were systematically supported in concurring that there were issues in the way science is taught in schools – *"even though it is done over and over again, it's never done properly and then they [students] switch off completely"* (Cathy, chemistry teacher). That then leads to *"rote learning rather than understanding"* (Mary, chemistry teacher). The identification process through the pilot scoping workshop in England allowed for the tricky topics workshop in a school science context for students aged ten and twelve years old.

Following on from establishing an understanding of the English context, a second workshop was carried out to check the transferability and applicability of tricky topics in a different geographical context. The workshop was conducted with a Grade 5 teacher, Annie, in the science lab of her primary school in Athens, Greece. Acknowledging that the teaching process is more important than the whole school context, the Greek workshop involved one teacher. This teacher provided in-depth information on the application of the science tricky topic process in a culturally different teaching context. The Grade 5 teacher identified two tricky topics – electricity and matter – in science among students aged 10 to 12 years old (Grades 5 and 6) (see *Appendix 4*). As it appeared, matter had already been identified as a transferable concept between the different teaching contexts. The workshop allowed for a cross-reference back to the previous workshop, ensuring the generalisability of the process. With regards to the nature of matter, Annie identified as a stumbling block the invisible existence of matter because students tended to believe that *"matter exists only when there is proof of it. That is, gases have neither mass nor volume. So, they can't be heated either"* (Annie, the Grade 5 teacher). In addition, she said that most of her current Grade 5 students *"had never observed the phenomenon of condensation. They have probably taken it for granted. So, when they [students] were asked to explain why there were droplets on a glass full of ice, they could not answer"* (Annie, the Grade 5 teacher). Among the reasons that the Greek teacher gave for

students' difficulties in matter was the difficult vocabulary that science has in general. She specifically argued that *"the way that students verbalise science events and phenomena … it is different from their daily talks… a different vocabulary, not so comprehensible… and they [students] get confused trying to remember things and words"* (Annie, the Grade 5 teacher). The second workshop in Greece helped to verify and justify the applicability of matter (and the particulate nature of matter) as a tricky topic in school science across culturally different contexts. In other words, the English workshop identified an issue with the science topic of matter, and the Greek workshop revealed that the issue was not isolated to one educational context, that of England. This cross-cultural identification sought to extend the possible generalisation of findings beyond only England or only Greece.

Once the tricky topic was identified, it was broken down into identifiable parts. These parts consisted of specific problem examples that the teacher identified that students said, did, or assumed, suggesting that they had found the topic tricky. These problems were then written down into a mind map *(Appendix 10)*, as in *Figures 3* and *4* below. Some identified problems were considered important underpinning issues that could evolve into key Stumbling Blocks (SBs). Other problems were not considered as vital, and as such, they could link to smaller problems that would form a Stumbling Block if put together again. The Tricky Topic process facilitated the creation of a mind map around matter, which was systematically built upon (or integrated) through the sequenced workshops between the English and Greek identifications. Integrating information from the two workshops helped to develop a universal conception for the development of the activities *(Figure 3* and *Figure 4).*
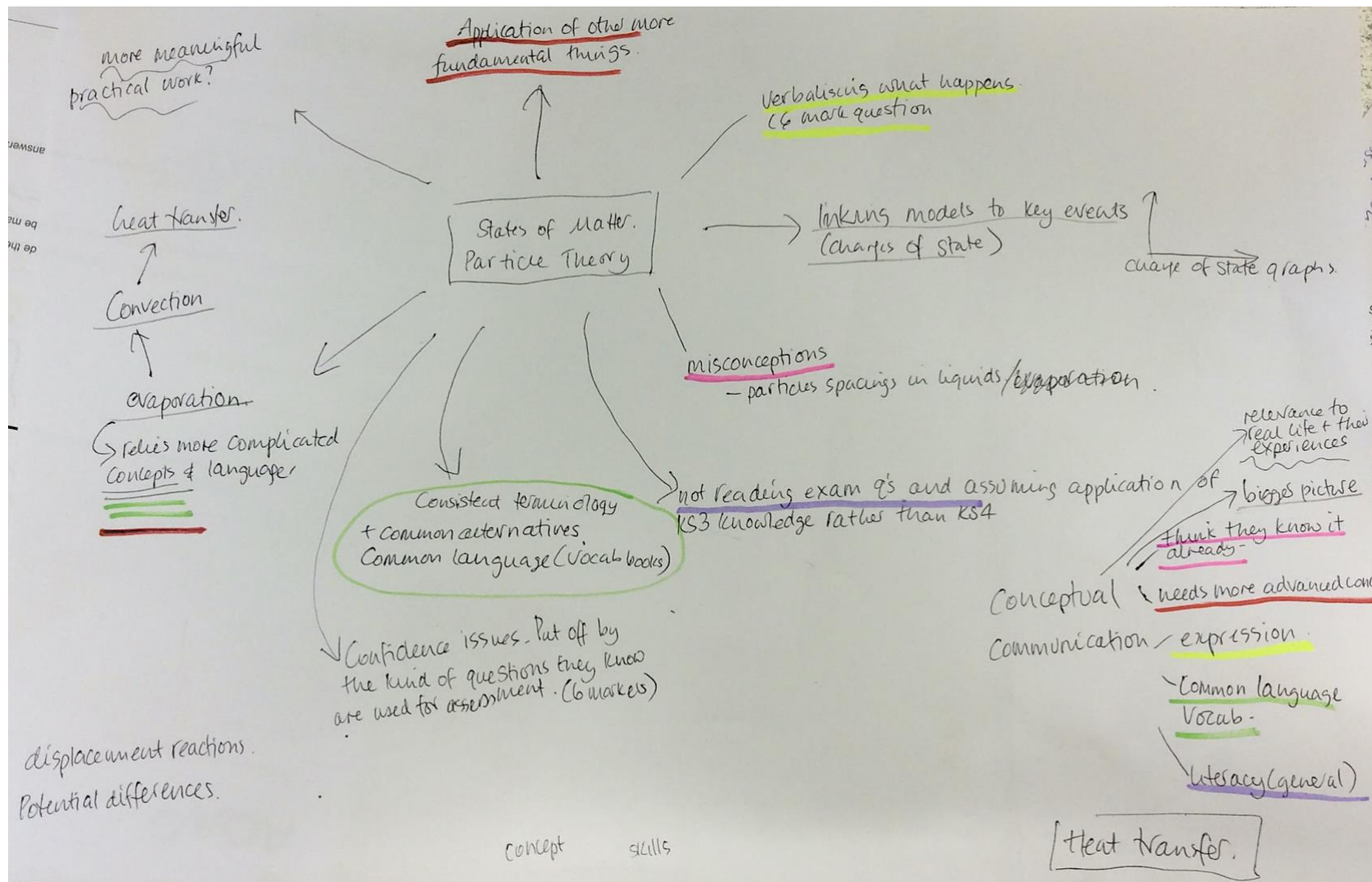
Figure 3: Mapping diagram for the Tricky Topic of matter, as identified by the group of English teachers

Problem

Children do not use the term 'temperature'; they usually say how hot or cold an object is.

Problem

How can we heat or freeze a gas if we can't see it?

Problem

The term 'temperature' in Greek is produced from the word 'thermos' which means hot; therefore, children often confuse temperature with heat, suggesting that temperature measures only heat.

Stumbling Block

Confusing heat with temperature

Stumbling Block

Does melting and freezing happen in all states of matter?

Problem

Tricky Topic

States of Matter

Problem

I don't understand why there are droplets of water on a glass full of ice.

Stumbling Block

How particles move when the temperature changes

Stumbling Block

Gases do not exist, because we can't see them

Stumbling Block

What are the differences between evaporation and condensation?

Problem

Why particles move fast and away from each other when an object is heated?

Problem

Problem

We can't see gases, so they don't exist and therefore they can't be heated.

Figure 4: Mapping diagram for the Tricky Topic of matter, as identified by the Greek teacher

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Figures 3 and *4* depict the mind maps used to identify the tricky topic of the matter. They show numerous problem examples that both the Greek and English teachers gave regarding their students' difficulties in matter. Combining information from the sequenced workshops, the Tricky Topic mapping diagrams helped structure the identified problems and summarise them in five Stumbling Blocks (SBs). The five SBs occurred from reviewing teachers' identification of students' barriers as a practice-based application of the activities within those two educational contexts (England and Greece). The five SBs were *1) movement of particles in all states of matter; 2) existence of gases; 3) differences between melting and freezing; 4) differences between evaporation and condensation, and 5) differences between heat and temperature. Table 7* below shows the five SBs in a numbered order.

Tricky Topic: States of matter	
Stumbling Blocks (SBs)	
SB1	Movement of particles in all states of matter
SB2	Existence of gases
SB3	Difference between melting and freezing
SB4	Difference between evaporation and condensation
SB5	Difference between heat and temperature

Table 6: The numbered order of the five Stumbling Blocks

The five SBs are not isolated categories, but they link to each other while some overlap with others. For instance, SB1 regarding the movement of particles overlaps with SB5 regarding temperature changes. Similarly, SB3 overlaps with SB5, as the difference between melting and freezing regards the energy transferred due to a temperature difference. Similarly, SB2 links to SB4 because condensation changes the gaseous state. *Figure 5* below illustrates the association of the SBs. SB5 can be considered a broader SB for two reasons: a) changes in the states of matter, such as melting, freezing, evaporation, condensation, occur at different rates at various temperatures; b) when substances change state, aided by heating or cooling, they gain or lose energy respectively. Heat is the energy that is transferred due to temperature differences, and when a substance changes states, then the closeness, arrangement and motion of its particles change.
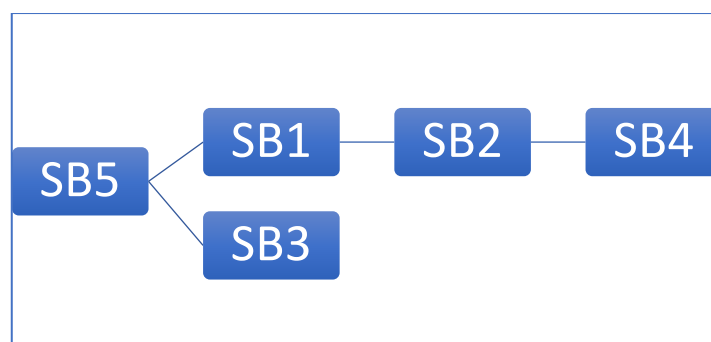
Figure 5: The overlapping relationship of the five SBs

The five SBs played an essential role in creating the digital storytelling activities, as they were the main problem areas that the English and Greek teachers identified as students' problems and barriers. Thus, the two activities (presented in section 4.3) were constructed to tackle as many of the five SBs as possible.

Step 2: Capture

This stage used the Problem Distiller of the online Tricky Topic Tool to capture and categorise the information collected through Stage 1. Using the tool with teachers in their teaching practice helped to classify problems and uncover why students the specific topic found tricky. The Problem Distiller enabled to structure students' problem examples into four main categories: *a) lack of underpinning pre-knowledge; b) flawed or unlinked prior knowledge; c) terminology; d) intuitive belief.* These categories provided valuable information about the significant reasons/ factors for students' problems and guided the design of the storytelling activities. For instance, both the Greek and English teachers concurred that the vocabulary students used to talk about science matched the third misconceptions category of *terminology* within the Problem Distiller. As a primary reason for students' difficulties, the teachers argued that "*they [students] didn't use the right sort of language... there is this language and common language... and they don't use the right vocabulary… and then they have difficulties to actually say what they want to say … they can't put those words together, they can't actually express it, as an expression*" (Cathy, chemistry teacher, English workshop).

In the final stage of the process, there was a discussion about possible learning activities and interventions that could tackle one or more of the five SBs. A common teaching approach that the English teachers shared in their science classes was drawing pictures and telling stories through those pictures. One chemistry teacher argued that her students were "*usually drawing that in pictures and I can see what's happening in the pictures … they're used to see pictures and themes and I can recognize different stages usually*" (Cathy, English chemistry teacher). The other chemistry teacher said - "*with the lower attainment class, I would start them off by getting them to use every bit of kid drawing a picture of how they think that's settled and then get them to write about what's happening in the experiment; that's how I would do this particular question, draw a picture*" (Mary, English chemistry teacher). The Greek teacher also favoured the use of digital stories and she prepares her "*own presentations, either in PowerPoint or in movie-making applications, using pictures and animations to introduce my students to a new science topic … or to assess one at the end of the unit*" (Annie, Greek Grade 5 teacher).

Considering all teachers' familiarity with the use of storytelling in science and drawing on their identification of students' barriers, this practice-based application of the activities combined elements from digital storytelling and problem-based learning. Digital storytelling is considered an interesting and engaging approach that promotes critical thinking. The two proposed digital storytelling activities were evaluated and approved by the participating teachers of this research, as discussed next.

4.3 Developing the two digital storytelling activities, SEeDS and Narration

The third stage of the TTP previously discussed led to creating two activities based on digital storytelling to tackle the identified SBs. Two digital storytelling activities were created to help students to externalise their understanding of matter and engage in the process of meaning making. The first activity (SEeDS) presented story scenes in an order that was not predefined and the second one (Narration) in a predefined order. Both activities could be implemented in numerous ways, individually or in groups, and the teacher would act as an observer.

The sources used to create the digital story plot were educational material available free on the web, such as animated videos from the BBC's Bitesize site for KS2 science (https://www.bbc.co.uk/education/topics/zkgg87h) or other educational channels on YouTube (see sources in *Appendix 5*). The animated videos presented entertaining curriculum material, and teachers could otherwise use them as supplementary or introductory material. Although these videos were short in presentation, lasting a few minutes, for this research – which sought to prevent a cognitive overload– they were broken down into smaller chunks, and each one lasted only a few seconds. After carefully selecting and thoroughly editing the animated videos to cover all five SBs, the videos were ordered to compose a plot about matter. The composition of the original plot was based on both the teaching sequence of matter as proposed in the programmes of study for science (see sections 3.7.4 and 3.7.5) and the notion of hierarchical sequencing (see section 2.3.2) – starting with the simple components of a topic and moving up to the more complex ones. In this case, it started with introducing the three states of matter and continued with the changes of states/phases.

The sources' original audio commentaries were removed, in line with the CTML theory (Mayer 2014, 2005) and the *limited capacity assumption* underpinning it (see section 2.4.1). So, information would be processed to one channel, the visual channel. This visual prompt aimed to help students create and tell a digital story while retrieving existing knowledge. The purpose was to help students externalise their understanding of matter as they processed and represented visual information into the auditory/verbal channel. It should also be made clear that the composition of the original story (selection, editing, and ordering of the animated videos) was based on the individual understanding of the creator – both a researcher and teacher. In doing so, the creator drew evidence from current teaching practices, existing research in both empirical and theoretical literature, and the availability of online educational resources that matched the learning ecologies of the school classroom. Having said that, it is acknowledged that a different teacher or researcher would make a different composition of the story. Any biases of the researcher due to her professional identity as a teacher are discussed in more detail in the limitations' section in Chapter 8 (section 8.4).

The next section discusses the composition of the SEeDs and the Narration digital storytelling activities.

4.3.1 The SEeDS (Sequencing of Events enabling Digital Storytelling) activity

The name of SEeDS stands for the *Sequencing of Events enabling Digital Storytelling (SEeDS).* The SEeDS activity involved a digital story about matter, broken down into fifteen scenes (*Figure 6*), without any written (text) or verbal (audio) commentary. The SEeDS activity was presented to students in an order that is not predefined. Students were required to create and invent their own story by ordering and sequencing its events.

The SEeDS activity was designed as a problem-based story (section 2.2.3). The presentation of its scenes in an order that was not predefined was considered a question that needed to be resolved (Jonassen, 2011). As a story problem, it is open-ended and has both multiple solutions and multiple paths or procedures to follow (Ertmer *et al*., 2009).

Figure 6 below shows one of the many ways of presenting the fifteen scenes of the SEeDS activity[6]. The length of the scenes was purposely defined between 10-30 seconds so that the chunks of information – that is the content of the scenes would not exceed students' cognitive load capacity (Sweller, 2007).
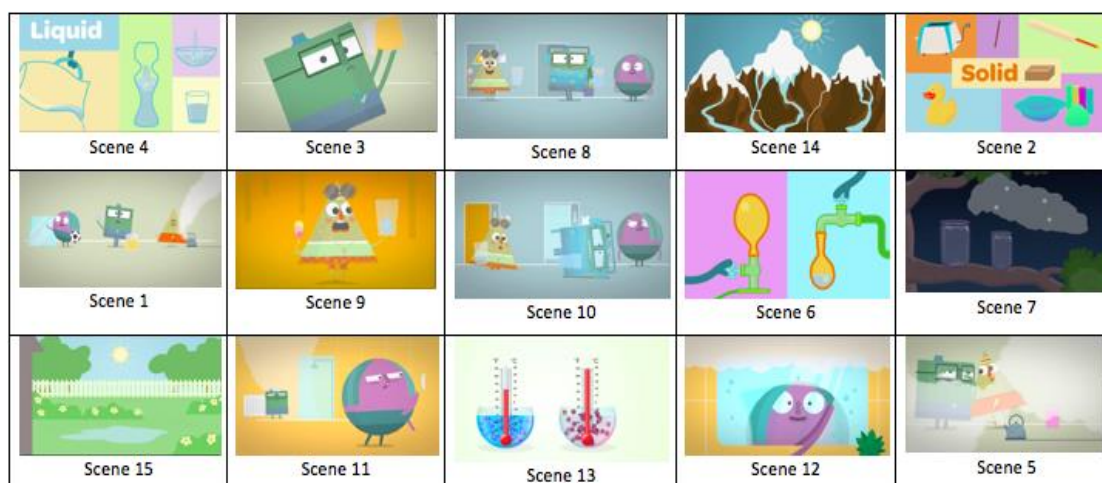
Figure 6: The SEeDS activity presents story scenes in an order that is not predefined

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[6] Given that story scenes were presented in an order that is not predefined, their presentation to students varied.

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The creation of the SEeDS activity was based on the five SBs identified at the first stage of the TTP, including particles' movement in all three states of matter, the existence of gases; the difference between melting and freezing; evaporation and condensation and heat and temperature. *Table 8 below* shows which scenes corresponded to each SB.

Tricky Topic: States of matter		
Stumbling Blocks (SBs)	Concepts included in the SBs	Scenes
1	Particles' movement in all three states of matter	1, 2, 4, 6, 7, 13
2	Existence of gases	5, 6, 7
3	Difference between melting and freezing	8, 9, 10
4	Difference between evaporation and condensation	11, 12
5	Difference between heat and temperature	13, 14, 15

Table 7: The five Stumbling Blocks of matter with their corresponding scenes

Annie, the Greek teacher with whom the Tricky Topic workshop was conducted, helped to refine the SEeDS activity into its final version. In doing so, she helped to edit (trim, cut, translate, remove audio) of each scene and then offered her input on the final product – the story. She consented to the use of the animated clips, clearly stating that *"they are really nice videos. And the plot is easy, I don't think they [students] will find it difficult"* (from anecdotal email communication). Similarly, Bill, the participating English science teacher, was sent the final story in advance for approval. The English teacher also considered the animated story appropriate for his school's middle-attainment students. He stated that *"this fit into teachers' daily lives... and it is changing my practice, I am very keen to support"* (Bill, science teacher, secondary school), as anecdotal evidence from email communication revealed.

4.3.2 The Narration activity

The name of the Narration activity suggests "telling a story". This activity included the same animated scenes about matter used in SEeDS, without any written or oral commentary. The Narration activity was presented to students in its original predefined order *(Figure 7),* and students had to invent the story plot.

The Narration activity was also designed as a problem-based story. It is open to interpretation and has multiple solutions as a story problem.

Figure 7 below shows the original predefined order of the story scenes. The ordering of story scenes in the Narration activity did not follow the traditional narrative sequence that begins with a problem/goal, continues with the character(s)' actions, and ends with a solution and some possible consequences for the characters. The ordering was based on *hierarchical sequencing* (Gagné, 1968), which resembles the proposed teaching sequence for science found in Greece and the UK (section 3.7). Hierarchical sequencing suggests that learning (a skill) starts with its simple components and then moves on to the more complex ones. The Narration story began by introducing the three states of matter – solids, liquids, and gases. Then it continued with the changes in conditions of the three states due to temperature changes – such as melting and freezing and evaporation and condensation. In particular, the order of scenes in Narration was as follow:

- Solids and their particles (scenes 1 and 2); SB1

- Liquids and their particles (scenes 3 and 4); SB1

- Gases and their particles (scenes 5, 6 and 7); SB1 + SB2

- Changing states: melting and freezing (scenes 8, 9 and 10); SB3

- Changing states: evaporation and condensation (scenes 11 and 12); SB 4

- Heat as energy and temperature as a means of measurement (scenes 13, 14, and 15); SB5

The ordering of the scenes corresponds to the five SBs as identified in *Table 8* in the previous section 4.2.1.
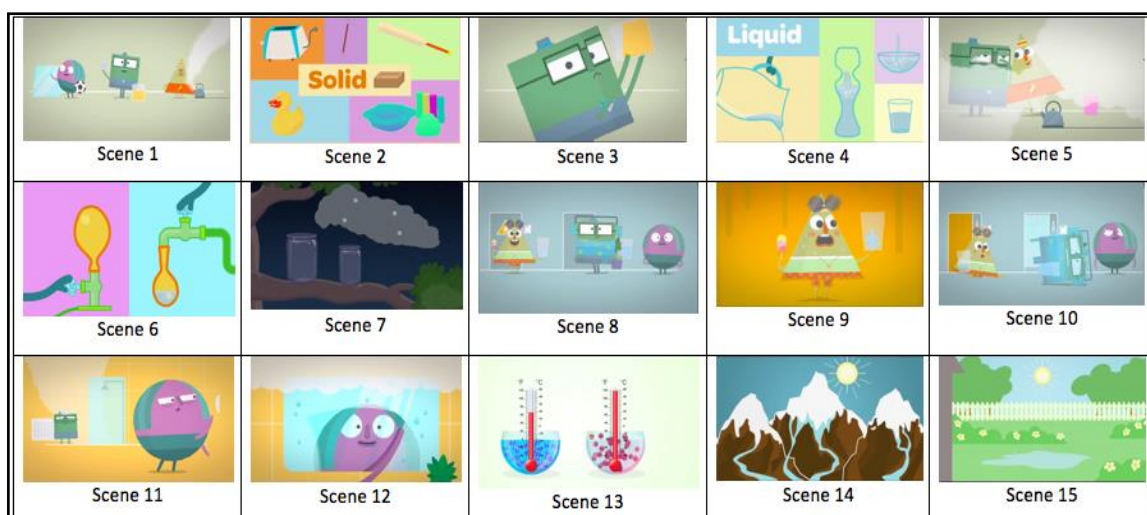
Figure 7: The Narration activity with its predefined order of story scenes

To conclude this section, the design of the SEeDS and Narration activity as problem-based stories would enable students to work independently as much as possible. The teacher would act as an observer, prepared to step in and interact with students only if asked for guidance and assistance.

4.4 Chapter Summary

This chapter documented the systematic identification of matter as a tricky topic across two cultural contexts and linked it to creating two digital storytelling activities, SEeDS and Narration. The two activities were designed as problem-based stories that were open-ended and offered multiple solutions. The following chapter, Chapter 5, will detail the route to implement both the SEeDS and the Narration activities in the science class, from pilot-testing SEeDS and the data collection methods to implementing both activities in two schools, one Greek and one English. Finally, Chapter 5 will address methodological issues regarding research design and data collection methods, deal with ethical considerations, code and analyse findings through a hybrid thematic analysis process.

CHAPTER 5: RESEARCH METHODOLOGY

5.1 Introduction

As discussed previously, a considerable body of research investigated students' barriers to understanding specific school-based science topics, most notably the topic of matter. Yet, there is still a gap in interventions that tackle them. Two digital storytelling activities were created to address the existing research gaps and help to tackle some or all of the problematic areas (Stumbling Blocks) of the tricky topic of matter (see Chapter 3). The first activity, SEeDS, presented story scenes in an order that was not predefined, and the second activity, Narration, in a predefined order. The design of the two activities was based on the problem-based learning approach, which has multiple solutions and multiple procedures to follow. This chapter starts by addressing the research questions that guide this research and continues with a discussion about the research design and the appropriateness of the chosen qualitative research methodology. Next, it sets out the background of the pilot studies that tested the suitability of the SEeDS activity and the instruments (iPads and story app) and the data collection methods. It then critically discusses the practical aspects of data collection, such as the participants' selection, the settings in which the research took place, accessibility issues and researcher reflexivity. Finally, it presents the data analysis methods and takes into account ethical considerations and how to establish trustworthiness in qualitative research.

5.2 Purpose of study and research questions

There is an existing gap in the interventions that science teachers use to help students overcome their difficulties understanding the tricky topic of matter. The purpose and contribution of this research are to explore how digital storytelling may support students' engagement in meaning-making through externalising their understanding of matter. In particular, this research seeks to address the following research questions:

RQ1: Whether, and, if so, how do the SEeDS and Narration activities support learners in each of the two contexts to access, reflect upon on, and apply prior science learning?

1.1.   Whether, and, if so, how does the SEeDS activity support learners in the Greek context to access, reflect upon, and apply prior science learning?

1.2.   Whether, and, if so, how does the Narration activity support learners in the Greek context to access, reflect upon, and apply prior science learning?

1.3.   Whether, and, if so, how does the SEeDS activity support learners in the English context to access, reflect upon, and apply prior science learning?

1.4.   Whether, and, if so, how does the Narration activity support learners in the English context to access, reflect upon, and apply prior science learning?

RQ2: Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?

2.1   Whether, and, if so, how does the SEeDS activity facilitate the types of peer talk that research suggests can support science learning in the Greek context?

2.2   Whether, and, if so, how does the 'Narrative' activity facilitate the types of peer talk that research suggests can support science learning in the Greek context?

2.3   Whether, and, if so, how does the SEeDS activity facilitate the types of peer talk that research suggests can support science learning in the English context?

2.4   Whether, and, if so, how does the 'Narrative' activity facilitate the types of peer talk that research suggests can support science learning in the English context?

RQ3: Whether, and, if so, how do the SEeDS and Narration activities engage and challenge learners in the two contexts?

3.1   Whether, and, if so, how does the SEeDS activity engage and challenge learners in the Greek context?

3.2   Whether, and, if so, how does the Narration activity engage and challenge learners in the Greek context?

3.3   Whether, and, if so, how does the SEeDS activity engage and challenge learners in the English context?

3.4   Whether, and, if so, how does the Narration activity engage and challenge learners in the English context?

All three research questions are phrased broadly to include subsequent themes that narrow the focus of the overarching questions. Thus, four sub-questions are constructed, seeking to provide enriching evidence.

5.3 Theoretical perspectives and philosophical underpinnings

It is widely acknowledged (Potter, 2006; Goodson and Sikes, 2001; Crotty, 1998) that the research design depends on the researcher choosing the most suitable methodologies and methods, considering their underlying assumptions, providing relevant and sufficient information data on the questions asked.

Crotty (1998, p. 3) supports that the philosophical underpinnings of the research design are constantly "informing the methodology and therefore, providing a context for the process and grounding its logic and criteria". The theories supporting qualitative and quantitative research must reflect the paradigmatic nature of contrasting ontological and epistemological positions, underpinning the pursuing goals and research claims (Twining *et al.*, 2017). The underlying ontological (nature of reality) and epistemological (nature of knowledge) positions and the research goals and questions, methods, results, and conclusions (Twining *et al.*, 2017) need to be aligned. The upcoming sections discuss the philosophical underpinnings that are important to the study's design and the choice of mixed methods as a methodology.

5.3.1 Philosophical Stance

When designing a research project, the educational researcher takes into consideration a set of ideas, a framework (theory, ontology) that specifies a set of questions (epistemology), which are then examined (methodology, analysis) in specific ways. Ontology refers to the nature of reality (what is the world like). Epistemology is concerned with acceptable knowledge (how do we know what we know) (Saunders *et al.*, 2016). *Table 9* outlines a comparative summary of commonly used research philosophies, including their underlying ontologies and epistemologies. The term research philosophy refers to a system of beliefs and assumptions about the development of knowledge (Saunders *et al.*, 2016).

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Philosophical stance	Ontology (Assumptions and beliefs about the nature of reality)	Epistemology (Beliefs about the nature and scope of knowledge)	Methods
Positivism	One true, objective reality	Knowledge is valid through observable and measurable facts	Quantitative analysis Sampling Measurement Statistical analysis
Critical Realism	Stratified/layered (the empirical, the actual and the real) realities	Knowledge is historically situated and transient	Qualitative analysis Interviews Observations Focus groups Journals
Interpretivism	Multiple meanings, interpretations, and realities	Knowledge is perceived and interpreted	Qualitative analysis Interviews Observation Case study Narratives
Postmodernism	Multiple realities, socially constructed through power relations	What counts as 'knowledge' is decided by dominant ideologies	Qualitative analysis Focus groups Interviews Participant observation
Pragmatism	Reality is the practical consequences of ideas	Knowledge is acquired through the combination of action and reflection.	Mixed Qualitative Quantitative Action research

Table 8: Comparison of five popular research philosophies (based on Creswell and Plano Clark, 2018; Saunders *et al.,* 2016; Bryman, 2012; Denzin and Lincoln, 2005).

The research questions in this thesis are similar, and it could be argued they sit within a number of accepted research philosophies because they share comparable ontological and epistemological beliefs. For instance, evaluation of students' engagement with problem-based activities could be situated within pragmatism, as it is recognised that knowledge is acquired through the combination of action and reflection.

Likewise, exploring students' views about the learning activities sits with interpretivism, as the evidence itself and its analysis are subject to personal understandings and interpretations and thus could take multiple meanings.

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The interpretivist approach acknowledges that "human action is inseparable from meaning" (Scott and Usher, 2011, p. 29). In interpretivism, the reality is not objective, single, and divisible but socially constructed, multiple, holistic and contextual (Ozanne and Hudson, 1989). Direct knowledge is, thus, not possible (Waring, 2012) because there are multiple realities and multiple accounts (Twining, 2010). All data collection includes subjectivity – in the sense that what one perceives depends on one's beliefs, knowledge, and interests (Twining, 2010). In the case of this research, for instance, students' understanding of specific scientific topics is already shaped by their everyday experiences, which in turn affects their scientific thinking and reasoning. The context, meanings and ideas that students bring to the table as part of the meaning making process they engage while working together can only provide indirect indications of phenomena (Waring, 2012). Thus, any knowledge produced is subject to the interpretation of these indications. Based on the ontology of interpretivism, this research seeks to understand how students perceive and interpret the science topic of matter while working together on a socially shared task (Garrison, 1994). The aim is to provide rich descriptions of students' understanding of matter by interpreting the meaning that participants confer upon their own and others' actions. In doing so, it will conduct a qualitative analysis of students' resultant digital stories and interaction transcriptions. It is important to acknowledge that any interpretation of such situations can not be entirely objective because of social reality's shared and constructed nature (Scott and Usher, 2011).

Unlike interpretivism, the philosophy of critical realism views reality as external and independent, yet not directly accessible through one's observation and knowledge of it (Saunders *et al.,* 2016). The current research does not share such a perspective, as it places great emphasis on the meanings that individuals attribute to their observation and experience. It does not share the positivistic perspective either. The philosophy of positivism entails working with an observable social reality to produce law-like generalisations like those produced by scientists. (Gill and Johnson 2010). This research does not seek to discover observable and measurable facts or look for causal relationships to produce credible and meaningful data (Crotty 1998). The purpose of the research is not to explain and predict participants' behaviour based on statistical measures but to look into and understand their behaviour based on their interpretations.

On a different viewpoint stands postmodernism, highlighting power relationships to question and challenge established ways of thinking and give voice to the suppressed and marginalised views (Saunders *et al.*, 2016). The research in this thesis does not sit within postmodernism either, as it does not seek to expose and question the power relationships by deconstructing any form of data, such as texts, images, conversations, voices and numbers (Saunders *et al.*, 2016).

Finally, it can be argued that this research does not fit in the philosophy of pragmatism, which considers theories, concepts, ideas, hypotheses and research findings not in abstract terms, but in accordance with their practical applications in specific contexts (Saunders *et al.,* 2016). In the philosophy of pragmatism, reality is seen as the practical effects of ideas, and knowledge is valued for enabling actions to be carried out successfully (Saunders *et al.,* 2016). While this research can share pragmatists' interest in practical outcomes than abstract distinctions, it values more the interpretations individuals make of their reality and the meanings they create based on that.

To conclude this section, the research framework chosen for this research is based on the philosophy of interpretivism, accepting that there are multiple meanings and realities subject to interpretation (Denzin and Lincoln, 2018). A qualitative research design was employed to explore science students' meaning-making through problem-based story activities. It was considered the most appropriate, employing qualitative data collection methods such as digital stories, interviews, and classroom observations to capture the 'thick description' (Geertz, 1973) of the participants' lived experiences. With this in mind, the following section provides the description and justification for choosing qualitative research.

5.4 Methodology: Qualitative Research

The research questions are of prime importance when choosing appropriate research methods (Creswell and Plano Clark, 2018) coupled with the researcher's own beliefs about the nature of knowledge and what it is that can be studied. As an educational researcher with teaching and learning experience, it was important to identify the kinds of approaches that would support answering the research questions through the most appropriate methods.

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Learners' experiences tend to be rich, unique, and varied, such as young students' experience with scientific events and understanding of scientific concepts. Hence, research into this type of understanding needs to involve methods that best capture the essence of the lived experience.

Qualitative research methods are based on the notion that "reality is constructed by individuals interacting with their social worlds" (Merriam, 1998, p.6). Qualitative research is considered interpretive in this thesis, and it takes place in the participants' natural settings (Denzin and Lincoln, 2008). Hence, it can be argued that the researcher's role in qualitative research is to capture the meanings that people have constructed through their experiences in the world and understand them. One of the most fundamental characteristics of qualitative research is understanding the meaning that people ascribe to situations, hence understanding people. This research uses qualitative methods to uncover how students can use science meaning-making through specific problem-based digital stories.

Taking the interpretive nature of qualitative research into account and aiming at an in-depth understanding of the question under study (Hoepfl, 1997), this research aims to investigate students' meaning making process based on their interpretations and understanding of certain scientific concepts. In qualitative research, "the researcher becomes the instrument for collecting data" (Arriaza et al., 2015, p. 85), suggesting that details of the data collection process must be provided, along with information about who carries out the data collection and who else is present, and the nature of the relationships between them (Tong et al., 2007). Also, the researcher's characteristics that may influence the research, including personal attributes, qualifications, experiences, relationship with participants, assumptions, and/or presuppositions (O'Brien et al., 2014), are discussed in detail in section 8.4. Chapter 8.
Thus, the context within which the research takes place matters (Spencer et al., 2003), so the setting will be described in detail. Also, how the data collection process evolved as the research progressed (O'Brien al., 2014) will be provided. This research, for example, concerns itself with the identification workshops carried out in an English and Greek school context, framing the tricky topic for these contexts. Doing so helped contextualise and yet generalise the identified topic across the two educational contexts (see section 4.2.1).

Another important characteristic of qualitative research is that researchers tend to collect data in the field where the participants experience the issue or the problem under study (Vrasidas, 2014). Students' interaction during a science class is the focus of this research, and thus, data collection is conducted in the natural setting of a school classroom during school hours. The design of the learning activity is done to disrupt as little as possible the learning habituate of the participating classes and school. Thus, using qualitative research methods, this research aims to uncover *why* certain learning activities may work better than others and facilitate *how* learners do it (Veletsianos *et al.,* 2015). That can provide teachers with practical guidance on using such learning tools.

On the other hand, quantitative research can yield more measurable information about *what* learners do during the learning process and *what* learning gains they achieve. In doing so, a quantitative researcher may enter the field with a coherent theory and structured hypotheses of what they expect to gain from the fieldwork. This research draws on existing pedagogical frameworks, such as problem-based learning to design the two activities, and Mercer *et al*.'s (1999) typology of talk in science learning to inform the data analysis. Also, the theoretical framework of tricky topics helped to identify matter as a tricky topic and define its five SBs. A thorough description of the process of analysis follows in section 5.8.

To conclude, the purpose of this research is to capture the meanings that participants constructed through their experiences and understand them. As such, qualitative research is considered a valuable and the most appropriate methodological kit for answering the questions of this research. Embracing the assumption that quantitative methods cannot answer certain questions and qualitative others (Walker, 1985), the choice of qualitative methods is based on the nature of the research. It depends on the researcher to understand the specific problem in science learning and how to best address it.

5.4.1 Methods and Instruments

Methods are described as procedures and techniques for collecting and analysing data (Twining, 2010; Strauss and Corbin, 1998). Different methods can be mixed and matched, and so can quantitative (i.e. numerical) and qualitative (i.e. non-numerical) data, if they are done

in a way that is consistent with the proposed methodology and design (Twining *et al.*, 2017). This research uses qualitative research to focus not on the quantity but the quality and the richness of information collected (Decrop, 2004).

The upcoming sub-sections describe the data collection methods considered the most appropriate and congruent with the purpose and research questions of this research. *Table 10* outlines how the research questions link to the data collection methods.

Research Questions	Data collected
1) Whether, and, if so, how do the SEeDS and Narration activities support learners in each of the two contexts to access, reflect upon on, and apply prior science learning?	9 resultant digital stories X SEeDS activity (Greek participants: 5 X Grade 5 & 4 X Grade 6) 9 resultant digital stories X Narration activity (Greek participants: 5 X Grade 5 & 4 X Grade 6) 3 resultant digital stories X SEeDS activity (English participants) 3 resultant digital stories X Narration activity (English participants)
2) Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?	9 transcripts of interactions X SEeDS activity (Greek participants) 9 transcripts of interactions X Narration activity (Greek participants) 3 transcripts of interactions X SEeDS activity (English participants) 3 transcripts of interactions X Narration activity (English participants)
3) Whether, and, if so, how do the SEeDS and Narration activities engage and challenge learners in the two contexts?	6 group interviews X SEeDS activity (Greek participants: 3 X Grade 5 & 3 X Grade 6) 6 group interviews X Narration activity (Greek participants: 3 X Grade 5 & 3 X Grade 6) 3 group interviews X SEeDS activity (English participants) 3 group interviews X Narration activity (English participants)

Table 9: A summary of the data collection methods linked to each research question

Group interviews often are used synonymously with focus groups to mean an organised discussion with a selected group of individuals to gain collective views about a research topic (Gibbs, 2011). Their main difference is that focus groups are interactive, dependent on the interaction within the group who discuss a topic supplied by the researcher (Gibbs, 2011), yielding a collective rather than an individual view. Hence, participants interact more with each other rather than the interviewer, so the emerging views of the participants instead of the researcher tend to predominate (Cohen *et al.*, 2007). It is from the interaction of the group that the data emerge. Unlike focus groups, in a group interview, the interviewer directs the inquiry and the interaction among participants. That is done in a very structured or unstructured fashion, depending on the researcher's purpose (Denzin and Lincoln, 2005). In the case of this research, the group interviewing took the form of a loosely structured interview and concerned a naturally occurring social group (Delamont, 2012), that of primary students, in a field setting such as a school classroom (Bamberg, 2004). Group interviews can also be brainstorming interviews, without any or little structure/direction from the interviewer, or they can be very structured, with the interviewer being directive (Denzin and Lincoln, 2005). In this research, the researcher/interviewer held a directive role, seeking to stimulate the experiences shared by homogenous (age and attainment level) groups of students that had worked together in a problem-based story activity. Having a homogeneous group of people in a group interview is ideal for exploring co-constructed reality and shared experiences, as it is easier for them to talk to one another. For instance, in the case of this research, the young participants felt more comfortable sharing their opinions among peers than they would do in an individual interview.

Group interviews are a valuable technique to gather information from children, as it encourages interaction between the group rather than simply a response to an adult's question (Cohen *et al.*, 2007). In this research, they were considered ideal for collecting students' collective views on the nature (learning process) of the digital storytelling activities and their feelings towards them (*Appendix 10*). One of the advantages of group interviews is that they use as a unit of analysis the view of the whole group and not the individual member (Delamont, 2012; Gibbs, 2011; Cohen *et al.*, 2007; Denzin and Lincoln, 2005). Choosing group

interviewing as a data collection technique in this research is based on the need for a collective group response, despite any individual differences or a range of responses within the group. That is to "ensure that no individual is either unnecessarily marginalised or subject to blame or being ostracised for holding a different view" (Cohen *et al*., 2007, p. 374).

Group interviews might be a complementary data generation method in the same study (Delamont, 2012). In the case of this research, group interviews were used after the digital storytelling activities as complementary data to students' resultant digital stories and recorded interactions. However, group interviews could "produce group think" (Cohen *et al.,* 2007, p. 373), discouraging individuals who held a different view or were not very articulate or confident to speak out in front of the other group members. The researcher ensured that all participants had the opportunity to talk. She encouraged shier or more hesitant students to say their opinion by asking supplementary questions [or repeating the question to each one of them personally] so that all students expressed their feelings or thoughts about the proposed activities (see extract in *Appendix 12*).

The structure of the group interviews is very similar to that of focus groups. Therefore, many guidelines for conducting focus groups also apply to group interviews. Regarding the group size, group interviews must include no less than four up to no more than twelve participants at a maximum, although there are no definite guidelines in terms of the size of the group (Delamont, 2012). However, "too few and it can put pressure on individuals, too large and the group fragments and loses focus" (Cohen *et al*., 2007, p. 376). Each group interview included three to four students in this research, based on the teams they formed during the storytelling activities. Moreover, the duration of an interview may not last longer than, at most, fifteen minutes (Cohen *et al.,* 2007). The group interviews in this research lasted between ten and fifteen minutes maximum, depending on the group size – three or four respondents respectively. Finally, considering that they were children, the language used was simple, to the point and without ambiguity (i.e. avoiding metaphors) (Cohen *et al.,* 2007). Findings from the group interviews were used to validate the suitability of the SEeDS over the Narration activity and thus provide evidence supporting such teaching practices.

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5.4.1.2 Observation

Observations are another complementary method of data collection, with the purpose to obtain a holistic picture of participants cooperation during the activities. One of the distinctive features of observations is that they allow the researcher to look directly at what is happening rather than relying on second-hand accounts (Cohen *et al.*, 2007). Observation-based research is a common technique used in the classroom, providing the researcher with their "own, presumably unbiased" views (Cohen *et al.*, 2007, p. 72) of the subjects under study. Observing students interact between them through both the SEeDS and the Narration activities provides additional information about the value of each activity and students' difficulties with the learning material.

For the course of observation, the researcher must become familiar with and accepted by participants to avoid disruption during the research (Angrosino, 2012). In this line, she visited all four participating classes before conducting the research to build rapport with students. She kept observations as field notes in quick jottings of keywords and descriptive form of detailed accounts of the events and learning strategies used (LeCrompte and Preissle, 1993). The descriptive form of notes is used when identifying a particular event.

5.5 Data Collection Procedure

This section discusses the data collection process as part of the research strategy. A detailed step by step account of the data collection procedure, along with the decisions made, is presented. It is vital to address some of the practical and methodological issues that emerged during the fieldwork. Next follows a presentation of the sampling strategy used to select schools and students and a discussion of the data collection methods.

5.5.1 Sampling Strategy

This section initially describes the strategic plan for recruiting the participants and the issues of negotiation and accessibility to the schools. Any references to the names of the participants and the schools make use of pseudonyms.

5.5.1.1. Selection of participants

Qualitative researchers tend to select their participants based on a non-probability sample since they target a particular group. They are in the knowledge that this group does not represent the wider population (Cohen *et al.,* 2007) as it merely represents itself. In the case of small-scale research, such as this one, the selected participants are young students aged 10-12 years from both Greece and England. Regarding generalisability and representativeness, it does not aim to produce a statistically representative sample but to gain a deep understanding and provide detailed student accounts. Another consideration that needs to be addressed is the limited resources (human resource, money, time) when choosing a particular sampling strategy over another (Flick, 2002). For instance, seeking to represent the field by concentrating on single examples or specific sectors (Flick, 2002), such as in this research.

It is also essential to consider that this research is cross-national and requires travelling in two different cultural contexts. Therefore, the limited resources (money and time) influenced the sampling procedure and the final number of the selected groups. Following a *purposive, convenient sampling* technique, the criteria for selecting the schools and students (Cohen *et al.*, 2007) were: choosing settings, groups, and/or individuals that are conveniently available and willing to participate in the research (Tashakkori and Teddie, 2010).

Table 11 shows the grouping of the Greek and English participants into the SEeDS and Narration activities.

Name of the group	The SEeDS activity	The Narration activity
Name of activity	Engagement with the SEeDS activity	Engagement with the Narration activity
Type of activity	Not predefined order of story scenes	Predefined order of story scenes
Number of final participants	31 Greek students (10 – 12 years old) formed into 9 teams, 5 X Grade 5/ 4 X Grade 6	30 Greek students (10 – 12 years old) formed into 9 teams, 5 X Grade 5/ 4 X Grade 6
	11 English students (11-12 years old) formed into 3 teams	11 English students (11-12 years old) formed into 3 teams
Type of cooperation	Teams of 3-4 students	Teams of 3-4 students

Table 10: Allocation of participants in each activity

Greek participants

Regarding the Greek participants, students at the age of 10-12 years are in the upper two grades of primary school. Those at 10-11 years old go to Grade 5, and 11-12 years old go to Grade 6 (see section 3.8.1). Sixty-four primary students from four different classes consented to participate in this research. In the two Grade 5 classes, there were 33 students – 18 in E'1 (name of the classroom) and 15 in E'2. The two Grade 6 classes counted 31 students, 15 in St'1 and 16 in St'2. However, on the days of data collection, three students were absent – two from Grade 5 E'1 class and one from Grade 6 St'2 – due to health issues (cold, flu), which means that the final number of the participating Greek students was 61 in total.

Students from the four classes were divided into two digital storytelling activities. The selection was based on the purposeful sampling technique (Patton, 2015; 2002; 1990). "A purposeful sampling strategy does not automatically eliminate any possibility for unsystematic selection of cases. For many audiences, purposeful sampling, even of small samples, will substantially increase the credibility of the results" (Patton, 2015, p. 432). In this review of sixteen types of sampling techniques used in qualitative inquiry, Patton (2015; 2002) stressed that the purposeful sample is not the same as a representative sample. "The purpose of a small sample is credibility, not representativeness. A small, purposeful sample

aims to reduce suspicion about why certain cases were selected for study, but such a sample still does not permit statistical generalisation" (Patton, 2002, p. 241). Thus, for the purposeful selection of the classes, the following were considered: first, the Greek students were mixed-attainers (described next) and so a homogenous group; second, the classes consisted of a small number of participants (described previously). The purposeful selection of the four classes into the two activities would help to avoid controversy about potential selection bias (Patton, 2015; 2002; 1990). Thus, for the SEeDS activity, the one Grade 5 and Grade 6 classes were selected in the order of numbers – E'1 and St'2. For the Narration activity, the selection was based on the reverse order of numbers (or the remaining classes), so E'2 (Grade 5) and St'1 (Grade 6). 31 children participated in the SEeDS activity and 30 in the Narration activity. Participants were then again allocated in small teams of three-fours, based on the criterion of friendship, so that they would feel more comfortable working together. Teams were given names (A, B, C etc.) based on their location in the classroom (sitting at the front, in the middle and at the back). All of them were fluent Greek speakers. Their teachers described these students as mixed-attainers (middle- and low-attainers), a statement that was also supported by the students' annual test results in various school subjects[7].

Fifth grade students were taught the topic of matter (Chapter 1: Materials and Chapter 5: Heat – see section 3.8.4 for the specifics) for the first time two months before the main study. Sixth-grade students were taught those two chapters the year before. None of the Grade 6 students was taught Chapter 2: Heat – Temperature (see section 3.8.4) before this data collection was conducted. Thus, Grade 5 and Grade 6 students were taught the same two chapters with a one-year difference between them.

English participants

Concerning the English participants, it is worth mentioning that students are in the first year of secondary schooling at the age of 11-12 years old, that is, Year 7. Twenty-four students consented to participate in the research, but one student was absent, and another withdrew on the data collection day. That is, a total of 22 English students took part in the study.

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[7] Due to school regulations regarding students' and teachers' data, no copies of students' records were allowed.

According to their school records, the specific science class was considered as mixed-attainment students (middle- and low-attainers), coming from different SET ability levels. One group of three students was diagnosed with special educational needs (SEN) and visual disabilities, and a teaching assistant accompanied them on the study day. Year 7 students were taught the topic of matter for the first time about a month before the research was conducted. All participants were fluent English speakers. Half participants worked on the SEeDS activity, and the rest on the Narration activity. Their selection was formed using the *purposive sampling* strategy (Cohen *et al.*, 2007), with the criterion of acquaintance. English students came from different SETs, and many of them were from different classrooms; thus, they were grouped according to their acquaintance with each other. Doing so would benefit their cooperation when working together in teams. The English teacher, Bill, helped to select the two groups. Then participants were free to allocate themselves in teams of three to four, based on the criterion of friendship.

5.5.1.2 Selection of schools

Establishing connections with one Greek school occurred after existing communication with an English primary school. The secondary school that participated in the English pilot scoping workshop failed due to curriculum pressures and urging matters. The choice of the Greek primary school occurred after establishing communications with a teacher who worked there as a Grade 5 teacher. The teacher (under the pseudonym Annie) then suggested three more teachers within her school – the other Grade 5 teacher and the two Grade 6 teachers – who were willing also to take part. The specific primary school, located in Athens, Greece, had a comprehensive intake and drew students from a wide range of attainment levels and social circumstances. Its students came from an area where social and economic conditions were relatively favourable. Students' overall attainment was above average. The ethnic classification of students was primarily Greek, with other mixed-race ethnicities such as Arabs and Syrians. The proportion of those students identified as having special educational needs was below average and the proportion of those with statements of special educational needs. All participants, native or not, were fluent Greek speakers.

It is important to note that the Greek teachers often used technology-enhanced/based activities in science (and other subjects) in the classroom, making them an ecologically valid strategy for exploring students' work through digital storytelling activities. It is common practice in Greek primary schools, nowadays, to use technology in the classroom, with reference made in the official science curriculum for primary education (Information and Communication Technologies) (ΥΠ.ΕΘ, 2018; Π.Ι, 2011). According to it, using ICT can facilitate the science objectives so that students can be active participants in the learning process and understand basic principles in science (for more information, see section 3.7.1). Although there is no reference to mobile learning or mobile technology/devices (neither for science nor any other school subject), any ICT equipment available at school can be used during the teaching and learning process only under the teacher's supervision (Nikolopoulou and Kousloglou, 2019). Apart from the electronic devices (computers, laptops, tablets, interactive boards and many more) the school owns, teachers can use their electronic equipment during the lesson. They can do so in the context of the educational process, always following the safety rules (protection of personal data of pupils and teachers) (Nikolopoulou and Kousloglou, 2019). In the case of this research, the teachers of the participating students confirmed that they frequently used electronic devices in their teaching, but not iPads.

As soon as the Greek school confirmed its participation in this research project, an English school expressed interest. More specifically, a science teacher from an English secondary school, who was previously involved in the JuxtaLearn Project, was interested in participating in new projects promoting STEM learning. That helped to establish fruitful communication. The specific secondary school, located in Brackley, Northamptonshire, was a public school accommodating secondary schooling from Year 7 to Year 11 and had a population of 1,500 students, with averages 59% A*–C at GCSE. Students were grouped according to the needs of the subject and to support the progress of all students. In Years 7 and 8, students were grouped via literacy ability for a literacy block of subjects: English, geography, history, Music, RE, drama, and PCSHE, and by their numeracy ability for a numeracy block: mathematics, science, art, computer science and languages. The development of these groupings responded to the attainment range of pupils, and a common structure involved a top set and several more mixed-ability classes. At Key Stage 3, students followed a common curriculum, and at Key Stage 4, there was a personalised curriculum for all. The school was part of the

Pupil Premium (PP) scheme, which provided additional funding to support students in Years 7 to 11, who belonged to low-income families, were in the care of local authority or had a parent in the army.

Like the Greek primary school, the English secondary school favoured digital tools to support learning. According to the school's science curriculum for Year 7, there was a recommendation for students to consolidate their learning at home to use BBC Bitesize (http://www.bbc.co.uk/bitesize/ks3/science/) as the best starting place. Moreover, according to the national curriculum for KS3 and KS4 in England, in secondary schools, teachers should use their judgement about when ICT tools should be used (DfE, 2014). Students' familiarity with the BBC's bitesize and teachers' freedom to use ICT tools in their lessons make digital storytelling an ecologically valid technique for exploring students' science understanding.

5.5.1.3 Negotiating and Obtaining Access

This research took place between February 2017 and April 2017 in Greece and in March 2018 in the UK. Greece was selected as the first context to conduct data collection. Ethical Approval had to be sought from the Open University UK (HREC) and the Greek Ministry of Education and Religious Affairs (DSPOPE).

Having obtained both ethical approvals in October and December 2016, the chosen Greek primary school was contacted to ensure that this research would not affect its smooth functioning. The Greek Headteacher was informed via phone about the research, its objectives, the sampling, and the planned timescale – the Greek teacher confirmed the headteacher's consent. During the first visit to the primary school, the Participant Information Sheet and Parent/Caregiver Consent Form (*Appendix 6*) were distributed. A second visit sought to establish familiarity with the participating students and teachers.

Like with the Greek school, communication was established in advance with the key person and the headteacher at the English secondary school. The Participant Information Sheet and Parent/Caregiver Consent Form *(Appendix 7) and* the Participant Information Sheet and

Student Consent *(Appendix 8)* were emailed in advance to secure permission from the headteacher. The English headteacher was also informed via phone about the research, its objectives, the sampling and the planned timescale, and the science teacher confirmed the headteacher's consent.

5.5.2 Piloting

The third stage of the Tricky Topic Process (see section 4.2.1) brought to the surface the use of storytelling as a common teaching practice among the English and Greek schoolteachers. Following that and acknowledging the contemporary mobile-technology affordances, an alternative version of digital storytelling, named SEeDS, was created. Two pilot studies were conducted to test, first and foremost, the suitability of both the instruments (iPads and digital story app) and the creative process (not predefined order of story scenes). There was also a need to test the feasibility of the cooperative learning environment and time allocation – so that the SEeDS activity would not exceed the regular school timeframes (two hours were allocated for a science class per week). Finally, piloting would help to evaluate the usefulness of group interviews in enriching data that the primary sources would yield for analysis within the timeframe of approximately one hour as proposed.

5.5.2.1 The first pilot study in an English school

A group of 12-year-old students from a secondary school in Milton Keynes who had previously participated in the JuxtaLearn project was chosen to pilot the data collection methods. To ensure that the learning process in which students would engage was comparable, they were provided with a digital story activity in maths (division of fractions), which was selected for three reasons. Firstly, the learning process of the activity (story-sequencing) would apply in the final activity of the main study. Secondly, maths, like science, included a variety of topics considered tricky. Finally, the activity was created on content that students had been recently taught. That meant that the pilot testers would focus first on the learning process and then on the content. By doing so, they would provide valuable information about any issues of practicality and/or conceptual complexity that might occur with the learning process.

The first piloting took place at the secondary school library, which turned into a learning lab for the day. Participants were five Year 8 girls of mixed attainment. These girls were in the same class but in different SET ability levels for Maths. They were all native English speakers. Participants were already allocated in groups from the JuxtaLearn project (see section 3.6, Chapter 3) based on the criterion of friendship. Students worked together on a large iPad (tabletop) to edit a digital story that was not predefined (*Figure 8*). The story was broken down into twelve scenes, presented to students in an order that was not predefined, without any visual or audio narration. The task was to invent the plot by sequencing the story events according to their understanding and then narrate it in their voices (see more details in (see more details in *Appendix 14*). The pilot study was video recorded.

Figure 8: A group of five girls working on large iPad (tabletop) with built-in keyboard

The pilot study with the English school confirmed that both the instruments (iPads and story app) and the learning process (story-sequencing) of the SEeDS activity were suitable for mixed attainment students at the age of 12 years old. The tabletop enabled students to easily review and restructure their story by dragging and dropping scenes in and out of the storyline. However, due to its big size, it was difficult to be carried elsewhere, and so it was replaced by regular iPads in the main study.

The girls (in the follow-up group interview) expressed that they enjoyed the predefined structure of SEeDS because they had their "*own way of doing it and not being told you have to do this and you have to do that, and you have to work this out right now.. you can be freer*

and more independent, and it is more creative and easier" [S2, Y8]. An issue that occurred, however, was that some of the participants did not feel comfortable with the voice recording – *"I didn't' really like my voice in there … I didn't want others to hear me … I didn't like how it sounded … I wouldn't do the recording again … maybe I could write them"* [S4, Y8]. Bearing that in mind, an alternative type of story commentary (hand-written commentaries) would use in the main study.

Evidence from the video recording showed that teamwork and cooperation went well, although some girls tended to prevail over the discussion by talking more than others. A proposed change was to reduce the team size from five to three or four students to interact more with each other. Also, the class teacher or the researcher would be present in the main study to counterbalance the discussion among the team members. Moreover, the pilot study showed that participants could work autonomously through the SEeDS activity, as they hardly asked for any help from their teacher or the researcher. It also highlighted the importance of students being at similar attainment levels so that there was equal participation and continuous argumentation/reasoning.

The first piloting offered some principles for the main research. For example, completing the study within the regular school hours seemed feasible, as the girls spent about 75 minutes completing the task. In addition to that, the duration of the follow-up group interview was approximately 15 minutes. Thus, the whole time spent was less than two hours (1h and 30 min), suggesting that it could be implemented within regular school hours. Furthermore, it confirmed the suitability of using group interviewing with young students. It appeared ideal (less intimidating than a one-to-one interview, with constant guidance/direction from the researcher) to gather students' (as a homogenous group) collective views about their learning experience with SEeDS.

Finally, the use of video recordings and video-analysis of naturally occurring phenomena could provide deep analyses of participants' actions and interactions – like talk, bodily behaviour, tool use. Using the method of video recording to gather data is largely context-shaped and context-dependent, which are not in the prime interests of this research. Video analysis is better suited but not limited to qualitative-based research, as it allows for multiple

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takes on the data and various interpretations of the same data. However, the focus of this research was on students' verbal interactions through the learning activity, which could be collected with the use of audio recorders. Thus, video recording was replaced by audio recording in the main study, as the latter was considered a more appropriate method for collecting and debating an analysis of students' discussions.

5.5.2.2 The second pilot study in a Greek school

The second pilot study also sought to test the suitability of the SEeDS activity (the creative process and the collaborative setting) and the feasibility of the group interviews with students and the one-to-one interviews with teachers in the Greek context. This piloting was conducted in the Greek primary school that took part in the main study. The pilot took place in the school's computer lab, and participants were twelve students aged 10 to 11 years old, selected from the school's two Grade 5 classes. Like the English participants of the first pilot study, the Greek participants were of mixed attainment. They were all native Greek speakers.

This piloting embraced the three changes from the first pilot study. The tabletop was replaced with regular iPads; the recorded script narration was replaced with commentary sheets; the teams included three or four students only instead of five (*Figure 9*). The pilot study was audio-recorded this time. The creative process was similar to the one implemented in the English school – students had to order and narrate (in written form) the not in predefined order story in the topic of fractions' division in Maths, broken down into twelve scenes. The follow-up group interviewing was conducted with one team of students. The Grade 5 teacher was also present during the piloting, observing the teams' cooperation and offering practical help where needed.

Figure 9: A group of three girls working on an iPad.

Findings from the Greek pilot study were, to a great extent, in line with those from the English one. Greek participants liked the predefined digital story and found it interesting. As one student stated – *"I liked it a lot because we were trying to find the right ones and if we made mistakes we could redo it many times until we got it right and this is what I liked the most" (S1, Grade 5).* Others found it challenging -*" This student and I got confused at the beginning but then we put it [the story scenes,] in order" (S2, Grade 5); "It troubled me because the videos we watched didn't have any commentaries to help us understand what was happening there" (S3, Grade 5).* Participants also felt at ease with making their story comments in written format.

There were also some differences between the Greek and the English students. One is that Greek students needed more time to complete the SEeDS activity – about ninety minutes – and ten extra minutes for the follow-up group interview. Thus, the total time spent on the was 1hr and 40 minutes, confirming again that it could be implemented within school hours. In terms of autonomy, three of the four teams asked for some help from the teacher about practical issues with the story application (how to reorder scenes in the storyline or delete unwanted scenes). In terms of content, three of the four teams managed to produce a comprehensible story, with a well-defined sequencing of events and corresponding commentaries. Only one team needed more guidance to carry out the process, and their final story was inconsistent, unclear, with an unfinished plot.

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Regarding group interviewing, participants felt comfortable expressing their opinions in the follow-up group interview, yielding valuable information about the SEeDS activity. The group interviewing also revealed that fifteen minutes were enough to cover the proposed questions *(Appendix 11),* and there was no need for adding extra items.

Finally, transcribing the group interview verbatim allowed for immediate reflection upon them and enabled them to address issues of re-approach (Maxwell, 2012) towards the interviewees' responses.

5.5.2.3 From the pilot studies to the main study

Reviewing findings from the two pilot studies across the English and the Greek contexts, the SEeDS activity was implemented in the main study embracing the following changes:

- The story was broken down into short scenes, without any visual or audio commentaries
- Commentary sheets *(Appendix 16)* were used instead of voice-recorders
- Teams consisted of three (to four students if necessary) instead of five
- iPads instead of Tabletops were the main instruments as they were easier to carry and use
- The whole process was audio than video-recorded
- Follow-up group interviews were conducted with some teams of students
- Teachers could be present during the process to offer practical assistance and promote interaction among team members (this was optional).

5.5.3 Main study

Findings from the two pilot studies helped to revise and redefine both the instruments and data collection methods used in this research. The upcoming sections describe how the research was carried out in two different contexts, Greece and England.

The data collection was conducted from late February to early April 2017. It took place on the school premises, in the participants' classrooms and students were aware of the purpose of the research. The final participating population was four classes (two Grades 5 and two Grades 6) with sixty-one students. The study was conducted during school hours[8] in four different days (one day in each classroom). The first two days involved gathering data from E'1 and St'2 working on the SEeDS activity. The subsequent two days included the data collection from E'2 and St'1 working on the Narration activity.

The procedure followed was the same for both the SEeDS and the Narration activities (see Instructions' Protocol in *Appendix 15*). On the study day, the teachers introduced the researcher to the students, who informed them that the research was from the university and had nothing to do with their schools and teachers. The researcher also told the students that the research's main interest was to find out how students of their age were thinking about some everyday science phenomena and discussing them among themselves in teams while working on digital storytelling activities. Then they were then instructed about using the activity on which they would work (SEeDS or Narration) and were shown how to use the iPads and the particular story application. This introductory part lasted approximately ten minutes, and then students worked on their assigned activity.

On the days of data collection, students worked on SEeDS or Narration from 10 to 11:30 a.m. (2X45'=90 minutes in total). At 11.30, they went out for a short break and returned to their classrooms at 11.45 and continued working on their activity until 12.25 p.m. (90 minutes). In this second round of 90 minutes, most students needed about another 30 minutes to finish their stories. In the remaining 60 minutes, they either continued with their regular classes with their teacher or participated in the group interviews. The purpose of the group interviews was to collect information about how students viewed the digital storytelling activity on which they worked. The group interviews were conducted with some teams of

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[8] The day in Greek primary schools starts at 8.10 a.m. and finishes at 1:15 p.m., including three intervals after every 90 minutes. Each school lesson lasts 45 minutes.

students, which were selected using the *purposeful sampling* technique (Patton, 2015; 2002; 1990) (see section 5.5.1.1. *Greek participants*). The purposeful selection of teams to be interviewed would help to avoid controversy about potential selection bias, considering that such a sample did not permit generalisations (Patton, 2015; 2002; 1990). Thus, based on their location in the classrooms, six teams from the SEeDS activity (in order from A, B, C, D, E, F) and six teams from the Narration activity (in reverse order from I, H, G, F, E, D) took part in the group interviews. Each group interview lasted approximately between ten and fifteen minutes.

The SEeDS activity presented the story scenes in an order that was not predefined. Students were free to determine the plot by making their own decisions about the ordering and sequencing of the story scenes, based on their understanding of how the story should be. Students were required to use all fifteen scenes, invent the story plot, give a title, and finally narrate it by producing hand-written commentaries.

The Narration activity presented the story scenes in the original predefined order. Students could not make any changes to the story plot. Like in the SEeDS activity, students were instructed to invent their story plot, give a title to it, and finally narrate it by producing hand-written commentaries.

Figure 10: The same cooperative environment through the SEeDS activity (left) and the Narration activity (right)

Each team used one iPad placed in the centre of the table. Participants were encouraged to use (touch on) the iPad in turns, given its limitation of single touch only. Students were given extra sheets (numbered with fifteen scenes – see *Appendix 16*) to comment on the story plot. The Grade 5 and Grade 6 teachers of the SEeDS group were present during the activities, acting as observers and offering practical guidance and help when needed.

Students' interactions through the activities and the group interviews were was audio recorded. There were 12hrs of audio data and 3hrs of group interview data for analysis. All sessions were observed, and notes were taken. Hand-written notes were then made digital.

5.5.3.2 The English study in Northamptonshire

The data collection took place in mid-March 2018 in the school's science lab. The data collection was conducted on a single day, starting at 9 a.m. and finishing at 11 p.m., with a duration of two school hours (60 minutes each).

The procedure followed was the same as in the Greek primary school. After students' allocated into teams of three to four, a brief introduction followed about the purpose of the research and instructions about the use of activity. Students then were shown how to use the iPads and the story application. That introductory part lasted approximately ten minutes, and after that, they started working on their assigned activity. The science teacher offered practical guidance to some teams which seemed disoriented and did not know how to work through the assigned activity. A teaching assistant provided constant support to a specific team of students with SEN from the Narration group. All students finished with their stories within one hour. They participated in the group interviews in the remaining hour and then continued with their regular classes with their teacher. Considering the small number of English participants and aiming to explore in-depth the students' views about two activities, the group interviews were conducted with all six teams. Each group interview lasted approximately between ten and twelve minutes.

Students' interaction during the two activities was audio recorded. There were 4hrs of audio data for analysis, which were transcribed later. The session also was observed, and notes were taken. Hand-written notes were then made digital.

5.6 Ethical Considerations

As with research projects, there are legal obligations and ethical guidelines that permeate the whole process of research, including the stages of access and acceptance (of schools and participants); the suitability of the design and methods; confidentiality; participants' anonymity and the handling of data; as well as analysis and dissemination of findings. These need to be negotiated with relative openness, honesty, accuracy, and scientific impartiality (Cohen *et al.*, 2007). In the context of this research, which involved the audio-recording of students' interactions, ethical obligations and standards applied to researchers and the participants (students and teachers) themselves. There was a need, thus, for conducting ethically and legally sound research, ensuring that those involved in the project followed best practices and adhered to any legal requirements. Working with students required a clear criminal record; thus, a DBS check (Disclosure and Barring Service, previously known as Criminal Records Bureau (CRB) was obtained at the very early stages of the research. At the same time, the ethics form for the full study *(Appendix 9)* was submitted. Its first submission was not approved, and changes had to be made before re-submitting. The final approval was obtained in November 2016.

Moreover, another ethical approval was sought from the Ministry of Education, Lifelong Learning and Religious Affairs for the study that would take place in Greece. That was received in February 2017. The ethical considerations, described next, derive from the Ethical Guidelines for Educational Research (BERA, 2011) and the Open University's ethical guidelines and the Ministry of Education, Lifelong Learning and Religious Affairs of Greece.

5.6.1 Access to and Recruitment of the participants

After obtaining ethical approval from the Open University and the Greek Ministry of Education, Lifelong Learning and Religious Affairs, the Greek and English schools' headteachers were contacted for official permission. The recruitment of the Greek teachers

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occurred during an introductory meeting that overviewed the research's purpose, the proposed methodology and their contribution to the research. Teachers were informed that participation was voluntary before giving verbal consent. Participants were asked again to consent for their participation on the study days, ensuring ongoing consent monitoring verbally. The two Greek teachers who initially agreed to participate (in the Narration activity) finally withdrew on the days of the data collection.

5.6.2 Informed consent and the right to withdraw

All participants were asked to give written informed consent *(Appendix 7) and* verbal consent at the beginning of the research. Participants were provided with information sheets and consent forms following official ethical guidelines (BERA 2011). Considering that participants were children, their parents/caregivers (BERA 2011) were required to give written permission and consent. Participants were informed about the right to withdraw at any stage of the data collection process without any reason. Participants who were not interested in taking part would follow the standard teaching approaches they usually did. Otherwise, they would go through a similar-to-the study activity using an iPad independently, and they would be neither recorded nor included in the data collected. Participants had the right to withdraw at any point during the research if they wished to no longer take part, without any explanations necessary. If they decided to withdraw, their data would be removed from the project with immediate effect and destroyed.

Sixty-four Greek and twenty-four English students were the original populations of the participating classes. All students and their parents/caregivers had to provide their written consent about participating, being audio-recorded and photographed. Consent forms were sent electronically to Annie, the Greek teacher, and Bill, the English teacher, a month before the study was conducted. Annie and Bill then distributed a hard copy of the consent form to students and informed the parents/caregivers over the phone. After being constantly reminded by Annie, most Greek students returned the consent forms within the first week and the remaining ones in the last week of that month. English students had returned the forms within the first two weeks. Both Annie and Bill informed the researcher that the forms

had been returned electronically. On the first day of the study, all forms were handed to the researcher in person.

Regarding the Greek participants, the parents/caregivers of four Grade 6 students (from the SEeDS activity) did not consent to their children's participation in the study. In that case, those four students were put together in the same team and would continue with their regular class. The parents of the remaining sixty students consented to the latter's participation. However, on the day of the data collection, the four students wanted to participate, and Annie got their parents' verbal consent over the phone. The consent was given for participation in only one activity, allowing the students' digital stories to be used in the final report. No audio-recording or photographs were allowed, and neither was students' participation in the follow-up group interviews.

Of the sixty-four participants, three students (two from Grade 5 and one from Grade 6) from the SEeDS activity were absent from school on the days the study was conducted. Thus, the final sample consisted of sixty-one Greek participants (see previous sections 5.5.1.)

Regarding the English participants, the parents of all twenty-four students in Year 7 consented to their children's full participation in the study. Yet, on the day that the study was conducted, one student was absent, and another one felt ill during the first hour and withdrew. His data was not included in the final report. That meant a total of twenty-two students participated in the main study.

5.6.3 Confidentiality and anonymity

Participants were fully aware of the intended purpose of the research and that quotes from the raw data and photographs would be used for reporting and disseminating findings to a broader audience. Also, they were informed that data quotes would be used anonymously had they consented to the particular use of the data. In terms of confidentiality, participants were fully informed about the research process and its timetable through the participation sheets and stated their willingness to get involved by giving written consent. Individuals were ensured that no undue influence would be exerted to persuade them to participate in the

research. They were also made aware that taking part was entirely voluntary and that refusal would attract no sanction.

Additionally, had they agreed to participate in the research, they were free to withdraw at any time without giving any explanations. The two Greek teachers from the Narration activity withdrew from the study last minute, as they were occupied with other school chores. So did one English student who felt ill during the activity and left. Finally, confidentiality was ensured by using coding and pseudonyms to identify the participants, and the names and locations of the schools were not disclosed. Additionally, no information or details that could reveal the identity of the schools and their participants would be included in the final report for the university or any future publications.

5.6.4 Data storage

Data was recorded on digital voice recorders and transferred to a password-protected memory stick for storage. Collected data could be shared with the participating schoolteachers, headteachers and the supervisory team. The data shared would be anonymised unless it regarded the participants themselves (i.e. if a schoolteacher asked specifically for the data regarding their school's participation). None of the participants (students or teachers) asked for their data. For this research, findings would be disseminated in this PhD thesis and publications.

5.7 Preparing data for coding and analysis

 Like other qualitative methods, gathering and analysing data are conducted concurrently, thus adding to the depth and quality of data analysis (Vaismoradi, Turunen and Bondas, 2013). However, collecting all the data before examining it is common to determine what it reveals (Vaismoradi, Turunen and Bondas, 2013). For example, students' audio-recorded interactions, follow-up group interviews, and observation notes were analysed to collect all relevant data.

Breaking down students' interactions through the two digital storytelling activities highlighted the identification of the themes and specified the thematic links' relevance across

categories. Then, audio recordings from the SEeDS and Narration activities were transcribed using NVivo11 (QSR) computer software, emphasising the interactions that took place as students worked collaboratively. Then all transcripts were reread and coded using the line-by-line technique to identify important themes (Coffey and Atkinson, 1996). The process of line-by-line reading helps the researcher read the data, disaggregate it into conceptual units and identify significant themes (Strauss and Corbin, 1998). Any concepts that became apparent in the data were associated with the research questions.

The data collected sought to provide answers to the driving questions of this research. For the first research question (R.Q.1), *"Whether, and, if so, how do the SEeDS and Narration activities support learners in each of the two contexts to access, reflect upon on, and apply prior science learning?"* the following data sources were analysed: (a) the resultant digital stories of the Greek and English teams from the SEeDS and Narration activities; b) the recorded interactions of the Greek and English students while working collaboratively through the two activities. The basic data sources for this research question were the story scripts (written commentaries) that students produced in paper worksheets (see *Appendix 16*) and the audio recordings which captured students' interaction. The use of audio recordings provided detailed and accurate transcripts as it allowed examining the recordings unlimited times. That proved to be easier for retrieving information and analysing the findings of this research.

For the second research question (R.Q.2) *"Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?"* the main data sources collected and analysed were the recorded interactions of the Greek and English students while working together through the two activities, SEeDS and Narration.

Finally, for the third research question (R.Q.3) *"Whether, and, if so, how do the SEeDS and Narration activities engage and challenge learners in the two contexts?",* evidence was drawn from a) the recorded interactions of students' collaboration across the two contexts; b) the follow-up group interviews with teams of SEeDS and Narration students across the two contexts.

It is important to note that a great part of the research was conducted in Greek. Thus, data was collected, transcribed, and analysed in Greek. This decision was based on several practical issues and benefits for the quality of the findings. On the one hand, a large volume of data was yielded from students' team interactions and group interviews. On the other hand, there was a time limitation in completing this piece of research. The purpose was to have a clear picture of the data to code the transcripts without losing any important information that emerged from the language itself and the implicit meanings of the participants' answers. Since in qualitative enquiry, the researcher is the primary "measurement device" and has the whole responsibility for conducting a high-quality study (Miles and Huberman, 1994, p.7), researcher's bias can be one of the most serious threats to validity (Johnson and Christensen, 2004).For this reason, the decision to retain the transcripts in Greek would help to minimise the researcher's mediation and the danger of bias. Thus, only the extracts discussed and presented in this thesis were translated into English. That also contributed to the accountability of the research. That, however, carried some limitations, which are discussed later in section 8.4 (Chapter 8).

5.8 Data Analysis

The research questions of this research were explored through the ontology of interpretivism, embracing a qualitative research design because of how it "attempts to make sense of or interpret in terms of the meanings people bring to them" (Denzin and Lincoln, 2008, p.3). This research was based on data collected from audio recordings, resultant digital stories and group interviews. Classroom observations were used as supplementary data.

Qualitative data analysis in this research aligns with a mixture of inductive and deductive processes, as justified by Patton (2002). Using both analysis strategies helped to establish rigour in the process of analysis (Fereday and Muir-Cochrane, 2006). In particular, in the beginning, the analysis began with an inductive, data-driven analysis of teachers' workshops that helped to scope the whole study by identifying the tricky topic of matter across the educational contexts of Greece and England. Then it continued with a theory-driven deductive approach that explored the initial theoretical concepts and ideas based on the

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analysis framework. Using a deductive approach allowed to embark on the theoretical framework of Mercer *et al.* (1999) about the typology of talk in science and test the applicability of their key features on the nature of the proposed learning activities. After that, another round of inductive analysis identified the emergent themes and issues that the participants' interactions revealed during their in-between collaboration (data-driven approach).

Combining data-driven and theory-driven *(a priori)* processes is a considerably common practice in qualitative research (Fereday and Muir-Cochrane, 2006; Miles and Huberman, 1994), reflecting a flexible approach to data analysis (Braun and Clarke, 2006; Patton 2002). A more detailed account of the systematic data analysis process used in this thesis is provided in the following sections.

The data analysis involved an overview and detailed analyses, drawing evidence from students' audio-recorded transcripts, resultant digital stories, and follow-up group interviews. To understand the appropriateness and contextualise data analysis, *Table 12* summarises what data was analysed and how it related to each research question.

Research Questions	Data sources analysed	Data collected	Data analysis methods
RQ1: Whether, and, if so, how do the SEeDS and Narration activities support learners in each of the two contexts to access, reflect upon on, and apply prior science learning?	The resultant digital story scripts collaboratively developed by each team	9 resultant digital stories X SEeDS activity (Greek students: 5 X Grade 5/ 4 X Grade 6) 9 resultant digital stories X Narration activity (Greek students: 5 X Grade 5/ 4 X Grade 6) 3 resultant digital stories X SEeDS activity (English students) 3 resultant digital stories X Narration activity (English students)	Hybrid process of thematic analysis (Clarke and Braun, 2014; Braun and Clarke, 2006; Fereday and Muir-Cohrane, 2006; Boyatzis, 1998)
	Transcripts of interactions from the audio recordings of students' collaboration	9 transcripts of interactions X SEeDS activity (Greek students: 5 X Grade 5/ 4 X Grade 6) 9 transcripts of interactions X Narration activity (Greek students: 5 X Grade 5/ 4 X Grade 6)	
RQ2: Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?	Transcripts of interactions from the audio recordings of students' collaboration	3 transcripts of interactions X SEeDS activity (English students) 3 transcripts of interactions X Narration activity (English students)	

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RQ3: Whether, and, if so, how do the SEeDS and Narration activities engage and challenge learners in the two contexts?	Transcripts from the follow-up group interviews with teams of students Supplemented by - Transcripts of interactions from the audio recordings of students' collaboration - Observational notes	6 group interviews X SEeDS activity (Greek students: 3 X Grade 5/ 3 X Grade 6) 6 group interviews X Narration activity (Greek students: 3 X Grade 5/ 3 X Grade 6) 3 group interviews X SEeDS activity (English students) 3 group interviews X Narration activity (English students)	Inductive process of thematic analysis (Clarke and Braun, 2014; Braun and Clarke)

Table 11: Summary of the data analysis methods for each research question

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The first step of the analysis looked at the content of the two activities in a hybrid manner, drawing on evidence from students' resultant digital stories and recorded team interactions. The aim was to identify if and how each activity might have supported students' access to, reflection and application of prior learning. The next step involved the process of inductive analysis, placing emphasis on students' team interactions and follow-up group interviews. It sought to explore if and how each activity engaged and challenged learners in the learning process. The following sections present the analysis process in more detail.

5.8.1 Thematic analysis – combining inductive and deductive analysis

Thematic analysis (TA) is a method "for systematically identifying, organising, and offering insight into patterns of meaning (themes) across a data set" (Braun and Clarke, 2012, p.57). Braun and Clark (2006) argue that in thematic analysis, there are two primary ways to identify themes or patterns within data: an inductive or 'bottom up' way (Frith and Gleeson, 2004), or a theoretical or deductive or 'top down' way (Boyatzis, 1998; Hayes, 1997). This research uses both ways of thematic analysis. The application of TA helps to produce data-driven or theory-driven analyses (Clarke and Braun, 2014). By focusing on the meaning across a data set, the researcher can see and make sense of collective or shared meanings and experiences by identifying what is common to the topic of interest (Braun and Clarke, 2012; 2006).

Thematic analysis is, thus, the analytical approach that involves the systematic development of codes and themes (Boyatzis, 1998). The research questions in this thesis used thematic analysis as an analytical approach to systematically develop codes and themes that answered those questions. The analysis used the Miles and Huberman (1994) definition of codes as "tags or labels for assigning units of meaning to the descriptive or inferential information compiled during a study" (p. 56). The coding process includes the identification and recording of "one or more discrete passages of text or other data items, such as parts of a picture, that exemplify the same theoretical or descriptive idea" (Gibbs, 2011, p. 2). Thus, TA allows for the identification of examples within the data that reflect the coding categories "guided by the frequency and fundamentality of the issues raised by the users – that is, emphasising those issues that occurred frequently or that were deemed of fundamental importance" (Adams *et al.*, 2008, p. 147).

As summarised in *Table 12*, in the initial steps of thematic analysis, a detailed inductive analysis of the topic was conducted to contextualise SEeDs and Narration. An inductive analysis would suggest that the themes identified linked strongly to the data (Patton, 1990), which was collected via the audio-recordings and group interviews. Data was coded without fitting it into a pre-existing coding frame or the researcher's theoretical preconceptions (Braun and Clark, 2006, p. 84). In conducting an inductive analysis, two important concepts were considered: the *unit of analysis* and *coding* (Boyatzis, 1998). More specifically, as *a unit of analysis*, Boyatzis (1998, p. 62) defined "the entity on which the interpretation of the study focused". As *a coding unit,* he defined "the most basic segment, or element, of the raw data or the information that could be assessed in a meaningful way regarding the phenomenon". In this research, the units of analysis were students' resultant digital stories and talk as parts of their collective activity. The coding units were the story plot, its commentaries, and students' interactions. As Boyatzis (1998) noted, the two concepts need to be related so that "the unit of coding should have a theoretical justification, given the phenomenon of interest and the unit of analysis, and should provide an opportunity to establish and observe a "codable moment" (p. 64).

5.8.2 Inductive and Deductive thematic analysis – a hybrid process

A synthesis of data- and theory-driven thematic analysis guidelines (Braun and Clarke, 2006; Fereday and Muir-Cochrane, 2006) was initially selected to address the first two research questions – *RQ1: "Whether, and, if so, how do the SEeDS and Narration activities support learners in each of the two contexts to access, reflect upon on, and apply prior science learning?"*; and *RQ2: "Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?"*

The first question looked at the resultant digital stories that students produced and the recorded interactions of students as they worked together. RQ1 was concerned with how each activity might have supported students in accessing existing knowledge, reflecting upon science concepts, and developing explanations about them. Considering that thinking is not visible, the data analysis was based on indirect evidence, such as what students said (recorded

interactions) and wrote (story scripts/commentaries). In doing so, *thinking* is broken down into the following three categories, as they derive from the first research question, helping to define the code manual:

- recalling prior learning of relevant concepts (access)

- thinking about the science concepts (reflection), and

- using prior knowledge to develop explanations or make arguments (application)

The three codes guided the analysis of the resultant digital stories and students' recorded interactions. Any data that did not involve talking or writing about matter were coded as side-story comments. Those comments also included cases that gave no answers, examples where the response was unintelligible and restatements of the text or unique responses that could not be categorised within the above set of categories.

The second research question examined data from students' recorded interactions as they worked collaboratively in small teams. Findings from the analysis of students' interactions showed that each activity engaged students in the process of sharing ideas and negotiating understanding. The language used could be categorised as exploratory talk, according to Mercer and his colleagues (1999).

This hybrid process (Fereday and Muir-Cochrane, 2006; Boyatzis, 1998) of combining inductive and deductive thematic analysis involves all the steps of the inductive, data-driven approach and at the same time allows the researcher to use preconceived theories or prior research as a guide for articulating meaningful themes (Boyatzis, 1998). Such preconceived ideas are typically present even when the data-driven approach is used, but in the hybrid process, the compare-and-contrast step helps to minimise possible distortions (Boyatzis, 1998). Using the hybrid process of analysis also helped to overcome the possibility of researcher biases in the qualitative analysis of SEeDS against the other activity, considering the researcher's involvement in developing SEeDS. In the case of this research, the hybrid process of analysis started as theory-driven and progressed to data-driven coding and analysis, including eight interwoven phases, as outlined next in *Table 13* below:

Phase	Description of the process
1) Familiarisation with the data	Transcription of data and field notes, reading and re-reading the data, noting down initial ideas.
2) Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code
3) Development of *a priori* codes	Determining important theoretical areas that can be used as initial codes to organize the data. Use of theory-driven coding that links to the theoretical framework of the study.
4) Carrying out theory-driven coding	Coding data in a systematic fashion within each audio-recording and across the entire data collating data relevant to each *a priori* code.
5) Reviewing and revising codes and carrying out additional data-driven coding	Checking and revising theory-driven codes work in relation to the entire data set. Additional coding is done at this stage, which is not confined by the a priori codes and inductive (data-driven) codes are assigned to the data.
6) Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme.
7) Reviewing themes	Checking if the themes work in relation to both the coded extracts and the entire data set, generating a thematic 'map' of the analysis.
8) Writing up	Weaving together the analytic narrative and (vivid) data extracts to tell the reader a coherent and persuasive story about the data and contextualising it in relation to existing literature.

Table 12: The seven phases of the hybrid process of thematic analysis used in this research (adapted from Clarke and Braun, 2014; Braun and Clarke, 2006; Fereday and Muir- Cochrane; 2006 Boyatzis, 1998).

Phase 1: The first analysis phase included familiarisation with all the transcribed data from students' recorded interactions. Familiarisation was based on the initial line-by-line reading and re-reading of all recorded data using the Word document. Using the Word document provided the opportunity to keep notes and mark ideas for coding that would allow coming back to in subsequent phases. *Figure 11 gives* a summary of the initial reading of data.

Start Time	Speaker		
00:00:54.1	Tony get done with it, we should put them in a right order		
00:02:34.6	Let's start with the cold first and then the hot	Popi Anastasiou	Identifying scenes
00:03:51.0	Guys I put them in order, what did you do? Did you delete them?	Popi Anastasiou	Disagreement between team members
00:04:43.4	Why did you take them out?		
00:05:01.3	Ok, which one is the first one?	Popi Anastasiou	Discussing right order
00:05:11.6	We started with the cold one and now we go to the hot one		
00:07:44.6	And look at the particles how they are here.. here in the hot, look how they move	Popi Anastasiou	Identifying content in scenes
00:10:10.7	Well, here we can say that the Sun warms up the mountains and the snow melts	Popi Anastasiou	Assignment of roles
00:12:30.0	I write the commentaries and you put them in order	Popi Anastasiou	Providing scientific explanations
00:17:14.1	So write.. water makes vapours when we turn it to hot	Popi Anastasiou	Mentioning/stating facts
00:17:43.6	When he takes a shower water makes vapours	Popi Anastasiou	Discussing order
00:21:53.6	So, we are in scene 7		
00:22:05.4	When the sun comes out above the field	Popi Anastasiou	Starting another conversation
00:23:51.5	So we re still left with melting, freezing, condensation	Popi Anastasiou	Identifying [missing] scenes
00:23:52.0	Do you know what melting is?		
00:23:53.2	Yes	Popi Anastasiou	Not reflecting/sharing information
00:25:25.8	And we are stuck with condensation		
00:25:33.9	Why don't we check the other scenes first? This one with the balloons	Popi Anastasiou	working with known content first
00:25:49.5	The particles ... of the gas		
00:25:56.0	They are moving		
00:26:00.7	Yes, they are moving but look the space between them	Popi Anastasiou	Providing scientific explanations

Figure 11: First phase of inductive analysis – familiarisation with data in Word

The aim was to identify anything interesting or relevant in the data to answer the first research question. In this sense, excerpts from data were coded in various ways to fit the purpose (Braun and Clarke, 2012; 2006). Initial ideas, thoughts, and reflections on explicitly or indirectly observed data were noted down.

Phase 2: The second phase began after having generated an initial list of ideas about what was in the data and what was interesting about them (Braun and Clarke, 2006). This phase involved the production of initial codes from the data. Data sets were imported into NVivo, which allowed the organisation of information into codes. Working systematically through the entire data set while giving careful attention to each data item helped identify interesting aspects in the data items that could form the basis of repeated patterns (themes) across the data set (Braun and Clarke, 2006). *Figure 12* outlines the initial codes created from the data.

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Figure 12: The initial codes created from the data

Coding data in NVivo allowed highlighting and colour-coding potential patterns by identifying data segments, as seen below. *Figure 12* shows the number of initial codes created using NVivo.

Reference 1 - 0.14% Coverage	
So what do you think this [scene] is about?	**Popi Anastasiou** GREEN: QUESTIONING THE CONTENT OF THE SCENES
Reference 2 - 0.01% Coverage	
We wrote here about him eating his ice-cream, we shouldn't write it again here	
Reference 3 - 0.01% Coverage	
Condensation happens when gases turn into solids?	**Popi Anastasiou** PURPLE: ASKING FOR CLARIFICATIONS/ EXPLANATIONS
Internals\\Story-making process\\E1 Group C part 1 - § 13 references coded [3.23% Coverage]	
Reference 1 - 0.26% Coverage	**Popi Anastasiou** YELLOW: STRATEGIES ABOUT ORDERING
So, we put Bo here because he's a solid	
Reference 2 - 0.04% Coverage	
Here we put this, this and that	
Reference 3 - 0.10% Coverage	**Popi Anastasiou** BLUE: PERSONALISATION TOUCHES
And we have to give them names	
Reference 5 - 0.30% Coverage	
Isn't this a solid?	
Reference 9 - 0.01% Coverage	
So this is Bo, the solid. This is Sugary, the liquid and this is Honeypie, the gas. And here we have put their story, where it's him, they both go in, something happens in there and then they come out. But we	
Internals\\Story-making process\\E1 Group D part 2 - § 4 references coded [1.68% Coverage]	
Reference 1 - 1.23% Coverage	
This goes first	
Reference 2 - 0.03% Coverage	
What happened here? A droplet just dropped from here	
Reference 3 - 0.29% Coverage	
Actually it shows that he makes something out of solid and the other one is holding [a jar of] honey..	

Figure 13: Second phase of inductive analysis: initial codes applied to data

Figures 12 and 13 show how the initially identified codes were matched with data extracts demonstrating that code. In this phase, all actual data extracts were coded and then collated together within each code using NVivo. The coding process was part of the analysis (Miles and Huberman, 1994), as data was organised into meaningful groups (Tuckett, 2005). Yet, the coded data differed from the units of analysis (themes), which were broader. Later phases included a more interpretative analysis of the data, which related to the arguments about the phenomenon being examined (Boyatzis, 1998).

Phase 3: In the third phase, a code manual (theory-driven) was created that allowed managing data for organising segments of similar or related text to aid interpretation (Crabtree and Miller, 1999). Using a code template provided a clear trail of evidence for the credibility of the research. According to the research questions, the template was developed *a priori*, drawing on the pedagogical frameworks outlined in the literature review (Chapters 2 and 3). A code manual (see *Appendix 17*) was developed before searching for

these codes in the primary data, and it represents the basis for organising an initial coding of the students' resultant digital stories, recorded interaction, and observational data. Three broad code categories formed the code manual, which was written with reference to Boyatzis (1998) and identified by:

- The code label or name

- The definition of what the theme concerns, and

- A description of how to know when the theme occurs.

An example of the four initial codes (*Table 20* in *Appendix 17*) developed is presented as follows:

- **Access:** how the activity supported students in recalling prior learning of relevant science concepts

- **Reflection:** how the activity facilitated thinking about the science concepts

- **Application:** how the activity facilitated learners to use prior knowledge, for example, to develop explanations or to make arguments

- **Types of talk:** how the activity helped (or not) speakers to engage with each other's idea critically and constructively.

According to the science programmes of study in Greece and England, the first three codes are associated with students' prior knowledge about the topic of matter, as it was taught at school. Aiming to examine how the two activities might have supported students across the two contexts, the relevant science concepts included in the topic of matter were linked to the five Stumbling Blocks (*Table 21* in *Appendix 17*).

After the line-by-line reading of data as informed by the research questions (*Table 12,* section 5.8.1), the resultant digital stories (plots) and the transcripts from students' team interactions were read and coded in NVivo 10 using the categories from the code manual. Then, the transcripts were reread, compared, and contrasted with the various categories. The codes are not all mutually exclusive. The same text from team interactions sometimes was coded using more than one of those codes. Some of them were also sub-categories of the principal codes.

The last code, *Types of talk,* was developed based on the relevant literature on the typology of talk as it occurs when students work collaboratively on a task in a science class (Mercer and Littleton, 2007; Mercer *et al.,* 1999). When students collaborate to carry out an assigned science task, their discussions can include constructive arguments and critical thinking, which are seen as key features of exploratory talk. Exploratory talk represents "a joint, coordinated form of co-reasoning in language, with speakers sharing knowledge, challenging ideas, evaluating evidence and considering options in a reasoned and equitable way" (Mercer and Howe, 2012, p. 16). Mercer and his colleagues were among the first who investigated the validity of exploring students' use of talk as a tool for reasoning and carrying out a collaborative approach in the study of mathematics and science (Mercer and Sams, 2006; Mercer *et al.,* 2004; Mercer *et al.,* 1999).

As such, the code *Types of talk* was analysed as follow:

Code label: Three types of student talk

Definition: Students' instinctive use (or lack) of critical and coordinated reasoning and constructive arguments without having received any training

Description: Episodes are coded as *exploratory talk* when students engage critically but constructively with each other's ideas; *disputational talk* when students explicitly challenge any claims made by team members; and *cumulative talk* when students share and build information in an uncritical way (*Table 22* in *Appendix 17*).

Phase 4: The fourth phase was concerned with theory-driven coding. Transcripts were edited in NVivo, which provided the opportunity to refine, merge or delete coding as necessary. This step began after all data had been initially coded and collated, and there was a long list of the different codes that were identified across the data set (Braun and Clarke, 2006). When starting to analyse the codes, it was considered how different codes might combine to form an overarching theme. The data was coded systematically across transcripts by collating data relevant to each *a priori* code (Braun and Clarke, 2006; Boyatzis, 1998). Coding, classifying, and labelling the data in this stage were based on observations made to determine the engagement points of the participants in relation to the theory-driven codes. Each code was used as a label attached to an excerpt from the audio-recorded data. That demonstrated its importance as a theme and/or concept, as demonstrated in *Figures 14* and *15* below.

Name	^	Sources	Referen...
▼ ◯ Exploratory talk		4	13
◯ Asking for clarifications or explanations		4	16
◯ Listening to each other		4	11
◯ Disputational talk		6	16
▼ ◯ Cumulative talk		5	11
◯ Not building on each other's previous comments		9	39

Figure 14: Fourth phase of analysis: matching *a priori* codes with data-driven codes

Internals\\Cumulative Talk – uncritical sharing of ideas\\E1 Group D part 2 - § 8 references coded [2.10% Coverage]

Reference 1 - 0.81% Coverage

The title goes first, that's why it's called title, it goes first

Reference 2 - 0.09% Coverage

Why is this first?

Reference 3 - 0.18% Coverage

Because they greet us in the first one, you know "hi" and he does all the tricks with his ball

Reference 4 - 0.55% Coverage

Look, they greet ... he is making his solid sculpture

Reference 5 - 0.01% Coverage

Look how it goes. This one first cos you see all three of them and they greet

Reference 6 - 0.13% Coverage

The guy with the honey goes second

Reference 7 - 0.26% Coverage

We will put this one first because they first get in and then they do what they do

Figure 15: Collating data relevant to each *a priori* code

The subsequent three phases of the analysis (Phases 5, 6 and 7 as outlined earlier in *Table 13*) were conducted as an iterative process. Particularly, during **Phase 5**, the process included reviewing and revising the theory-driven codes in the context of the audio data. The focus was on the code labels' appropriateness, the codes' definitions and on how the codes were applied or were going to be applied to the data (DeCuir-Gunby *et al.,* 2011; Boyatzis, 1998;). The code labels needed to be conceptually meaningful, clear, concise, and related to the collected data of the study (Boyatzis, 1998). The reliability, utility, and applicability of the codes to the new data was achieved by closely reading through each audio transcript line by line and applying the initial codes to the text to identify meaningful units of text (DeCuir-Gunby *et al.,* 2011; Boyatzis, 1998). The analysis, thus, focused on a consistent observation, labelling and interpretation of the codes. The importance of the process is emphasised by how it affects the potential utility of the code and the research findings resulting from using the code" and subsequently the "potential for replication, extension, and generalizability of the research" (Boyatzis, 1998, p.144).

At the fifth phase, while reviewing the theory-driven codes, further coding was undertaken as inductive (data-driven). As observed in the audio transcripts, codes were assigned to the data segments that illustrated a new idea or a concept (Fereday and Muir-Cochrane 2006). This inductive analysis involved a combination of the continuous refinement of the initial codes and the development of the new data-driven codes (Ezzy, 2002; Boyatzis, 1998). This process enriched the depth of analysis and offered a refined understanding of the data, as shown in *Table 14*. The aim was to successfully allow the codes to emerge to adequately address all the sections of the data set and answer the research questions.

Initial coding	Examples
Finalising opinion without debate	S3: *'I am going to pass out because of too much heat'*...
	S3: *Look at the clip again and you will understand why he [character] dropped his pant... got it?*
Accepting ideas and information passively	S2: *yeah ... are we doing condensation now?*
Arguing in an uncritical way	S1: *No, we did heat and cold*
	S2: *Nooo, we did something stupid. We should put it [scene] there, after that [scene] water evaporates... it's the cycle of water*
	S4: *We did it wrong*

Popi Anastasiou
Making commentaries about a scene

Popi Anastasiou
Explaining the previous commentary based on what's depicted in the scene

Popi Anastasiou
Accepting passively

Popi Anastasiou
Looking at another scene

Popi Anastasiou
Disagreeing with teammates suggestion

Popi Anastasiou
Emphasing a possible mistake ...

Popi Anastasiou
... by providing [wrong] scientific explanation

Table 13: Phase 5 of analysis – further coding/data driven codes

Phase 6: The sixth phase of the data analysis involved sorting and collating codes by identifying potential patterns, categories, themes and relationships that would explain the findings. The process of discovering themes, patterns and relationships in the data was achieved by linking the theory- and the data-driven codes (Boyatzis, 1998). In doing so, possible similarities and differences among the diverse data sources, areas of interest, areas of consensus and potential conflict emerged, and clustered themes were directly linked to the research questions. Throughout this phase, the analysis of the relevant data involved an iterative, non-linear process in which the identification of key concepts, themes and their relationships were confirmed or disconfirmed (Fereday and Muir-Cochrane 2006).

A benefit of using the hybrid thematic analysis process is found in the combination of theory-driven, and data-driven codes, which allowed to code identified themes or concepts that are linked to the theory but also to those that emerged or evolved from the primary data itself (DeCuir-Gunby *et al.*, 2011; Fereday and Muir-Cochane, 2006). In particular, the *a priori* codes used in the analysis, which were based on Mercer *et al.* (1999) talk framework, resulted from the teachers' guidance on student talk in group tasks (section 2.2.5). By contrast, students in this research were not guided to use exploratory talk during their cooperation. Thus the primary data collected included examples of the three types of talk that Mercer *et al.* (1999) proposed, along with others that were either collated or discarded. For instance, the code *assignment of roles,* which included the sub-codes *writing the commentaries/script,*

making sketches or keeping notes on paper, and *dragging and dropping scenes,* was discarded as it was not regular across the data. That approach, therefore, provided the opportunity to refine both codes and themes, determining their credibility (Fereday and Muir-Cochane, 2006) and, at the same time, to organise and re-organise them in "free nodes" or "tree nodes" (hierarchical and parallel coding). Critical thinking and reflexivity were necessary during this stage (Ezzy, 2002). They were simultaneously employed to confirm that the codes were sensitive to the data they contained (i.e., the data coded to each node) and that each thematic grouping of codes was meaningful and concise.

Phase 7: During the seventh phase, emphasis was placed on refining the codes and themes at the level of the collated data extracts (all the collated extracts for each theme) and the individual themes in relation to the whole data set, as seen in *Table 15*. Refining the themes sought to identify what each theme was about, in line with the themes overall and deciding what aspect of the data each theme captured (Braun and Clarke 2006). It should be stressed that the collated data extracts of each theme were reviewed and organised into a coherent and internally consistent account. At this point, the collated data extracts were checked for a second time for consistency to validate the conclusions drawn from the themes (Bazeley and Jackson, 2013). As Braun and Clarke (2006) noted, the process of coding data and generating themes could be an endless one. The saturation point was reached when further analysis of the evidence provided little in terms of further themes, insights, perspectives or information in a qualitative research synthesis (Suri, 2011), and there were no new meanings and/or findings in the data. At this stage, a good understanding was gained of the diverse themes, how they fit together, and the overall story they could tell about the data.

Code from framework (Mercer *et al.,* 1999)	Data-driven codes	Examples from students' discussions
Exploratory talk : 🔸 speakers engage critically but constructively with each other's ideas. 🔸 Statements and suggestions are sought and offered for joint consideration. These may be challenged and counter-challenged, but challenges are justified, and alternative hypotheses are offered. 🔸 Knowledge is made publicly accountable and reasoning is visible in the talk	*Disagreeing with evidence*	S2: Wait a minute! That can't be first because he [character] says 'Look at me and what I can do' and then it's this [phenomenon]. The rest of the characters did not introduce themselves, why should this [scene with Bob the solid] come in here? There need to be the other characters too
		S1: The other ones will come later
	Asking for further explanations/clarifications	S2: Ok, can someone explain this to me?
	Providing reasonable evidence	S3: All of them [characters] must first introduce themselves and then comes the solid [scene].
	Seeking opinions/agreement	S2: Yes! Now which one is the liquid?

Table 14: Phase 7 of analysis – refining and collating theory-driven and data-driven codes

Phase 8: The final stage of the data analysis referred to writing-up findings and discussing them in the upcoming Chapters 6 and 7. In particular, the process included a selection of vivid extract examples, the final analysis of the selected extracts, linking the analysis with the research questions and literature and, finally, producing a scholarly report of the analysis (Braun and Clarke 2006). These are presented analytically next in Chapter 6. The aim was to present a concise, coherent, logical, and insightful account of the data by providing sufficient evidence of the themes within the data, supported by rich data extracts. The selected data extracts were compelling examples, capturing the essence of the point illustrated. The data in the discussion chapters is presented concerning two different contexts. The purpose of indicating the data extracts' origin in this manner was for contextualising the data, which allowed enhancing transparency as to where the data came from.

5.8.3 Inductive Thematic Analysis – Addressing research question 3

The process of inductive thematic analysis was undertaken to provide answers to *RQ3: "Whether, and, if so, how do the SEeDS and Narration activities engage and challenge learners in the two contexts?"* The final question of this research referred to how each activity might have engaged and challenged students. In the process of inductive analysis (section 5.8.2) discussed in the previous section, data from students' group interviews and teams' recorded interactions was sequentially analysed to produce the themes outlined in *Table 16.*

In the first phase of inductive analysis (*Phase 1, Table 13,* section 5.8.2) there was familiarisation with all the transcribed data from students' group interviews and recorded interactions. Data excerpts were then coded in various ways to best address the research question. After reviewing the data, some initial codes were created (*Phase 2, Table 13*). Conducting a systematic review of the entire data set helped to identify repeated patterns (themes) across the data set (Braun and Clarke, 2006) *(Phase 6, Table 13*). Finally, codes and themes were refined at the level of the collated data extracts and were related to the whole data set (*Phases 7 and 8, Table 13*), as seen in *Tables 16* and *17.*

Codes	Description	Examples
Ownership of Creation	How each activity engaged students if it did so	*You 've got to find out the answers like work out yourself (S1, SEeDS)*
Fun/ Enjoyability		*Ours [activity] I think was more fun because it's very confusing when you have to order the scenes (S1, Narration)*
Conceptual complexity	How each activity challenged students if it did so	*We had to think harder about how to order the scenes and we didn't know where to start (S, SEeDS)*

Table 15: The final codes created from students' group interviews data

The findings identified two themes related to engagement: *Ownership of Creation and Fun/ Enjoyability,* and one theme for challenge: *Conceptual complexity.*

Code: Conceptual complexity	
Data-driven codes	**Examples from students' discussions**
Making an assertion	S4: this must be the bathroom [scene], this is evaporation
Disagreement about the initial assertion	S1: no, that's condensation
Providing alternative explanation	S2: it's liquefaction
Correcting alternative explanation	S3: this [scene] is liquefaction
Providing explanations about the ordering of certain scenes	S2: so, this [scene] goes after the other [scene] with that thing because it tells you that it turns it [thermometer] down because it's hotter and then it tells you, you know why steam is created because the temperature goes up
Elaborating on previous explanation	S4: and water becomes gas
Final agreement	S2: yes.

Table 16: The final codes created from students' recorded interactions data

Findings will be presented in more detail in Chapter 6 and discussed extensively in Chapter 7.

5.8.4 Ensuring trustworthiness of the research

Constructs of validity and reliability apply to different types of research, and the way they are addressed varies according to the approach used (Cohen *et al.*, 2007). The two constructs are mainly related to positivist research seeking to check the robustness or strength of research. However, within a qualitative methodology, these constructs are "problematic because they conflict with relativist ontological and epistemological positions" (Twining *et al.,* 2017, p. A6). The following principles have been considered to address the trustworthiness of this qualitative research: validity and credibility, transferability, dependability, and confirmability (Lincoln, 2001), which are considered more suitable for making judgements about rigour in qualitative research.

To account for *validity*, reference will first be made to *descriptive validity*, about the notion of truth in research – what actually happened. It can be addressed in terms of the "factual accuracy of the account" (Winter, 2000, p.4) and completeness, including the natural setting of the source of data and how the data was collected. Thus, a detailed description of the natural setting in each context, the participants' recruitment process and the data collection methods (section 5.5 and 5.4) are provided.

Then there is the notion of *interpretative validity*, which refers to the ability of the research to catch the meaning, interpretation, and intentions of the participants (Cohen *et al.,* 2007). Threats to this principle are found in the role and influence of the researcher, generally known as the *researcher bias* (Maxwell, 2012), which can affect the quality of the study during not only the design process but also the analysis stage (Darder *et al*., 2008). For instance, the researcher's composition and evaluation of the SEeDS activity are based on her expertise as a teacher from a different cultural context, which might influence the analysis and interpretation of the findings. To minimise the possibility of the researcher bias, specific strategies were followed: methodological triangulation, participant checking, thick description, audit trail and peer debriefing – these are outlined in the following paragraphs.

In terms of the *credibility* of this research – making sure that it 'measured' what it claimed to do (Creswell, 1998), there was a triangulation of sources, methods and theories (Vrasidas, 2014). The credibility of a qualitative study is affected by "the extent to which systematic data collection procedures, multiple data sources, triangulation, thick and rich description, external reviews or member checking, external audits, and other techniques for producing trustworthy data are used" (Yilmaz, 2013, p. 321).

First, there was data triangulation by gathering data from different participants at different times. Two learning activities were used, which included the same story scenes but differed in presentation and implementation. Triangulation of data from the two activities gave a more precise picture than simply reviewing data from one approach. Second, *method triangulation* by using different data collection methods. Data was cross-checked across the digital stories, audio recordings, group interviews and observation notes, providing thus more insights on the phenomenon under investigation. Third, theoretical triangulation by analysing and explaining data based on the pedagogical framework of problem-based learning and the

typology of talk in science learning. Drawing on elements from those frameworks helped to define the process of meaning making in this research. Fourth, *analytic triangulation* or *peer debriefing* by discussing methodology, analyses and emerging findings with the supervisory team. That allowed to check the plausibility of and for blind spots in the analysis. Lastly, *participant checking* was used as an instrument of validation by asking some participants to elaborate on and clarify what they have said in interviews or done in observed sessions. Also, when designing the digital story, Annie, the Grade 5 teacher, was asked to offer her insight. She also commented on the researcher's interpretations of interviews and observations. The construct of credibility corresponds to that of internal validity in positivist research (Συμεού, 2006).

In accounting for *transferability* – how findings could be transferred from one research context to another (Lincoln and Guba, 1985), a detailed description of the studies in Greece and the UK was provided. That included detailed information on contextual research setting, design, processes and participants, to help the reader identify if any elements of this research can be applied in other contexts. According to Lincoln and Guba (1985), it is the reader's and not the researcher's responsibility to identify if this research is transferable. The construct of transferability addresses that of external validity in positivist research (Συμεού, 2006).

Finally, *dependability* and *confirmability* refer to "the consistency of the data collection instruments and procedures and the detailed description of the research process" (Riazi, 2016, p. 87). These were established through an 'audit trail' that described the purpose of the research and the theoretical framework used. It also provided a detailed and thorough account of the selection and recruitment of the participants, a rich description of the research design decisions by clearly describing and explaining the data collection methods (Chapter 4) and the analysis techniques (Chapter 5) and reporting the research findings (Chapters 6). Eventually, attention was given to the researcher bias (Maxwell, 2012), which refers to the role and influence of the researcher as potentially affecting the quality of the research (Denzin and Lincoln, 2008). For instance, the researcher's main ideas and preconceptions in supporting science teaching and learning were derived from personal teaching experiences. That could have influenced the research process and the interpretation of findings (section 8.4). To minimise the researcher bias, both the Greek and English science teachers were asked

to be present during the studies to address students' content-related inquiries. The researcher acted as an observer and facilitator of the process, dealing with any technical issues. Moreover, the supervisory team acted as external auditors, seeking out and correcting the researcher's prejudices (Decrop, 2004). They also reviewed part of the data and analytical procedures, confirming thus adherence to sound research practices (Riley, 1996).

Providing a detailed account for all research decisions and procedures would allow readers to trace the course of the research (Patton, 1990), redraw how the author came to the conclusions reached (Decrop, 2004) and discern any methodological and interpretive judgements (Houghton *et al.,* 2013).

5.9 Chapter Summary

This chapter explored the most suitable methodology to address the purpose of this research, including aspects of the research design approach and the data collection methods. It provided a detailed account in which a step-by-step process was presented and discussed to guide the reader through data collection in the Greek and English schools. In addition, the methods used for the data collection were presented with illustrative examples to demonstrate how each method contributed to the research. Such a detailed account sought to provide clear documentation of all research decisions and approaches, adding to the rigour of this research as a qualitative design. Findings from the Greek and English studies were then coded and analysed using deductive and inductive thematic analysis. Chapter 6 offers a thorough insight into students' implementation of and engagement in the SEeDS and Narration activity.

CHAPTER 6: PRESENTATION OF FINDINGS

6.1 Introduction

The previous chapter, Chapter 5, has discussed the research methodology considered the most appropriate to address the purpose of this research. Considering that the purpose of this research was to evaluate the use of digital storytelling in helping students to make meaning in science, data analysis highlighted the role of problem-based learning. A thorough look into the data revealed that the two digital storytelling activities helped students to externalise their thinking about and understanding of the tricky topic of matter. Data analysis also showed that students' naturally occurring talk while working collaboratively through the two activities included more elements of *exploratory* than *cumulative* or *disputational* talk. Finally, students' views regarding the two activities were acknowledged in terms of engagement and challenge.

The presentation of findings in this chapter unfolds through the three themes that emerged from the thematic analysis. This chapter initially presents the findings related to how the two activities might have supported students' access to, reflection on and application of prior knowledge (Theme 1). Then it continues with further evidence regarding the types of instinctive talk students used while carrying out collaborative work (Theme 2). Finally, it considers students' views (Theme 3) regarding the two activities in terms of challenge and engagement in the learning process.

The three themes draw on and correspond to the three research questions. The first theme aims to answer the first research question *(RQ1) "Whether, and, if so, how do the SEeDS and Narration activities support learners in each of the two contexts to access, reflect upon, and apply prior science learning?".* The second theme addresses the second research question, *(RQ2) "Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?"* The final theme responds to the third research question (RQ3) *"Whether, and, if so, how do the SEeDS and Narration activities engage and challenge learners in the two contexts?".*

In sum, the three themes are presented in the following order:

1) **Access to, reflection on and application of prior knowledge (Theme 1)**

- The SEeDS activity in the Greek context

- The SEeDS activity in the English context

- The Narration activity in the Greek context

- The Narration activity in the English context

2) **Students' use of talk whilst carrying out collaborative work in science (Theme 2)**

- SEeDS students' talk in the Greek context

- SEeDS students' talk in the English context

- Narration students' talk in the Greek context

- Narration students' talk in the English context

3) **Challenge and engagement through the two activities (Theme 3)**

- The Greek students' views about the two activities

- The English students' views about the two activities

In the presentation following, the themes refer to specific datasets about students, highlighting the code excerpts and story pieces used within the chapter. Examples from the three themes are chosen first to represent a typical (repeatedly occurring) exemplar of an event or practice and then a non-typical case (less repeatedly occurring), worthy of further discussion. Non-typical cases, in which participants viewpoints or final products differ from the main body of evidence, help to ensure validity in qualitative research like this one. Despite completing a systematic process of data reduction (Miles and Huberman, 1994), and due to space constraints, not all the coded excerpts are presented.

Finally, given the interpretive philosophy underpinning this research, it should be stressed that the notion of social reality is not a tangible device. Therefore, due respect is paid to the interpretations of all those involved in this research, including the researcher and the researched. The influence of multiple and social worlds (Blaikie, 1993) is also acknowledged.

6.2 Access to, reflection on and application of prior knowledge (RQ1)

In answering the first research question *(RQ1):* **"Whether, and, if so, how do the SEeDS and** *Narration activities support learners in each of the two contexts to access, reflect upon on, and apply prior science learning?"* the two activities, SEeDS and Narration, were reviewed to identify how they supported students in accessing, reflecting on, and applying prior knowledge about matter, if they indeed did. The comments that Greek and English students made in their story plots through the two activities reveal their prior knowledge (or lack) of the relevant concepts found in the topic of matter.

The two activities were different in structure, with SEeDS presenting story scenes in an order that was not predefined and Narration in a predefined order (see section 4.3). Thus, it was important to explore how they might have helped students externalise prior knowledge. Seeking to provide answers to the first research question, evidence was drawn from the resultant digital stories (plots) and the recorded team interactions of students through the two activities across the two contexts (section 5.8.2).

The next four sections (the two activities in the two different contexts) highlight how the different data sources supported the analysis of each section, and the fifth one provides a summary. More specifically, Section 6.2.1 presents findings from the SEeDS activity in Greece and Section 6.2.2 from SEeDS in England. The subsequent two sections, 6.2.3 and 6.2.4, focus on the Narration activity in Greece and England, respectively.

6.2.1   The SEeDS activity in the Greek context

The analysis of all teams' resultant digital stories revealed that Greek students produced short commentaries that included scientific explanations about relevant concepts (see *Figure 16*). A typical example of story plot was that of Team C, presented next.
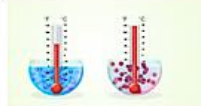
Scene 1	**Scene 2**	**Scene 3**	**Scene 4**	**Scene 5**
-Hi, I am Bob and I am a solid. -Hi, I am Sugary and I am a liquid. -Hi, I am Honeypie and I am a gas. -I, Bob, can create solid things from ice.	Objects that are solids are a rubber duck, a bat, a toaster, a pencil. The particles in solids vibrate on the spot and they are packed closec together.	Liquids tend to flow.	In liquids, the particles stay close together.	Substances can change condition.
Scene 6	**Scene 11**	**Scene 7**	**Scene 13**	**Scene 8**
Particles in gases are far away from each other and they move quickly.	Due to heat, water evaporates.	Gases take the shape of the container they are in.	When the temperature increases, particles in substances start to move faster.	When solid enters the hot room ... When liquid enters the cold room ...
Scene 9	**Scene 10**	**Scene 14**	**Scene 15**	**Scene 12**
.... it gets hots. ... it freezes.	Solid melts, which suggests MELTING is happening. Liquid freezes and that implies FREEZING is happening.	When the sun comes out, ice melts and becomes liquid.	Water evaporates with the help of the sun.	When water is heated, it changes into gas. This process is called EVAPORATION.

Figure 16: Story script of Team C, Greek students, (Grade 5, SEeDS activity)

As shown in *Figure 16*, Team C students ordered the story scenes first, starting with the main story characters that represented the three states of matter. In Scene 1, students first made a side-story comment, naming the story characters. Then they described solids, commenting that Bob, the solid [character], *"can create solid things from ice".* In including this information, students may have been acknowledging the hardness of ice as a solid feature, underscored by their decision to place next Scene 2, categorising as solids the rubber duck, the toaster, the bat, and the pencil. Students appeared to not differentiate between hard rigid solids (pencil, bat, toaster) and soft elastic solids (rubber duck). Thus, they mentioned plasticine as neither a hard nor soft piece of solid substance. They decided not to specifically reference the plasticine, which might indicate that they could not decide if it was a hard or soft solid substance. It might also be that students considered plasticine as an intermediate between a solid and a liquid, so they did not categorise it as purely solid or were uncertain about what the item really was. Students described the solid particles' movement in the same scene, stating that *"particles in solids vibrate on the spot"* and their arrangement – *"and they are packed closely together"*. From these comments, it seemed that Team C students drew on

existing knowledge, implying that hardness is a property of solids, and explained how their particles move in scientific terms.

In Scene 3, students described liquids, mentioning their physical properties, such as that *"liquids tend to flow".* Next to scene 3, they placed scene 4, in which they referred to liquid particles' arrangement, commenting that *"in liquids, particles stay close together"*. In terms of using prior knowledge, students attributed the property of flowing to liquids and explained the liquid particles' arrangement. But whilst they stated the movement of the liquid, they did not mention the movement of its particles, so it could not be assumed that they understood the particles' movement.

Then Team C students ordered Scene 5, possibly introducing gases because they commented that *"substances can change conditions".* Then in Scene 6, they described the gas particles' arrangement – *"particles in gases are far away from each other"* and movement – "*and they move quickly"*. Placing together Scenes 5 and 6 would imply that students acknowledged the existence of gases. Yet, they were uncertain about the content of Scene 5, or they did know how to conceptualise gases. In Scene 6, students revealed their prior knowledge about the gas particles' movement, providing scientific explanations about the movement and the arrangement.

Next students ordered Scene 11, which they seemed to relate to gases, and so they commented that *"due to heat, water evaporates".* Students seemed to have sufficient knowledge of the concept of evaporation, even though they did not provide rich scientific explanations about its process. They may have also been implying the existence of gases because when a liquid (water) receives heat, it will turn into a gas. That could explain why they placed next Scene 7, in which they commented that *"gases take the shape of the container they are in"*. In doing so, students referred to the property of gases to take the shape of or occupy all the containers they are put in.

In Scene 13, students continued to describe particles' movement at a high temperature, stating that "*when the temperature increases, particles in substances start to move faster".* There was no reference to particles' movement when the temperature decreased nor

to the use of the thermometer. It could be that students had incomplete prior knowledge about the concept of temperature and no knowledge about the use of the thermometer.

In Scene 8, students described how the story characters got into two different rooms – *"when solid enters the hot room … When liquid enters the cold room"*. Students did not refer specifically to the objects in the characters' hands – the solid character held an ice cream in one hand and a glass with ice cubes in the other, while the liquid character held a glass of water. It could be that students attributed the properties of solids and liquids to the two characters, so they did not feel the need to mention the objects in hand. Students might be putting human qualities on the substances (anthropomorphism) in connecting liquid to the story character, which will be discussed extensively in section 7.2.2.

Later, in Scene 9, students commented that one character *"gets hot"* and the other *"freezes"* after entering the hot and cold rooms, respectively. Making the decision to order Scene 8 and Scene 9 together allowed students to describe the melting and freezing processes briefly.

Then followed Scene 10, in which students labelled the two processes, stating that *"solid melts, which suggests melting is happening. Liquid freezes, which suggests freezing is happening".* Students' explanations about how solids and liquids changed conditions after melting and freezing might seem incomplete in Scene 10, however, this understanding was presented in the following scene.

In Scene 14, students became more explanatory about melting, explaining that *"when the sun comes out, ice melts and becomes liquid".* They made specific reference to how a solid body turns into a liquid one with the help of the sun. In Scene 15, students described the process of evaporation, stating that "*water evaporates with the help of the sun".* Students' decision not to mention that water changes into a gas during evaporation might indicate that they were unsure about the actual process or would explain it in another scene (as they did later in Scene 12). In both scenes, students emphasised the sun as the main source of heat, which helps substances in a natural setting to change conditions. Students' prior knowledge of the sun as the main heat source seemed prevalent in those scenes.

Finally, Team C students ended their story with Scene 12, in which they explained the process of evaporation – *"when water is heated, it changes into a gas. This is called evaporation"*. Students acknowledged that adding heat to the liquid substance helped it to change its condition. It is worth mentioning that originally Scene 12 was about condensation, for which students made no comments throughout the story, as opposed to evaporation, which was repeated in Scenes 11, 15 and 12. It might be that students had strong prior knowledge of evaporation but not of condensation, and this would explain why they did not recognise the process of condensation in Scene 12.

Analysing all teams' recorded interactions enriched evidence about the Greek students using short and simplistic descriptions to explain their thinking. The interaction of Team C would be a typical exemplar, confirming how they made the plot commentaries described previously. In the following transcript excerpts, students are referred to by number, for example, S1 refers to Student 1.

In Team's C story (see *Figure 16*), students' commentaries appeared to be concise statements, which, whilst accurate, lacked detailed explanations. This approach was also identified during their recorded interaction (see *Appendix 18* for the complete transcript of Team's C recorded interaction):

> S2: This not a solid, because it wouldn't slip, it couldn't come out... It wasn't a liquid...
>
> S3: This is a solid.
>
> S1: This is not a solid.
>
> S3: Here we put this, this and this.

> Transcript 1/Seq1, Team C, Greek students, SEeDS

As *Transcript 1/Seq1* shows, while Team C students were trying to decide the order of the scenes, they thought to put together the scenes that included solids initially. They identified some of the properties of a solid, like that *it does not slip, it cannot come out,* concluding that *it is not a liquid.* That would relate to the ordering of Scenes 1 and 2, their resultant digital story *(Figure 16),* in which they commented about solids.

S2: This shouldn't be a solid, given that it melts.

S1: This is a change of condition, but what change?

S3: Did it freeze?

S1: How do we call this change?

S2: Freezing.

S1: Cool, so we are looking in here to find more about freezing.

In *Transcript 1/Seq2*, students continued arguing about what constitutes a solid, with S2 clarifying that something is not solid because it melts. No one seemed to share a different opinion about that, and the discussion continued. S1 added that they might be talking about changes in conditions instead, but she did not use a precise label for that change. S3 and S2 pointed out that they talked about freezing without details about what substances change conditions. The focus of the discussion shifted to finding more scenes that depicted freezing, as S1 suggested.

Whilst trying to put scenes together, two students in Team C recalled the process of melting, during which a solid, like ice, turns into a liquid, like water:

S3: What is showing here? The ice? It melts and turns into water. What's this change called?

S1: Melting

In *Transcript 1/Seq3*, whilst S3 did not use the label 'melting' to describe the relevant process, he produced the appropriate scientific explanation to express his understanding.

On other occasions, like in *Transcript 1/Seq4,* students used their prior knowledge to explain melting briefly. For example, S2 explained that ice melted because it was solid without clarifying adding heat.

S2: We should put this here because it's ice, meaning that it does melting, it's a solid.

S3: Yes.

During their interaction, Team C students went back and forth in their discussion about different concepts, depending on the scenes they were viewing at the time. For example, in *Transcript 1/Seq5*, students discussed liquids and then found a scene depicting a change [of conditions] in liquids. At the same time, they also considered gases as being relevant to the change of conditions in liquids, so they concluded about the process of evaporation, but without clearly explaining the link between those scenes:

> S1: This one shows the liquids, it presents the liquids. It says that liquids are a state.
>
> S2: So Sugary is a liquid.
>
> S1: It's a liquid, yes. So, we should find something that describes a change.
>
> S3: This is a gas.
>
> S1: What do we have here?
>
> S2: Evaporation.
>
> S3: Evaporation. Isn't this related to Sugary?
>
> S2: Yes.

<div align="right">Transcript 1/Seq5, Team C, Greek students, SEeDS</div>

Even when S3 sought to confirm that they made the right choice putting together liquids and evaporation, the response he got was affirmative but without any underpinning scientific explanation, as *Transcript 1/Seq6* reveals:

> S3: Now does this make sense the way we put it?
>
> S2: Here it shows the liquid, and then what does it show?
>
> S1: Evaporation

<div align="right">Transcript 1/Seq6, Team C, Greek students, SEeDS</div>

Team C seemed to acknowledge that evaporation involves both liquids and gases, although they could not provide sufficient scientific explanations for it. That could be due to incomplete or mistaken prior knowledge, considering that students also confused evaporation with condensation, as *Transcript 1/Seq7* shows:

> S3: What's happening here?

<div align="right">190</div>

S1: It's Bo, who does evaporation.

S3: What do you mean?

S1: That the mirror got wet from the hot water

The discussion in *Transcript 1/Seq7* referred to Scene 12 *(Figure 16),* with S1 proposing that it depicted evaporation because the [bathroom] mirror got misty from the hot water. In *Transcript 1/Sep8,* S2 asked her teammates for further clarifications about the misty mirror, but the answers she received were unclear:

S2: What do you mean it got wet?

S1: No, because of the weather, because of the weather…

S3: Because of the temperature!

S2 insisted on seeking explanations about Scene 12, but she got a variety of short answers, which made her feel more confused at the end, as *Transcript 1/Seq9* reveals:

S2: So, what happened to the mirror?

S1: Humidity?

S3: Yes, it has humidity, it got foggy.

S1: From the cold air.

S3: From the heat.

S2: You guys I don't understand what you are saying. Make a sentence!

Team C students did not seem to have a solid prior understanding of the process of condensation because they could neither label nor produce satisfactory explanations to explain it. Team C students recognised that the hot water created steam but could not justify it in more depth either because they lacked basic underpinning knowledge or had incomplete or mistaken knowledge. That gap in students' existing knowledge will be further discussed in later section 7.2.3.

Overall, the SEeDS activity revealed the gaps in Team C students' prior understanding of the categorisation between hard rigid solids and soft elastic solids; particles' movement in liquids and when the temperature decreases; the use of a thermometer and condensation.

6.2.2. The SEeDS activity in the English context

Unlike the Greek teams' (section 6.2.1) short commentaries, the English teams' commentaries appeared to be richer, combining scientific explanations with side-story commentaries. A typical example of a story plot was that of Team F.

Scene 10	Scene 1	Scene 3	Scene 5	Scene 6
When warmth is applied to a liquid, condensation happens, which evaporates and turns into gas.	When Marginen sculpts solid ice, she only just realised that soon enough it will liquify.	When Bob tries to tip some honey into his mouth, nothing came out. He tipped it a bit then and all the honey spills out and gets him all messy. After that he pulls out some water and splashes it on his face. You can see that honey is still a liquid but has a consistency of a solid.	When Jeff puts the kettle on near the end of this, condensation comes out and makes a cloud of fog. After that he drinks a fizzy drink. All this gas builds up and it comes up making a burp.	When you apply water to a balloon it gets heavier and all of gas bubbles are crammed together and haven't got much room. But compared to air it is lighter and the particles have more room to move.

Scene 7	Scene 9	Scene 11	Scene 12	Scene 13
When you have smoke it fits into small places but hasn't got too much room to move compared to if it has a bigger place there is more room for the particles to move.	When you apply heat to something frozen it will melt but if you apply something cold to a liquid it will freeze.	When you turn the heat up	... condensation starts which is a fog and the condensation melts water which will start to drip from the fog.	If something is cold, the temperature goes down but when it's not the temperature goes up.

Scene 14	Scene 15	Scene 2	Scene 4	Scene 8
When ice settles on a mountain, it becomes a solid but when the sun comes out it melts the ice and turns into water.	On grass, the sun picks up any water. That's called evaporation but on a desert there is no water. But if there was water on a desert, the sun would dry it out as it is so hot.	Solids are hard objects where all the gas particles are all crammed together and have no space to move.	Liquid can fit into any space as it is flexible. Even the tightest holes it can fit through.	If you go in a freezer you can freeze as everyone has water their body and in the cold freezer it will freeze everybody.

Figure 17: The completed story of Team F, English students, (Year 6, SEeDS activity)

Team F students began their story with Scene 10, in which they attempted to explain condensation but described evaporation instead – *"when warmth is applied to a liquid, condensation happens, which evaporates and turns into gas".* Students' prior knowledge about adding heat to a liquid body to turn into a gas seemed adequate. Still, the label *condensation* might have confused because students either used it superficially, without the necessary underpinning knowledge or understood it wrong.

Next, students placed Scene 1, in which they first referenced solid substances, stating that *"When Marginen sculpts solid ice…".* Students mentioned *solid ice* either because they could not recognise ice as a solid substance or wanted to emphasise that ice is a solid. They then linked it to the process of liquefaction, commenting that *"…. she only just realised that soon enough it will liquefy".* Although students did not clearly describe nor label melting in Scene 1, their comments were pointed in that direction.

After introducing solids in Scene 1, students continued with liquids in the next scene. In Scene 3, Team F students recognised honey as a composition of both a liquid and solid because it did not pour easily – *"When Bob tries to tip some honey into his mouth, nothing came out. He tipped it a bit then, and all the honey spills out and gets him all messy. After that, he pulls out some water and splashes it on his face. You can see that honey is still a liquid but has a consistency of a solid".* Students seemed to acknowledge pouring/flowing as a property of liquids, even though they did not mention it, and recognised honey as mixed consistency.

When finished with liquids, students proceeded to gases in Scene 5, relating them to condensation first – *"When Jeff puts the kettle on near the end of this, condensation comes out and makes a cloud of fog".* Students did not provide a clear explanation about the process of condensation, but they pointed out the fog as a characteristic of gases. They then acknowledged the existence of gases in fizzy drinks, commenting that *"after that, he drinks a fizzy drink. All this gas builds up …"* while making a side-story comment *"… and it comes up*

making a burp". Adding funny elements in their commentaries allowed students to personalise their stories.

Next to Scene 5, they placed Scene 6, in which they described the movement of gas particles – *"when you apply water to a balloon it gets heavier, and all of the gas bubbles are crammed together and haven't got much room. But compared to air, it is lighter, and the particles have more room to move".* Students acknowledged that the liquid particles are close to and move around each other instead of the gas particles, which are far apart and move in all directions, yet they labelled both the liquid and gas particles as *gas bubbles*. That might be due to the animations and/or students' insufficient or misunderstood knowledge about particles in all three states of matter. The role of animations in hindering or facilitating the conceptualisation of scientific concepts will be discussed in section 7.2.2.

Team F then continued discussing the gas particles' movement in Scene 7 – *"when you have a smoke, it fits into small places but hasn't got too much room to move compared to if it has a bigger place there is more room for the particles to move".* Students seemed to have a (mis)understanding (or lack thereof) of particles' movement in gases, which could be affected by the animation in Scene 7 that showed gases flowing into different shapes and sizes of containers.

Having finished with the particles' movement, Team F students commented about melting and freezing in Scene 9. They considered heat and cold as separate entities stating that *"when you apply heat to something frozen, it will melt, but if you apply something cold to a liquid, it will freeze".* Students appeared to consider heat and coldness as two distinct entities that could transfer from one body to another by direct contact.

In the next two Scenes, 11 and 12, students seemed to confuse evaporation with condensation because they commented that *"when you turn the heat up … condensation starts".* Students considered that the two scenes depicted the process of condensation, probably because there was steam in both of them. Considering that students had previously used the label condensation to describe evaporation in Scene 10, it could be argued that their prior understanding of the two concepts was either mistaken or misinterpreted.

In Scene 12, Team F viewed condensation as an entity, *"which is a fog",* responsible for creating water droplets from the fog – *"the condensation melts water which will start to drip from the fog".* Students seemed to have a vague understanding of condensation, and the animation in Scene 12 seemingly did not help them to clarify things further.

In Scene 13, students made a general comment about using a thermometer, stating that *"if something is cold, the temperature goes down, but when it's not [cold], the temperature goes up".* Students did not comment on particles' movement when the temperature changed, possibly because they did not acknowledge it or did not know what to comment on. That could imply students' misunderstanding of rising temperatures, which might be connected to not being cold.

In Scene 14, Team F students attempted to describe freezing – *"when ice settles on a mountain, it becomes a solid…".* They did not seem to recognise ice as a solidified liquid, mentioning that it *became a solid* when it *settled on a mountain*. Next, when they described melting, their comment was precise about which substances changed conditions with the help of the sun – *"but when the sun comes out it melts the ice and turns into water."*

In Scene 15, they described how evaporation happened *on grass*, commenting that *"… the sun picks up any water. That's called evaporation…."* They mentioned what would happen to water in the desert, in their next comment, without commenting how substances would change conditions – "… *but on a desert, there is no water. But if there was water on a desert, the sun would dry it out as it is so hot".* Team F students' decision not to mention that a liquid (water) turned into a gas during evaporation might be because they lacked the appropriate scientific vocabulary or had an incomplete or mistaken understanding of the process of evaporation. That could also explain their previous confusion in labelling evaporation and condensation in Scenes 10 and 11, respectively.

Next, in Scene 2, students described *"solids are hard objects",* composed of gas particles – *"where all the gas particles are all crammed together and have no space to move".* Seemingly, students recognised that particles in solids are packed very close together and vibrate on the spot, but they kept labelling them gas particles. Considering that in Scene

6, they also commented that there were gas particles in water, it could be argued that Team F students considered that all three states of matter consisted of gas particles. That might be an indication of an insufficient or mistaken knowledge.

In Scene 4, students referred to flexibility as a property of liquids, commenting that liquid substances take the shape of the container they are in – "*liquid can fit into any space as it is flexible. Even the tightest holes it can fit through".* Arguably, Team F students decided to focus on liquids as space-filling substances, without any reference to the property of running/pouring, which was also depicted in that scene.

Finally, in Scene 8, Team F students made a general statement about freezing, without mentioning which substances changed conditions – "*If you go in a freezer you can freeze as everyone has water in their body and in the cold freezer it will freeze everybody".* Students focused on how human bodies would freeze in the cold instead of how liquid substances would change into solids in a cold environment. Students acknowledged that the human body consisted of water in its greatest part, and they seemed to link it with the animation in Scene 8, which showed one of the story characters becoming frozen in the cold room. That freezing connection to the story character could relate to anthropomorphism, as it occurred from the animations (see section 6.2.1).

The ideas that Team F students exchanged during their recorded interactions provide enriching evidence about how they made the commentary for a scene, as the extract from *Transcript 2* below shows:

S3: Ok guys look, I think we should start with the solids, put together all the scenes about solids and then go to liquids and put together all about liquids and then gases […]

S4: There must be the ice [scene] somewhere I believe

S3: This where they get hot and cold

S1: Now he goes in, and it shows what they are doing in here

S2: It's that one

S3: No, the one that it was in the cold room, he [character] got in there and then it would turn into ice…

S1: That's the one … and they freeze in there because everyone has water in their bodies

S4: Yeah, we humans have water in our bodies

S2: We do, yeah

Transcript 2, Team F, English students, SEeDS

Seeking to order the story scenes, S3 proposed to first start with the solids, put together all the relevant scenes, then continue with the liquids and their related scenes, then with the gases, and so on. In doing so, S4 looked for the scene with the ice, which he seemed to categorise as a solid substance. Then S3 mentioned the scene in which the story characters *"get hot and cold",* with S1 adding that when the one character *"goes in, it shows what they are doing in here".* Neither S3 nor S1 explained what happened when the two characters got into the hot and cold rooms. S3 later pointed out that when the character *"was in the cold room … it would turn into ice",* without clarifying the original condition of the character liquid. S1 agreed with S3 and tried to explain further that the reason *"they freeze in there is because everyone has water in their bodies".* As it appeared, S3's statement about the water found in human bodies was robust enough so that Team F reached a common agreement. Lastly, S4 extended the previous statement agreeing that *"we humans have water in our bodies",* with S2 consenting.

The evidence found in *Transcript 2* could again indicate anthropomorphism or perhaps a poor phrasing or even misunderstanding by the Team F students, which will be discussed in more detail in section 7.2.2.

Generally, the SEeDS activity revealed the gaps and misunderstandings of Team F students' prior knowledge of: condensation (often confused with evaporation), particles' movement in gases and at temperature changes (increase or decrease), the distinction between heat and

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coldness as two entities, the existence of gas bubbles in all three states of matter and the property of pouring in liquids.

6.2.3   The Narration activity in the Greek Context

Much of the Narration teams' commentaries were rich in description, built on a combination of scientific explanations and side-story comments, like those made by the English students from the SEeDS activity (section 6.2.2). A typical example drawn from the data of the Greek Team J is presented.

Scene 1	Scene 2	Scene 3	Scene 4	Scene 5
-Hi there, I am Mauvey. I just found a piece of ice and an idea came to my mind! -I've just created my prototype, which, if not stored at 0ºC, will change from solid to liquid and then it will evaporate and turn into gas.	Solids can be a rubber duck, a stick, a pencil, a toster, plasticines ... which have particles and they cannot become liquids nor gases.	-Hello, I am mr. Square. Today I want to eat some honey. -Oh, no. Honey was pretty thick and without me expecting it, it got poured all over me. -I used water, which is liquid, to clean my face but then it evaporated.	In some liquids, like water, particles constantly change positions.	Heat makes liquid bodies to evaporate.
Scene 6	Scene 7	Scene 8	Scene 9	Scene 10
	By lighting a fire, particles in smoke constantly move and change positions. Initally, they keep a distance between them but when they are about to get into a small container, they come closer to each other.	A solid changes into a liquid in heat and a liquid can change into a solid in 0ºC.	When solids, like ice-cream or ice cubes, are heated they melt and change into liquids. On the contrary, when a liquid is in a cold place, then it changes into a solid, like this glass of water.	Coming out of the temperature rooms ... The glass with the ice-cubes changed into a liquid body, water, because of the high temperature. Coming out of the cold room, the glass with water had turned into a solid.
Scene 11	Scene 12	Scene 13	Scene 14	Scene 15
When the temperature is high, water evaporates and vapors make the atmosphere misty.	When hot water evaporates, windows become misty, and then it changes back to liquid.	When the temperature is high, particles in water move faster... whereas in low temperature particles move slower.	Snow starts to melt because of the sun's heat and changes into a liquid. Melting happens.	In a lot of heat, water will evaporate faster.

Figure 18: The completed story of Team J, Greek students, (Grade 6, Narration activity)

Initially, in Scene 1, Team J students began with a side-story comment to introduce the character representing solids – *"Hi, there, I am Mauvey…"*. Then they continued with a scientific explanation about how certain substances could change conditions – *"…if not stored at 0ºC, [ice] will change from solid to liquid, and then it will evaporate and turn into gas"*. It could be that the presence of the three characters in Scene 1 made students think that the scene was about the changes of conditions in all three states of matter or about substances, like ice, which underwent a complete change of conditions (solid-liquid – gas) in a natural setting. The way that students phrased that comment sounded like they were repeating something from the science textbook, making sure they covered all the necessary details – temperature, change of conditions in all three states.

In Scene 2, students mentioned that all the depicted items – rubber duck, stick, pencil, toaster, and plasticine were solid substances. Team J students did not categorise between hard rigid solids and soft elastic solids because either they did not have prior knowledge of that categorisation or did not consider it necessary to make such a categorisation.

After solids, in Scene 3, students described pouring as a property of liquids, whilst they recognised that honey is thicker than average liquids – *"honey is pretty thick and …. It got poured all over me"*. Students sought to clarify that despite its thickness, honey could be poured. Then they made a clearer distinction between honey and liquids, commenting that *"I used water, which is liquid, to clean my face, but then it evaporated"*. An assumption would be that Team J students linked evaporation with the liquid substances, in which honey was not included. Team J students seemed to recognise that honey is more solid than liquid in terms of composition, but they did not directly reference it.

In Scene 4, students commented on particles' movement in liquids, using water as the main example of a liquid substance – *"in some liquids, like water, particles constantly change positions"*. Students seemed to recognise that particles in liquids move around each other but distinguished between *some liquids, like water,* possibly implying that particles might not behave the same in other liquids. It could be assumed that students' prior understanding of

the classification of liquids was inaccurate or that the animations in Scene 4 confused students.

In Scene 5, students acknowledged that *heat* is needed to change a *liquid body's* condition – *"heat makes liquid bodies to evaporate"* without specifying if the heat should be added or removed.

In Scene 6, they did not comment, either because they did not understand the scene's content or because they did not have sufficient knowledge about the properties of gases.

In Scene 7, which referred to particles' movement in gases, Team J students explained that *"… particles in smoke constantly move and change position".* Students' understanding of particles' movement in gaseous substances seemed unclear, especially when gases were put in various sizes and/or shapes containers. Their comment about how gas particles *"initally, they keep a distance between them but when they are about to get into a small container, they come closer to each other"* could imply either insufficient understanding or misunderstanding of particles' movement in gases. This approach was also identified during their recorded interaction, as shows the relevant extract from *Transcript 3/Seq1*:

S1: So, what's happening here?
S2: It's night and cold and this guy needs to light up a fire
S3: Yes, and there is something else… I see something else
S2: These particles get into some jars and…
S1: Yeah, the smoke particles … they get into these containers
S3: Ok, so this guy lit up a fire and the smoke particles got into a big jar and then into a small one.
S1: Yeah, and here they have a distance between them …
S3: yeah…
S1: and here… in the small one they come closer to each other… Do you see that?
S2: Ok, got that. So, we are done here… Where shall we go next?
S3: I think in this one

Transcript 3/Seq1: Team J, Greek students, Narration activity

When S1 asked about the content of Scene 7, S2 first made a side-story comment based on what the animation showed – a guy lighting up a fire in the night. Then S3 pointed out that there was also something else in the scene, and S2 stated that the particles *got into some jars.* S1 clarified that those were *smoke particles*, and S3 summarised the content of the scene - *"…so this guy lit up a fire, and the smoke particles got into a big jar and then into a small one".* At this point, S1 explained that the (smoke) particles had *a distance* in the big jar as opposed to the small jar, in which they came *closer to each other.* None of the team members seemed to question S1's statement, and they agreed to move on to another scene.

In Scene 8, students described how different substances could change conditions during melting – *"solid changes into a liquid in heat"* and freezing – *"a liquid can change into a solid in OoC"*. In this scene, Team J distinguished heat and coldness (OoC), which was also evident in the next scene's commentary.

In Scene 9, students exemplified how solid substances would turn into liquids when they received heat – *"when solids, like ice cream or ice cubes, are heated they melt and change into liquids".* This statement acknowledged that solid substances needed to receive heat to change conditions. Then, they explained how liquids changed into solids after they were put in a cold place – *"On the contrary, when a liquid is in a cold place, then it changes into a solid, like this glass of water"*. Students considered heat and cold two different entities because they did not refer to removing heat from liquids to help them change into solids.

Then, in Scene 10, students elaborated more on how substances would change conditions at different temperatures – *"Coming out of the temperature rooms … the glass with the ice cubes changed into a liquid body, water, because of the high temperature".* Students emphasised the need for solids to be at a *high temperature* to turn into liquids and for liquids to be at a low temperature to change into solids – *"Coming out of the cold room, the glass with water had turned into a solid".* With this statement, Team J again made the distinction between heat and coldness clearer.

In Scene 11, Team J commented that liquids turned into gases during evaporation –*"when the temperature is high, water evaporates, and vapours make the atmosphere misty".*

In Scene 12, students made an unclear comment about evaporation and condensation – *"when hot water evaporates, windows become misty, and then it changes back to liquid".* There seemed to be confusion between evaporation and condensation, as with the English students in the SEeDS activity (section 6.2.2). The animations in Scene 12 may have helped students to recognise the process of condensation. Still, students' insufficient underpinning knowledge or incomplete understanding of condensation did not allow them to explain it properly.

In Scene 13, students described the liquid particles' movement when the temperature changed – *"when the temperature is high, particles in water move faster … whereas in low temperature particles move slower".* It was the first time that Team J students referred to particles' movement throughout the story – despite Scenes 2,4, and 6 also showing particles' movement in the three states of matter – perhaps guided by the animations, which depicted two thermometers with *high* and *low temperatures,* respectively.

In Scene 14, Team J students described the process of melting in a natural setting, commenting that *"snow starts to melt because of the sun's heat and changes into liquid. Melting happens".* Students emphasised how the *sun's heat* would help a solidified substance, like snow, *change into a liquid* without offering a detailed explanation. This approach was also evident in their recorded interaction, shown in the extract from *Transcript 3/Seq2*:

S1: It snows in the mountains
S2: And then the sun comes out and water is created
S1: How is water created?
S2: Because the snow dried out
S1: I don't think that the snow dried out
S2: You know what I'm saying… It melts
S3: Right, it melts. Shall we write why it melts?
S2: Because of the sun. Of the sun's heat.
S3: Got it.

Transcript 3/Seq2: Team J, Greek students, Narration activity

When S1 pointed out that Scene 14 depicted *snow in the mountains*, S2 offered a more detailed description of how the *sun comes out and water is created.* S1 sought further explanations about the creation of water, with S2 clarifying that *the snow dried out.* S1 disagreed with S2's statement, so S2 clarified that the snow *melts.* S3 agreed with that and asked the reason that snow *melts.* S2 then explained that melting happened because of the *sun's heat*, and S3 seemed content with that answer. As the example from *Transcript 3/Seq2* revealed, S1's prior knowledge of melting was limited and S2, who had a better understanding, offered two different explanations (*snow dried out/snow melts*) to help S1 overcome that gap. It is uncertain whether S2 confused *drying out* with *melting* or thought they had the same outcome.

Finally, in Scene 15, Team J students commented that *"in a lot of heat, water will evaporate faster",* making a stronger statement about how higher temperatures would help water evaporate faster.

In total, the Narration activity revealed the gaps in Team J students' prior understanding of condensation (often confused with evaporation); particles' movement in gases, and the distinction between heat and coldness as two entities.

6.2.4 The Narration activity in the English context

The Narration students' commentaries were based on scientific explanations with side-story commentaries, similar to the English students from the SEeDS activity (section 6.2.2) and the Greek students from the SEeDS activity (section 6.2.1). A typical exemplar from Team B is presented.

Figure 19: The completed story of Team B, English students, (Year 6, Narration activity)
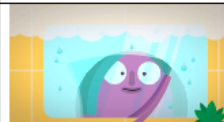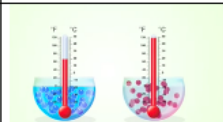
Team B students began their story by introducing solids through a side-story comment: *"Curtus was playing football and came across an ice cube, which is a solid …."* Students referred to hardness as a property of solid substances by commenting that *"… [Curtus] carved himself out with a hammer and a screwdriver, using anything weaker it would be hard to cut out".* Although students did not differentiate between hard rigid and elastic soft solids, they indirectly referenced hard solids by stating that a weaker tool would not cut out a solid.

In Scene 2, students continued with solids, describing their particles' movement – *"particles in a solid don't move as much as particles in a liquid".* Students' decision to make a general

comment about particles' movement in solids and liquids might be because they were uncertain about particles' closeness and/or arrangement.

Having finished with solids, Team B continued with liquids in the next two scenes. Particularly, in Scene 3, students began with a side-story comment – *"Brinch got a cup of orange juice…".* They did not seem to recognise the thick orangey liquid like honey, commenting that *"the liquid turned into solid, later on, the juice got warmer…"* Students acknowledged that a liquid could turn into a solid and then back again into a liquid if it received heat. Then Team B made a general reference to the property of liquids as being runny materials, stating that *"… it spilt all over him".*

In Scene 4, students commented on the liquid particles' movement – *"the particles in a liquid move more than particles in a solid".* Students' comment in Scene 4 is a rephrased statement of their comment in Scene 2. That could mean that students' knowledge about the particles' movement in solids and liquids was incomplete.

In Scene 5, students referred to boiling– *"Flash boils some water and drinks it"* – and then melting – *"but it is way too hot and spat it out, and it went all over the ice block, and the ice turns into a liquid".* They explained that when a hot liquid substance, like boiled water, is spread all over a solid substance, like an ice block, it turns the solid into a liquid.

In Scene 6, students referred to particles' movement in gases – "*When balloons are filled up with air, the particles move around a lot"* – and in liquids – *"and when the balloons are filled up with liquid it becomes heavier, and the particles don't move as much".* Students made general comments about particles' movement in gases and liquids and did not specify the closeness or arrangement of particles when they move. This approach was also found in Team B's recorded interaction, as shown evidence from *Transcript4/Seq1*:

S4: So, after the first one it shows particles in solids and how they move...

S3: Cells in solids don't move

S4: Of course, they do, look!

S3: No, they don't move

S1: They move slightly

S3: Oh, well. What about this one [scene]?

In *Transcript 4/Seq1*, Team B members initially had a disagreement about particles' movement in solids, during which S4 pointed out that solid particles move and S3 rejected that statement. S4 insisted on her statement and prompted S3 to look at the scene. The content did not convince S3 of the scene, and S1 sought to clarify things stating that solid particles move slightly. S3 accepted S1's explanation and suggested continuing with another scene.

In Scene 7, still, on the concept of gases, Team B students made a side-story comment inspired by the animations in the scene – *"Billy was cold, so he made a fire and smoke went up causing pollution"*. They probably did not feel like repeating similar things because they commented on the gas particles' movement in the previous scene.

In the next three scenes, 8, 9 and 10, students commented on the process of melting and freezing. Starting with Scene 8, they stated that "*Flash goes into a hot environment and Brinch goes into a cold environment"*, suggesting that the two rooms had different temperatures. In Scene 9, they referred to the items that the story characters held -– "*Flash starts with a solid and Brinch started with a liquid".* They described how solids turned into liquids in heat – *"when Flash entered the hot environment, his solid turned into a liquid"* – and how liquids turned into solids in the cold – "*When Brinch went into a cold environment, then his liquid turned into a solid".* Students did not explicitly label the two processes as melting and freezing, but they provided satisfactory scientific explanations about how solid and liquid substances would change conditions at given temperatures. It could also be argued that students considered heat and cold as separate entities if taken into account that they did not

refer to heat as being added to or removed from a body. In Scene 10, students made a side-story comment about the outcomes of melting and freezing – *"When Flash comes out of the hot room his liquid spills on the floor, and when Brinch comes out of the cold room the block of ice falls out of the cup"*. That would mean that the character's solid became a liquid during melting and the other character's liquid became a block of ice during freezing. Team B students seemed to have sufficient prior knowledge about melting and freezing, despite not having labelled them precisely.

Likewise, in Scene 11, Team B students focused on making a side-story comment about the story characters – *"Brinch is in the shower trying to warm up when Curtus turns the shower up to go really hot"*. This side-story comment about the increase of temperature in a room was linked to the next scene, in which the mirror misted up after the character Curtus turned up the temperature in Scene 11.

Thus, in Scene 12, students viewed condensation as an entity, commenting that "*condensation is on the mirror and Curtus rubs it off so now he can see clearer"*. They seemed to recognise mist as a condensation characteristic, yet they could not explain the process using scientific terminology. That was also evident in the following abstract from Team B's recorded interaction:

> S1: Have we done condensation?
> S2: No, we 've still got condensation
> S4: Condensation is about steam, right?
> S3: Yeah… So, we did all the changes of the states? Shall we tell this one next?

> Transcript 4/Seq2: Team B, English Students, Narration activity

As *Transcript 4/Seq2* shows, none of the students in Team B provided sufficient scientific explanation about condensation other than that it is linked to steam.

In Scene 13, students again made an abstract comment about how *"they are both thermometers, the one on the left is in cold water, and the one on the right is in hot*

water". Students did not describe the particles' movement when the temperature was high or low nor refer to a thermometer.

In Scene 14, Team B referred to melting, commenting how a solidified substance like snow melts with the help of the sun – *"It is cold and snowy and then the sun comes out and melts all of the snow".* They made an indirect reference to the sun as the main source of heat that melts the snow.

Finally, in Scene 15, Team B students referred to evaporation, commenting that *"there is a puddle in a hot place and the sun evaporates the puddle and creates rain clouds".* Students recognised the sun as the main source of heat that helped liquid bodies to evaporate, an approach evidenced in the next extract from Team B's recorded interaction:

> S3: Yes, it happens here as well! But it's not the same... the sun picks up any water, its evaporation here.
> S2: Yeah, it's evaporation here 'cause you see how it's transferred, the sun picks it up
> S4: So, what's evaporation about? Water or air?
> S2: It's both

Transcript 4/Seq 3: Team B, English Students, Narration activity

In *Transcript4/Seq3*, students described evaporation as how *the sun picks up any water,* and how [water] *is transferred.* Still uncertain about the process of evaporation, S4 asked clarification about which substances were involved in evaporation to receive a response from S2 that it was both liquids (water) and gases (air). Students' choice to refer abstractly to the sun that *picks up water* might be because Team B students did not have a solid understanding of evaporation.

Overall, the Narration activity revealed the gaps in Team B students' prior understanding of particles' movement in solids, liquids, and gases and when the temperature changes (increase or decrease); the distinction between heat and coldness as two entities; condensation; the use of a thermometer.

6.2.5   Summary

This section provided evidence about how the SEeDS and the Narration activity might have supported students across the two contexts to access, reflect on and apply prior science learning. Drawing on the data sets from students' resultant digital stories and recorded interactions, the findings showed that students differentiated between heat and cold, describing them as two different entities. All students across the four representations of data sets recognised that in heat, certain solid substances turn into liquids (melting) and that in cold certain liquid substances change into solids (freezing). Similarly, all students recognised the sun as the main source of heat.

The Greek and English students did not provide complete scientific explanations about particles' movement in all three states of matter. Still, they made general comments about how the solid particles would move less than the liquid particles and how the gas particles kept a distance between them and moved around. Finally, the two activities revealed gaps in the Greek and English students' prior knowledge regarding the concept of heat, which was seen as a different entity from coldness, and the concept of condensation. Both the Greek and English students acknowledged that condensation was linked to steam and vapours, yet they could not explain how it would happen and which substances changed conditions.

6.3 Students' use of talk whilst carrying out collaborative work in science (RQ2)

The next step of this analysis (section 5.8.2) focused on the types of talk students naturally used while working collaboratively in each activity. With the aim to provide answers to *RQ2: "Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?"* this section drew on evidence from all the Greek and English students' recorded interactions, presenting extracts from both activities across the two contexts. Considering that the framework for the coding and analysis of students' talk was developed in an English-speaking context, data from the Greek students' talk is compared with that of English students. Doing so will address a fair comparison and strengthen findings across contexts. Section 6.3.1 presents findings from the SEeDS activity in Greece, section 6.3.2 from SEeDS in England,

while the following sections, 6.3.3 and 6.3.4, refer to the Narration activity in Greece and England, respectively.

6.3.1 SEeDS students' talk in the Greek context

Whilst working collaboratively through the SEeDS activity, Greek students' talk appeared to include often characteristics of the talk that Mercer and his colleagues (1999) defined as *exploratory talk*, involving constructive dialogue and critical thinking (Mercer and Howe, 2012). Drawing on data from the recorded interactions of all the Greek students helped to identify the characteristics of *exploratory talk.* A typical example could be found in the following extract from Team D:

(Note: In all transcripts, T = teacher; S = student; implied words are in brackets; all student names have been replaced by Students in Numbers, e.g., S1, S2 etc and Greek teachers' names have been replaced by English pseudonyms).

Indications of exploratory talk	Examples
Disagreeing without evidence - Relating content	S4: This must be the bathroom [scene], this is evaporation
	S1: No, that's condensation
	S2: It's liquefaction
	S3: This [scene] is liquefaction
Providing explanation – justifying opinion	S2: This [scene] goes after the other [scene] with that thing because it tells you that it turns it [thermometer] down because it's hotter and then it tells you, you know why steam is created because the temperature goes up
	S4: And water becomes gas

Transcript 5/Seq 1: Team D, Greek Students (Grade 6, SEeDS activity)

As can be identified in *Transcript 5/Seq1*, Team D's interaction included elements of *exploratory talk*. Students expressed their views clearly and explicitly, listened to each other's ideas, and provided explanations when necessary before reaching a joint decision. For

example, Team D students seemed to initially disagree about the scene's content if it showed *evaporation, condensation,* or *liquefaction*. *"This must be the bathroom [scene], this is evaporation"*, claimed S4, with S1 stating the opposite – *"No, that's condensation".* Then S2 stated that *"it's liquefaction",* with which agreed S3 - *"this [scene] is liquefication"*. Students disagreed without evidence until S2 provided a scientific explanation – *"it … turns it [thermometer] down because it's hotter and then it tells you, you know why steam is created because the temperature goes up"* (S2). S4 then explained further that *"… water becomes gas"*. Both students sought to explain that the depicted phenomenon was condensation and provided justifications about how it was created. After their initial disagreement, participants seemed to be engaged with one another's thinking. So there was a flow in their discussion, as the following example shows:

Asking for clarifications	S2: Yes. What happens here then?
Providing explanations	S1: It's raining
	S4: What do you mean it's raining? It's the steam that created the droplets
	S1: Ohhh, I see… I thought it was dripping … oh, they [characters] have put a glass … a protective glass
	S3: So … when Nikos saw Alexandros coming in …
	S2: He dropped his pants [laugh]
Seeking joint agreement	S4: You guys, maybe it's because he was sweating?
Reaching joint agreement	S3: Yes, you are right!

Transcript 5/Seq 2: Team D, Greek Students (Grade 6, SEeDS activity)

As the discussion continued in *Transcript5/Seq2*, S2 asked for clarifications about a scene, and S1 thought it was *raining*. S4 tried to explain that it was not rain but *"steam that created the droplets"* (S2), yet S1 seemed confused or surprised – *"ohhh… I see … I thought it was dripping"* (S1). S2's answer did not convince S1 as she was also confused about the appearance of the glass in the bathroom – *"…oh, they [characters] have put a glass … a protective glass"* (S1). No student commented on S1's statement, and they continued with a

side-story comment about the story character who *dropped his pants*, for which they quickly reached a joint decision.

Asking for clarifications	S1: So where will this one, with the thermometer, go then?
Relating ideas to content	S2: It goes to the one with heat
	S4: We should put the thermometer here because it is a liquid too
	S3: No, I don't think so, it includes liquid. Just like heat.
Asking for clarification	S1: Is this temperature or heat?
Providing incomplete explanations	S3: It's heat, in fact. Here is the cold one, at 20 degrees Celsius.

Transcript 5/Seq 3: Team D, Greek Students (Grade 6, SEeDS activity)

When they finished their discussion around evaporation (*Transcript 5/Seq1* and *Transcript 5/Seq2*), Team D students continued with the scene of the thermometers. As *Transcript 5/Seq3* reveals, S1 first sought to clarify *where the scene with the thermometer would go.* Trying to relate their ideas to the scenes' content, S2 proposed putting it together with the heat scene, whilst S4 suggested ordering it with other liquids because it was a liquid. S3 disagreed and clarified that it *included liquid* instead, *just like the heat.* S1 seemed uncertain about the ideas shared by his team members and asked for further clarifications – *"is this temperature or heat?"*. Then S3 provided a partial explanation, possibly guided by the animations in the scene – that *"it is the heat, in fact. Here is the cold one, at 20 degrees Celsius",* making a clear distinction between heat and coldness. There was a flow in Team's D interaction in *Transcript 5/Seq3*, in which students built on each other's ideas.

Whilst much of Team D's interaction included elements of exploratory talk, with clarifications sought and justifications provided, there were also moments of disagreement without satisfactory explanations, which indicate elements of *disputational talk* (Mercer *et al.*, 1999). The episode in *Transcript 6* shows a less typical event, worth of discussion:

Indications of disputational talk	Examples
Making an assertion	S4: That's [scene] what we need
Disagreeing	S3: No, it isn't
Disagreeing – offering alternative explanation	S1: No, this [scene] doesn't come here guys, 'cause I think it's the last one
Insisting on the assertion	S4: That one is the same as that
Disagreeing without explanation	S2: No, I don't think we need that one
Making a command	S3: Put this one here... This is melting too
Talking back	S4: Why don't you do it?
Defending oneself	S3: 'cause you said you 'd do it

Transcript 6: Team D, Greek Students (Grade 6, SEeDS activity)

As seen in *Transcript 6*, there was little evidence of joint engagement with each other. Much of Team D's interaction consisted of disagreement, commands and assertions and unproductive quality. S4 initially asserted that they had found the necessary scene, with S3 disagreeing without explanations. At that point, S1 also disagreed but offered an alternative explanation – *"No, this [scene] doesn't come here guys, 'cause I think it's the last one"* – still without justifying it. S4 insisted on his opinion, and then S2 expressed her disagreement – *"no, I don't think we need that one"*. While ideas flaunted, S3 commanded his teammate to *put the scene there because it showed melting*. S4 declined the command and proposed to S3 to do it himself, only to get S3's defensive answer, *"'cause you said you'd do it"*.

In this shared example of *Transcript 6,* Team D's talk involved examples of the type of talk that Mercer and his colleagues (1999) defined as *disputational,* which prevailed individualised assertions that were not supported by reasoned arguments. That, however, was a short incident that barely appeared during their collaborative interaction, as there was no pattern or sequence of reappearance. Students' responses used constructive dialogue as shown in the following *Transcript 7:*

Indications of exploratory talk	Examples
Making a suggestion – asking for clarification	S2: Guys, I think it doesn't go here. How is this melting?
Attempting to explain – questioning the scene	S4: From solid … wait, the sun came out, warmed it and it started running …
Agreeing with and confirming previous suggestion – relating to evidence	S3: Yes, look here …. the sun comes out, it warms it and so water runs
Disagreeing – attempting to clarify	S1: Yes, but that doesn't happen here … the way it's transferred, it evaporates
Offering an explanation	S1: Evaporation is here, when it's transferred, because the sun shines on it
Seeking joint decision	S2: Ok, so, where do we put the thermometer?
Providing further explanation	S4: Here, after this one… 'cause the thermometer shows us how much temperature increases

Transcript 7: Team D, Greek Students (Grade 6, SEeDS activity)

As seen in *Transcript 7,* S2 asked for clarifications about a scene, which resulted in another student (S4) realising that something else was happening in that scene – "*From solid … wait, the sun came out, warmed it and it started running".* S3 agreed with them and repeated the previous statement by S4 – *the sun came out, it warmed it, and water ran*. Then S1 expressed his disagreement and attempted to clarify that the process they were looking at was evaporation (instead of melting). S1 explained that *"evaporation is here when it's transferred because the sun shines on it"*. Then S2 sought a joint decision regarding the scene with the thermometer. S4 explained where they should place the scene because *the thermometer showed how much the temperature increased*.

Generally, students' interaction in Team D had *exploratory* and *disputational talk elements.* The short inferences of *disputational* talk rarely appeared, as Team D students often engaged with each other and shared a mutual understanding, without being trained to use *exploratory talk,* as it will be discussed extensively in section 7.3.

6.3.2 SEeDS students' talk in the English context

Like the Greek students' talk (section 6.3.1), the English students' talk seemed to include characteristics of *exploratory talk*. After analysing all the English teams' interactions, an example from Team E is shared in *Transcript 8*, showing how students regularly engaged with each other's ideas before reaching a common decision (Mercer and Howe, 2012):

Indications of exploratory talk	Examples
Seeking opinion	S1: Where do you think this is going to?
Offering ideas	S4: Well, I guess that one [scene] must surely go first
Agreeing with suggestions	S3: Yes, I was going to put that one [scene] first
	S1: That one is like they are in this room
	S1: So, I would say this one to go first
	S2: Right
Seeking [joint] agreement	S1: Is it this one?
Providing evidence from the content	S4: Yes, 'cause he goes in there
Seeking understanding	S1: Does it make sense?
	S4: Yes
Disagreeing with previous statement	S3: No, wait that doesn't look right
	S2: I know
Providing some explanations	S3: The sun has to melt the water or whatever above this place
	S4: Yeah, but still that doesn't make sense
Common agreement	S1: I think she's right
	S2: That [scene]would be there
Offering ideas	S2: I think when they go in there, the one in the cold and the one in the heat
	S3: Let's put it here then
	S4: Yeah

Transcript 8: Team E, English Students (Year 7, SEeDS activity)

In *Transcript 8*, English students' interaction began with students discussing the ordering of a scene. The four students agreed that the particular scene should *go first* without any scientific explanations*.* At some point, S1 wanted to ensure that *made sense,* with S4 consenting to it. Seemingly, the SEeDs activity brought to the surface the role of sensemaking – *"does it make sense?"* – helping the students to understand what they were producing. Nonetheless, one student (S3) disagreed with S1 because it *did not look right.* S2 agreed, without providing supporting evidence, which resulted in S3 providing some explanations about her point of view – "*The sun has to melt the water or whatever above this place".* S4 was uncertain about her teammates' statements, arguing that it *still did not make sense.* S1 agreed with S4, yet none provided any justifications for their point of view in the disagreement. Finally, S2 shared her idea about the one character *going in the cold and the other in the heat,* with the rest agreeing.

Nevertheless, Team E's exchange of ideas did not always unfold engagingly. There were occasions, for example, where students' talk had obvious features of *cumulative talk*. Students engaged in short moments of uncritical sharing of ideas (Mercer *et al*., 1999) along with repetitions and confirmations. The extract in *Transcript 9* reveals the less typical appearance of *cumulative talk* that is fundamentally important to discuss:

Indications of cumulative talk	Examples
Seeking joint decision	S4: So that is the first one 'cause that's the one they are introducing themselves and then we said it was this one 'cause it's showing the kettle and the gases
Making a suggestion	S2: Wouldn't it be after the balloons?
Repeating the suggestion	S3: After the balloons
Accepting the suggestion	S1: Oh, maybe yeah
Seeking for confirmation of decision	S4: So, shall we use that one? Or? Because we are not sure
Confirming decision	S3: Yeah, that one and then watch the other one first …
Re-confirming of suggestion	S4: Yeah, because they seem like the gas particles
Proving some explanation	S3: That's when the boy lit the fire
Seeking confirmation	S2: But should we use that one?
Confirming decision	S4: Yeah...
Explaining the decision	S3: It's actually the same...
Re-confirming and repeating decision	S1: Yeah, it's actually the same... we can put it back for now and then we can decide

Transcript 9: Team E, English Students (Year 7, SEeDS activity)

In *Transcript 9*, there were points in Team E' discussion in which students contributed ideas that were accepted passively. Although there was a cooperative interaction, there was no critical consideration of ideas but indications of repetitions and confirmations. For example, when S4 sought the team's opinion about a scene, S2 suggested placing it after the [scene with the] balloons, and S3 repeated the suggestion. Another student (S1) accepted the suggestion but had some doubts about it. Then S4 sought to confirm the team's decision, with some hesitation. None of the other members seemed to share S4's hesitation, and S3 reconfirmed the previous statement and proposed to *"watch the other one first"*. S4 seemed to agree with her teammates, reconfirming the previous statement finally – *"…. they seem like the gas particles"*. Then, S3 provided some explanation for choosing that scene guided by the animations – *"That's when the boy lit the fire"*, making thus a side-story comment. S2 was

still uncertain about that scene, but S3 reassured her that it was the same. Team's E discussion ended with S1's idea to *"put it back for now and then we can decide".* Although incidents like this one were not repeated in Team E students' discussion, they were worth mentioning to establish the various types of students' naturally occurring talk while working collaboratively.

Overall, students' discussions in Team E had *exploratory* and *cumulative talk* elements. Despite the short inferences of *cumulative talk*, Team E's talk was most engaging and constructive in an instinctive way, without having received the training that participants in the study of Mercer and his colleagues, as it will be further discussed in section 7.3.

6.3.3 Narration students' talk in the Greek context

Whilst working through the Narration activity, the Greek students seemed to instinctively make use of *exploratory talk*, as they engaged with each other's views before reaching a joint agreement (Mercer and Howe, 2012). A typical example of that is documented in the extracts from Team B *(Transcript 10):*

Indications of exploratory talk	Examples
Seeking for joint decision	S3: What should we write here?
Making a suggestion	S2: Evaporation
Disagreeing with previous statement	S4: That's not evaporation
Relating to content	S1: Can't you see that it becomes gas! Evaporation means gas, G-A-S!
Seeking for clarifications	S3: Guys, isn't it evaporation when it makes boom, and you get blinded?
Providing answers without explanation	S1: No!
Asking for further clarifications	S3: So, which one is evaporation?
Providing answers	S1: This one here, where he cleans the window
Seeking for further clarifications	S3: From what?
Providing answers with some explanations	S1: From evaporation
	S2: It's from the liquid which did gas
	S3: Did what?
Providing answers with some explanations	S4: Evapor…. It became a gas

Transcript 10: Team B, Greek Students (Year 5, Narration activity)

As seen in *Transcript 10*, Team B's interaction included elements of *exploratory talk* such as seeking a joint decision by S1 at the beginning of the discussion, which resulted in S2 making a suggestion and S4 disagreeing with that. Although neither S2 nor S4 explained their statements, S1 emphasised that it was about *evaporation*, relating it to the content of the scene, which showed *gas*. Then S3 wanted to clarify if evaporation was about an explosive-like process, with S1 denying it without justification. S3 asked for further clarification as to *which scene was evaporation*, and S1 pointed out the scene in which the character *cleaned the window*. S3 was still uncertain about the scene's content and asked for further

clarification. S1 stated that the character *cleaned the window from evaporation*, whilst S2 offered a more detailed explanation that the liquid *did gas.* Finally, S4 confirmed that evaporation was about the liquid that *became a gas*, even though she had difficulty pronouncing the term evaporation.

In the episode shared in *Transcript 10*, students seemed to engage with each other, despite the simplistic and often unjustified exchange of ideas. There were other occasions, appearing less often, in which students would engage in the sharing and building of information in a positive yet uncritical way, defined as *cumulative talk* (Mercer *et al.*, 1999), as shown in Team's B example of interaction in *Transcript 11*:

Indications of cumulative talk	Examples
Making a statement	S3: So, we should write that the particles in solid bodies do not move
Repeating previous statement	S1: Yeah, in solids particles do not move
Relating evidence to content	S2: Guys, look what they are doing
Repeating previous statement	S4: They are not moving
Refuting previous statement	S2: They are moving… they are moving slightly
Accepting new statement	S1: So, write that down... in solids particles move slightly, and they are close to each other...

Transcript 11: Team B, Greek Students (Year 5, Narration activity)

As seen in *Transcript 11*, Team B students exchanged ideas about the scenes' content but did not build on each other's ideas nor offer any explanations as to why they accepted or refuted those ideas. For instance, one student (S3) suggested making a commentary about *the particles in solid bodies* that *do not move,* and S1 accepted that suggestion by repeating S3's statement. Then another student (S2) pointed out the animations in the scene, trying to relate evidence to the scene's content. S4 did not see anything different; thus, he repeated the previous statements about the *solids' particles not moving.* S2 refuted S4's statement, arguing that *solids particles were moving slightly,* perhaps guided by the animations of the scene. Eventually, S1 accepted S2's statement, despite his initially opposing statement, and

repeated what they should write down – *"in solids particles move slightly, and they are close to each other".*

Overall, Team B students' interaction was defined by *exploratory* and *cumulative talk* elements. There was a flow in their interaction, which was often constructive and sometimes passive. Students mainly engaged with each other's ideas and provided explanations where necessary, which will be discussed in section 7.3.

6.3.4 Narration students' talk in the English context

Elements of *exploratory talk* were also found in the interactions of all the English students, who worked collaboratively through the Narration activity. Drawing on evidence from Team A as a typical example, the English students seemed to build on each other's ideas whilst offering satisfactory scientific explanations in *Transcript 12*:

Indications of exploratory talk	Examples
Making a side-story comment	S2: This [scene] shows two balloons... they are filled up with air
	S3: And with water
Relating evidence to content	S1: Look at the particles
	S3: Particles in water move more
	S2: So, that would be...?
Relating evidence to content	S4: The particles in here, they move around a lot
Building on previous statement	S2: And when they [balloons] are filled up with the liquid, the particles don't move so much
	S3: Yeah
Making a side-story comment	S1: So, what's with the smoke here? ... The boy made a fire 'cause he was cold and smoke went up causing pollution
Seeking for clarifications	S2: And what's with the jars? I don't get it
Providing explanations	S4: I think it's the particles in the smoke and they get into the jars
	S3: In the bigger jar, they spread out but in the small one they don't spread out that much ...
	S4: They [particles] are closer to each other in the small jar
Reaching joint decision	S2: Yeah. Let's write it out

Transcript 12: Team A, English Students (Year 7, Narration activity)

In this episode of *Transcript 12*, indicative elements of *exploratory talk* are found in the constructive way students build on each other's ideas while seeking and offering explanations before reaching a common agreement. Team A's discussion began with a side-story comment about a scene, which resulted in S1 suggesting that they should *look at the particles and* relate the scene's content to scientific evidence. Then S3 explained that *particles in the water moved more,* and S4 added that particles *moved around a lot,* without clarifying if he referred to the gas or the liquid particles. S2 built on the previous statements, arguing that when *[balloons] are filled up with liquid, the particles don't move so much...* After a side-story comment by S1, guided by the scene's animations, S2 wanted to clarify why there were jars in the scene, with S4 and S3 providing some scientific explanations about it. S4 stated that the smoke particles

would get into the jars, and S3 explained in more detail that *particles spread out in the big jar, but in the small one, they did not spread out that much.* S4 also added that *particles were closer to each other in the small jar,* and S2 agreed and proposed to write it down in their commentary.

During their interaction, the English students would disagree without justifying their claims or engage in competitive communication, which are considered key features of *disputational talk* (Mercer *et al.,* 1999). The episode in *Transcript 13* provides supporting evidence of the less typical incidents of *disputational talk* found in the Narration students' interactions:

Indications of disputational talk	Examples
Making a statement	S1: So, ok, this [scene] is about gases
Adding to the previous statement	S3: Evaporation
Disagreeing with initial assertion - pointing out an alternative option	S2: Not that [scene], this [scene] is about evaporation
Disagreeing …	S3: No, it's not that. Wait
… making a counterclaim	S3: Here's the liquid with evaporation
Disagreeing – proposing an alternative	S2: This is not evaporation, this is!
Disagreeing	S3: No, it's not that either
Proposing an alternative	S4: The one with the bathroom, this must be evaporation
Disagreeing and making a different assertion	S3: No, that's condensation
Moving on to the next scene	S4: We can decide later … What about this one?
Checking assertion	S3: Is it evaporation?
Rejecting assertion	S1: Nah… that's in the other one [scene]
Providing some explanation	S2: That's when the sun comes out and snow melts

Transcript 13: Team A, English Students (Year 7, Narration activity)

As seen in *Transcript 13*, students from Team A disagreed a lot during this episode, without justifying their opposing views and counterclaims, trying to impose their opinion on each other. For instance, at the beginning of their discussion, S1 stated that a scene showed gases and S3 related it to *evaporation* without justification. S2 seemed to disagree with S3, pointing out that *evaporation* was in another scene. The two students (S2 and S3) kept disagreeing, offering counterclaims without supporting explanations. S4 then made a different suggestion, pointing out the scene *with the bathroom*, which he thought might have been *evaporation*. S3 shared an opposing view, claiming it was *condensation.* At that point, and perhaps realising that they would not reach a joint decision, S4 changed the subject and continued with another scene. S3 wanted to check whether the new scene was about *evaporation*, but S1 rejected S3's assertion, stating that *[evaporation] was in another scene.* The episode in *Transcript 13* ended with S2 explaining the scene's content whilst making an indirect reference to melting – *when the sun comes out, snow melts.*

The shared examples from Team A's recorded interaction revealed that English students' talk included elements of both *exploratory* and *disputational talk*. Students seemed to engage constructively with each other, making suggestions, offering justifications, and seeking joint consideration. On some occasions, students would become more competitive, expressing their disagreement and individualised decision-making, which will be discussed in more detail in section 7.3.

6.3.5 Summary

This section shared examples of how the Greek and English students' instinctive talk included elements of *exploratory talk* as they worked together to implement the SEeDS and the Narration activity. Unlike Mercer, Wegerif and Dawes' (1999) study participants, neither the Greek nor English students received any prior training in using *exploratory talk,* meaning that the two digital storytelling activities – SEeDS and Narration – engaged students in a coordinated form of co-reasoning and argumentation. Both the Greek and English students from the SEeDS activity had elements of *exploratory talk* in their interactions as they exchanged and built on each other's ideas, provided explanations, and reached joint decisions about the content of the scenes and their ordering. In a similarly constructive way, the Greek

and English students from the Narration activities used *exploratory talk*, as they shared a common understanding and offered justifications about the scenes' content. Most of the time, the explanations students provided as they worked through each activity were simplistic and minimal, which is quite expected because of their young age (Mercer *et al.,* 2004).

The occasional appearance of elements of either *cumulative* (sections 6.3.2 and 6.3.3) or *disputational talk* (sections 6.3.1 and 6.3.4) in both the Greek and English students' recorded interactions established the existence of various types of talk found in students' collaboration. While working together to implement the activities, students occasionally engaged in a positive yet uncritical interaction *(cumulative talk)* or a competitive and conflicting exchange of ideas *(disputational talk)*, which was part of their social interaction. A deeper discussion about the three types of talk found in participants' collaborative interaction is conducted in Chapter 7.

6.4 Challenge and engagement through the two activities (RQ3)

The final step of the thematic analysis (section 5.8.3) sought to answer RQ3 "*Whether, and, if so, how do the SEeDS and Narration activities engage and challenge learners in the two contexts?".* Deriving evidence from students' group interviews and team interactions allowed for categorising students' views about SEeDS and Narration into three themes, *Ownership of Creation, Fun* and *Conceptual Complexity*. Section 6.4.1 presents the Greek students' views about the two activities and section 6.4.2 shares examples from the English students' views.

6.4.1 The Greek students' views about SEeDS and Narration

The Greek students' views about the two activities were analysed based on the code manual (identified from the data analysis, section 5.8.3) presented in *Table 18* below. The quote excerpts presented below reveal that Greek students enjoyed their activity, SEeDS or Narration, and found them creative. The SEeDS students felt that their activity was hard and sometimes tiring, while the Narration students found it easier having to invent only the story plot.

Category class: The structure of SEeDS and Narration			
Properties (attributes)	**Ownership of creation**	**Fun**	**Conceptual complexity**
Dimensional range (attributes)	less … more	less … more	hard … easy
Quote Examples			
SEeDS students	*S5: we had to first think about ordering the scenes and then invent the plot* *S1: we had to think hard so that it [the ordering] make sense* *S3: I liked that we had to order the videos [scenes] in our own way and to make commentaries about them* *S2: I liked the fact that we had to make the commentaries* *S1: I liked that we worked together – we don't do it often – to create our own story*	*S2: it was quite fun; we've never done it before* *S4: awesome* *S1: we should do it again in other classes as well* *S3: amusing* *S5: fun*	*S5: some scenes gave us a hard time and we got tired* *S1: we had to think harder about how to order the scenes and we didn't know where to start* *S2: it was hard because we had to match the scenes together …* *S2: because there were many scenes, it wasn't easy to figure out which scene goes where, which one goes first and so on* *S4: it was hard because there weren't any captions, and we didn't know how the right order should be* *S3: it was a bit hard… but fun… and we certainly learnt from it … learnt about each scientific phenomenon*
Narration students	*S2: we had to use our imagination* *S3: I enjoyed watching these videos and having to make the plot commentaries* *S5: there were some 'crazy' videos I really liked, and we*	*S1: ours [version of activity] I think was more fun because it's very confusing when you have to order the scenes*	*S1: it's easier having to only invent the plot* *S3: our [activity] was easy, all the scenes were connected* *S2: if we had the other activity, we would think*

	used our 'crazy' imagination to make commentaries **S1:** I liked that we could personalise the story, naming the characters as we liked	**S4:** I like animations, they are child-friendly, quite funny	harder and we would get tired at the end. I prefer ours

Table 17: Categorisation of the Greek students' views about SEeDS and Narration

In terms of engagement, the first theme, *Ownership of creation,* revealed that the Greek students were excited with the activity they implemented and felt they had personal ownership. Students from the SEeDS activity liked that they were free to order the scenes according to their understanding and make commentaries about them. For instance, Student 5 stated, *"We had to first think about ordering the scenes and then invent the plot"* (S5), while S3 pointed out, *"I liked that we had to order the videos [scenes] in our way and to make commentaries about them"* (S3). That kind of ownership, however, seemed hard to some students – "*We had to think hard so that it [the ordering] make sense"* (S1).

Narration students also felt excited about how they owned the creation of their story. Indicative of what Narration students said are the views: "*I enjoyed watching these videos and having to make the plot commentaries"* (S3) and *"There were some crazy videos I really liked, and we used our crazy imagination to make commentaries"* (S5). Students from the Narration group also mentioned personalisation as a way of ownership. *"I liked that we could personalise the story, naming the characters as we liked"* (S1), a statement that no student from the SEeDS activity made, despite having also named their story characters. That personalisation touch was also found in the Narration students' recorded interaction. An example of students' typical interaction is documented in *Transcript 14*:

> S3: So, guys, first it's the three guys who present themselves. Shall we name them now?
>
> S2: Yes, so, this is Glassy and he's a liquid, because all he does is to drink from this glass. And this is Firefly, and he is a gas, because he drinks this weird drink and he burbs.
>
> S1: We forgot the round-shaped one.
>
> S3: He 'll be Roundy.

<div align="right">Transcript 14:Team E, Greek students, Narration</div>

Narration students liked to name the story characters; it felt more personal. As shown in *Transcript 14*, Team E students named the story characters after their basic features (e.g. round shape, drinking from a glass etc.). That was a typical, indicative example of how the Narration students added personal touches to their stories.

The second theme regarding engagement, *Fun*, indicated that students from both groups enjoyed their activities and would like to do them again in other lessons. Students from the SEeDS group said they had never worked through similar activities. Students stated that *"It was quite fun; we've never done it before"* (S2) and that they *"should do it again in other classes as well"* (S1).

Students' enjoyment of the SEeDS activity was also noted in the observation notes *(Appendix 19)* taken during the day, which documented that all the teams from St'2 (Grade 6) felt excited about the SEeDS activity because they found it interesting and mind-challenging:

> *Point 4) Although all of the groups said that they felt excited about this activity and they found it "mind-challenging" and interesting enough, Group D wasn't very keen on writing the dialogues.*

> *Point 6) Group C said about the intervention: "it was a bit difficult that we had to order the clips but that was mind-challenging, and we liked it"/ "it helped us understand physics better"/ "it was a great activity, I wish we could do more like that"/ "we wouldn't have preferred the activity any other way (like with the ordered clips)"*

However, as shown in Point 4, Group D was not very keen on making the written commentaries, despite being the group with the best ideas and most appropriate answers regarding the story plot.

Similarly, students from the Narration group found their activity very funny, favouring *""animations, they are child-friendly, quite funny""* (S4). Some of them seemed to prefer the Narration over the SEeDS activity because it was an easier one. As S1 explained,

"ours [version of activity] I think was more fun because it's very confusing when you have to order the scenes" (S1).

In terms of challenge, the third theme, *Conceptual Complexity*, revealed that the structure and creative process of the SEeDS activity were sometimes tired and confused students. *"Some scenes gave us a hard time, and we got tired",* stressed S5. The rest of the team agreed and added that they *"had to think harder how to order the scenes and didn't know where to start"* (S1) and *"it was hard because we had to match the scenes together" (*S2). The absence of visual or audio commentaries and the presentation of the scenes in an order that was not predefined seemed to have troubled SEeDS students. As one student pointed out, "*because there were many scenes, it wasn't easy to figure out which scene goes where, which one goes first and so on"* (S2), while another student (S4) highlighted that *"it was hard because there weren't any captions, and we didn't know how the right order should be"*.

The findings from the recorded interactions of the SEeDS students enriched evidence in support of the activity's conceptual complexity. In the shared example of *Transcript 15*, while Team J students were trying to determine the right order of the story scenes and make sense of the story content, they were confused about the content of a single scene:

> S2: So, in the first one they greet, 'hello', and he does his trick
>
> S4: And then he is the Solid and makes a solid ice
>
> S1: This one **confuses me**; he makes something solid…
>
> S4: He makes a solid ice
>
> S3: He makes his solid sculpture
>
> S2: And then it's this guy with the honey

<div align="right">Transcript 15: Team J, Greek students, SEeDS</div>

As *Transcript 15* shows*,* students had to decide about the ordering of the scenes after they reviewed every scene. That appeared to be challenging, considering that there was no narration embedded in the scenes. Thus, S1 seemed confused by that scene which showed the character making an ice sculpture of himself. S4 and S3 explained that the character was related to solids, creating *"a solid ice"* (S4) and *"his solid sculpture"* (S3), making an indirect

reference to solids in the first scene. After the scene with the solids, they would place the scene in which was *"the guy with the honey"* (S2).

The absence of narration from the scenes seemed to challenge another SEeDS team, as students were troubled about the content of particular scenes, as *Transcript 16* documents:

> S3: Ok, so what do I write? Solids, liquids, gases?
>
> S1: Yes, solids, liquids, gases
>
> S2: It is **very confusing!**
>
> S4: **Very confusing!**
>
> S2: I don't know though; I don't think that commentary goes there

<div align="right">Transcript 16: Team D, Greek students, SEeDS</div>

Transcript 16 shows that, even after determining the order of some scenes, Team D students (S2 and S4) were confused about the scenes' content, not knowing what to comment on.

Students' difficulty in implementing the SEeDS activity was also evidenced in the observational notes taken on the day (Appendix 19). Group C, for example, at the end of the activity, commented, "*It was a bit difficult that we had to order the clips, but that was mind-challenging, and we liked it*" or that *"it helped us understand physics better".*

Students from the Narration group did not face similar difficulties through their activity. As S1 said, "it's *easier having only to invent the plot"* (S1)*,* with S3 agreeing that *"our [activity] was easy, all the scenes were connected"* (S3). Students generally favour easy tasks that do not require much effort. As S 2 admitted, *"if we had the other activity, we would have to think harder, and we could get tired at the end. I prefer ours"* (S2).

To conclude this section, the two digital storytelling activities, SEeDS and Narration, seemed to engage the Greek students. They found them enjoyable, fun and felt they had personal ownership of their creation. In terms of challenge, the SEeDS activity appeared hard-thinking, difficult and occasionally troubling because it required students to think about the story plot

and the ordering of the story scenes. The Narration activity was characterised as easy to implement, allowing more time for its students to focus on the story plot.

6.4.2 The English students' views about SEeDS and Narration

In *Table 19* below, quotes from the English students' group interviews are shared to show that English students not only enjoyed SEeDS and Narration, but they also favoured it more than a regular science lesson at school. The SEeDS students felt that the activity was hard, taking longer to complete. The Narration students found their activity easy because it helped them to focus on the content.

Category class: The structure of SEeDS and Narration			
Properties (attributes)	**Ownership of creation**	**Fun**	**Conceptual complexity**
Dimensional range (attributes)	less … more	less … more	hard … easy
Quote Examples			
SEeDS students	*S2: you have your own way of doing it and not being told how you do this and how you do that…* *S5: you can be more free and more independent, and it is more creative and easier* *S3: you don't have like any short notice to do this and to do that, definitely you don't feel the pressure on you*	*S3: it's quite fun* *S4: I think it's a good idea that these videos … you 've got learning, you learn about them* *S5: I thought that was fun* *S2: and useful* *S1: I like it because we don't do anything like this at school*	*S2: it was harder* *S4: it takes too much time to put together all the characters, think of the storyline...* *S1: it takes too long to create the storyline and think what the characters might be doing and make possible speech as well* *S5: it was a bit hard trying to find the right place for each video*

	S1: and you 've got to find out the answers like work out yourself		S3: it's not like some notes the teacher gives, you do this and this and this and you just go for it… and you don't really get it then … but if you spend more time, you get and understand it and you can re-watch it
Narration students	S5: more creative way of doing that rather than getting little notes and writing them like we do in lesson S3: it's easier for us because it shows it step-by-step, like easier than the teacher goes ... you can read them independently but if like in a group with a teacher in the whole class… S1: it feels like we could all do something S2: it makes it quicker as well and no one gets left out	S5: I would do it again S2: It was good S1: It was really fun … I'm glad I came S4: we should do it in like in different topics S3: we never do anything like this at school… I think we should have like an extra lesson, in which we are doing this kind of stuff	S5: it makes it easier for us to think about the content S1: I didn't think it was complicated … S3: it was easier to know the story because it was … S2: visual S4: visual, only thing that you had to do is look and then it reminded you of what it was…

Table 18: Categorisation of English students' views about SEeDS and Narration

Regarding students' engagement in the two activities, the first theme, *Ownership of creation,* revealed that like the Greek SEeDS students, the English students liked the activity because it allowed them to be creative while working independently, without being told how

to do something. An indicative example was given by S2, stating that she owned the "*way of doing it and not being told how you do this and how you do that".* Another student (S5) added that he felt "*more free and more independent and that [the activity] is more creative and easier".* At the same time, S3 compared the SEeDS activity with a regular science lesson, stating that he *"didn't have like any short notice to do this and to do that, definitely you don't feel the pressure on you".* In addition, S1 liked that they could determine the content themselves, arguing that "you've *got to find out the answers, like work out yourself".*

Being able to replay each story scene as many times as they wanted, helped the English students to take the time to focus on the content before ordering the scenes. A typical example is found in students' recorded interactions shown in *Transcript 17*:

> S4: Erm… shall we see that one again?
>
> S2: Well, that doesn't really show that much
>
> S1: It's like kind they are going into two rooms
>
> S3: They 're doing something before going in there but I have no idea what…
>
> S4: Yeah… and where would you put it? Before or after?
>
> S2: I think you put it just before they go in
>
> S4: Let's look that again, shall' we?
>
> S3: Yeah, but it's actually the same... we can put it back for now and then we can decide

<p align="right">Transcript 17: Team D, English students, SEeDs</p>

In *Transcript 17*, one student (S4) asked her teammates to watch a particular scene again before deciding where to place it. None of the students was sure about the content of that scene, as their responses revealed – "*Well, that doesn't really show that much"* (S2); "They're *doing something before going in there, but I have no idea what"* (S3). S4 sought a joint decision about – *"Where to put it? Before or after?"* and S3 suggested to *"put it back for now, and then we can decide".* Having the opportunity to change the order of the scenes as many times as they wanted, allowed Team D students to rethink the story content and work out possible solutions until they reached the most desirable ones.

Like the Greek students, the English students also found that Narration was creative and easy to complete because the activity allowed all the students to get involved in creating the story

plot. An indicative example came from S5, who compared the Narration activity to a regular science lesson, stating that it was a "*more creative way of doing that rather than getting little notes and writing them like we do in the lesson*". S3 added that it was "*easier for us because it shows it step-by-step, like easier than the teacher goes … you can read them independently but if like in a group with a teacher in the whole class…*". Also, other students, like S1 and S2, agreed that the Narration activity made all students feel like they "*could all do something*" (S1) and that it made it *"quicker as well and no one gets left out"* (S2).

The second theme regarding engagement, *Fun*, showed that the SEeDS and Narration students enjoyed their activity and would like to do it again in other lessons, as it was not an activity they did often. Students found the SEeDS activity as *"fun"* (S3, S5), *"useful"* (S2) and informative, while S4 referred to the animated videos – "*I think it's a good idea that these videos … you've got learning, you learn about them*". Another SEeDS student (S1) stated that he liked the activity because they *"don't do anything like this at school"*.

Like the Greek Narration students, the English students also enjoyed their activity and felt glad to have participated in it because they found it "*really fun"* (S1) and *"good"* (S2). They wished they could *"do it again"* (S5) "in different topics" (S4), because they *"never do anything like this at school … I think we should have like an extra lesson, in which we are doing this kind of stuff"* (S3).

In terms of challenge, the third theme, *Conceptual Complexity,* documented the English students' views about the challenges they faced through the two activities. Same as the Greek SEeDS students, the English students found that the SEeDS activity "*was harder"* (S2) because it took *"too much time to put together all the characters, think of the storyline"* (S4). Moreover, S1 pointed out that it took "*too long to create the storyline and think what the characters might be doing and make a possible speech as well",* whilst S5 added that *"it was a bit hard trying to find the right place for each video".* Despite SEeDs being hard to implement, S2 praised the fact that they were required to think hard to understand it – "*it's not like some notes the teacher gives, you do this, and this and this and you just go for it… and you don't really get it then ... but if you spend more time, you get and understand it and you can re-watch it".*

Regarding the challenge found in the Narration activity, the English students (like the Greek Narration students) found it "*easier to think about the content*" *(S5)* and "*did not think it was complicated*" (S1). A student (S3) stated that with Narration, it "*was easier to know the story*" because it was *"visual, the only thing that you had to do is look and then it reminded you of what it was"* (S4).

Watching the whole story as many times as they wanted, helped the English Narration students focus on the story content and the plot invention. A typical example could be seen in *Transcript 18*:

> S1: Shall we just watch it from, like from, the top?
>
> S2: Yeah
>
> S3: Let's watch it through and think then what we should write in that one…
>
> S4: So, here he's telling them about the two rooms. The man will go into the hot room and the lady will go into the ice room.
>
> S1: And then this guy, who was next to him goes in and wipes the mirror to see himself.
>
> S2: Yeah, let's do that then
>
> S3, S4: Yeah

<div align="right">Transcript 18: Team C, English students, Narration</div>

In *Transcript 18,* Team C students decided to watch the story again from the beginning to help them think about what they should write in the commentaries. Doing so, one student (S4) pointed out what the scene depicted - *"… here he's telling them about the two rooms. The man will go into the hot room and the lady will go into the ice room".* Then, another student (S1) explained what happened in the next scene until they all reached a joint decision about what to write in the commentary.

In conclusion, SEeDS and Narration seemed to engage the English students, who found the two activities enjoyable and creative, giving them time to work independently. The SEeDS activity was characterised as hard to implement in terms of challenge. That is because it required much time to think about the order of the scenes and the plot. Yet, some SEeDS students liked that the activity required hard thinking because it helped them better

understand the science topic. The Narration activity was characterised as easy, not complicated to implement because students could look at the whole story to remind them what it was about.

6.4.3 Summary

In this section, extracts from students' group interviews and recorded interactions and observational notes were used to demonstrate how engaging and challenging the two activities, SEeDS and Narration, might have been for Greek and English students.

The Greek students stated that they enjoyed the activity on which they worked, SEeDS or Narration because it allowed them to be creative and use their imagination. The Greek students who implemented SEeDS found the activity hard, tiring, and occasionally confusing. The Narration students found their activity easy to implement because all the scenes were connected, and they only needed to invent the plot.

The English students enjoyed the activity they implemented, SEeDS or Narration, comparing it to a regular science lesson. The English students who worked through SEeDS felt that their activity was hard and challenging and that they had to spend a lot of time on it to understand it and figure out the answers. The Narration students found their activity easy because it showed them all the scenes, step-by-step, helping them focus on the story's content.

6.5 Chapter Summary

A systematic analysis of this research's findings (Chapter 5) helped to review the data collected in response to the three driving research questions of this research. Each section demonstrated evidence from the Greek and English students who worked collaboratively to implement the SEeDS or the Narration activity. The two activities, SEeDS and Narration, helped the Greek and English students to think about and externalise their understanding of many scientific concepts related to matter (RQ1). The activities also revealed students' gaps in prior knowledge about the particles' movement (especially in gases and liquids and when the temperature changes), the concept of heat (seen as a distinct entity from coldness), and condensation.

Moreover, SEeDS and Narration appeared to promote the Greek and English students' instinctive use (as they were not taught this type) of *exploratory talk (RQ2),* which included elements of shared understanding, building on each other's ideas, providing explanations, and reaching joint agreements. The occasional appearance of elements of either *cumulative* or *disputational talk* in the Greek and the English students' recorded interactions established the existence of various types of talk found when students work together to implement a science activity.

Finally, regarding the third research question (RQ3), the data analysis identified that SEeDS and Narration engaged the Greek and English students, who enjoyed the activities and found them creative and fun. SEeDS appeared to have sometimes tired and troubled both the Greek and English students because, as they stated, they had to think harder about the plot and the ordering of the story scenes. Across the two contexts, the Narration students found the activity easy to implement, stating that it gave them enough time to think about the story plot.

CHAPTER 7: DISCUSSION OF FINDINGS

7.1 Introduction

This discussion chapter aims to review in-depth the findings and determine the extent to which the driving questions of this research have been answered. The chapter draws on the findings from Chapter 6 and cross-references these with the literature discussed in Chapters 2 and 3. It is not the aim of this chapter to assert a specific position, but instead to present the discussion in a way that enables the reader to get closer to students' collaborative interaction and engagement with the two digital storytelling activities, allowing them to draw their conclusions (Grbich, 2007).

The three main research questions provide the organisational structure for this chapter, underpinned by Mercer, Wegerif and Dawes (1999) framework for the typology of peer talk in science learning and the pedagogical framework of problem-based learning. The chapter argues that the two digital storytelling activities, SEeDS and Narration, can support students in accessing, reflecting upon and recalling many scientific concepts relevant to the topic of matter. At the same time, it helps them to identify gaps in their prior knowledge. The two activities also seem to promote students' instinctive use of *exploratory talk,* considering that students have not previously been trained into using it. The occasional appearance of elements of either *cumulative* or *disputational talk* in students' interaction establishes the variety of talk used when working together to implement a science activity. The final section of the chapter argues that SEeDS and Narration engage and challenge students in the two contexts. The SEeDS activity is challenging, making it hard to complete and tiring and confusing, whilst the Narration activity is easy to implement and provides the opportunity for students to focus on inventing the story plot.

7.2 Supporting learners to access, reflect upon on, and apply prior science learning (RQ1)

It was essential to this research to establish and document how SEeDS and Narration might have supported the Greek and English students in thinking about and externalising their prior learning, as reflected in the first research question:

"Whether, and, if so, how do the SEeDS and Narration activities support learners in each of the two contexts to access, reflect upon, and apply prior science learning?"

In response to the first research question, the overall conclusion is that the SEeDS and Narration helped students to recall, think about, argue about, and explain relevant to matter concepts, such as the *particle's movement (in solids), heat, temperature, melting, freezing and evaporation* (section 6.2). The two activities also helped to identify gaps in students' prior knowledge about *the particles' movement (in gases and/or liquids and when the temperature changes), the distinction between heat and coldness as two separate entities and the concept of condensation.* This overarching finding is discussed next as three interrelated subsections.

Firstly, the problem-based nature of the two digital storytelling activities is emphasised, highlighting the carefully scaffolded learning experience found in SEeDS and Narration in helping students to externalise their understanding of the science topic of matter.

Secondly, digital storytelling in science can facilitate serendipitous learning and stimulate interest in science while supporting prior knowledge.

Finally, the use of scientific explanations as part of the story plot can indicate how the students externalised their understanding (or lack thereof) of matter and its relevant concepts.

7.2.1 The problem-based nature of the two activities

The findings of this research (section 6.2) reveal that the problem-based nature of the two digital storytelling activities, SEeDS and Narration, helped the Greek and English students recall and externalise and identify gaps in their prior knowledge about matter. Deriving evidence from the Greek (sections 6.2.1 and 6.2.3) and English (sections 6.2.2 and 6.2.4)

students' resultant digital stories and their recorded interactions showed that students were able to state most of the scientific concepts related to the topic of matter. Still, scientific explanations did not always underpin these. The argument is that the two activities' problem-based nature helped students engage and interact actively with the learning material. Yet, some concepts like *condensation* and/or *heat (heat and cold seen as distinct entities), particles' movement in gases or when the temperature changes* were hard to (understand and) explain (see section 7.2.3) despite any collaborative engagement and interaction.

PBL methods are constructivist, student-focused approaches that promote reflection, skills in communication and collaboration (Yelland, Cope and Kalantzis, 2008) and help learners to develop strategies and construct knowledge (Hmelo-Silver, 2004). This research acknowledges that the information that team members exchange to solve a problem does not coordinate into a new piece of knowledge in each member's head (Hatano and Inagaki, 1991). Still, it values students' sharing and expanding on each other's ideas instead of individual solutions until a common ground is reached (Barron, 2003; Clark, 1996). The findings of this research align with existing research on the beneficial role of problem-based instruction in primary students' collaborative solving competency in science learning in a seamless learning environment (Song, 2018). This research goes beyond Song's (2018) assessment of students' problem-solving skills. It highlights how engagement in collaborative problem-solving can help students to reflect on and identify gaps in their existing knowledge (see more in section 7.2.3).

Considering the limitations in research examining the use of problem-based digital storytelling activities in science learning (sections 2.5 and 3.8), this research designed SEeDS and Narration activities as digital story problems. Having to decide about the sequence of events and devise the storyline (SEeDS) or devise the storyline of a given story (Narration) are seen as jigsaws, whose solutions require different strategies. The SEeDS and Narration activities were based on ill-defined story problems that did not have a single identifiable answer. Students had to brainstorm and generate ideas related to the problems to identify issues (Araz and Sungur, 2007) involved in the stories. Unlike the study of Araz and Sungur (2007), in which teachers guided students on approaching the story problem, this research made a difference by allowing students to work autonomously and take full responsibility for

solving the story problem. That increased the possibility of all team members to contribute to the discourse (Arvaja and Häkkinen, 2010) by thinking about and exchanging new ideas (Linn and Eylon, 2006); resolving opposing views (Amigues, 1988); explain one's thinking (Webb *et al.*, 1995); receive explanations, and make critique (Chi, 2000).

The SEeDS activity required students to analyse a digital story problem (how to order the story scenes) and define the context (sequence of story events) and content (externalise prior knowledge). Then, students had to apply deductive and inductive processes to understand the problem (which story scenes match together) and find a possible solution (invent the plot) (Etherington, 2011). The Narration activity required students to understand the problem (what the ordered scenes represent), define its content (externalise prior knowledge) and find a possible solution (invent the plot). Students had to comprehend relevant visual information through the two activities, conceptually organise the data, recognise the problem's deep structure, correctly sequence their solution activities, and evaluate the procedure used to solve the problem (Jonassen, 2011). Students' inquiry skills can be developed through PBL instruction when students work together to gather the necessary information from the available material and solve the problem, following a step-by-step problem-solving procedure (e.g., representation of problem(s), development of solutions, and monitoring and evaluation of a plan of action) (Chen and Chen, 2012). This research goes beyond what Chen and Chen (2012) noted, showing that primary students can engage in the problem-solving of ill-structured problems (Lesh, English, Riggs, and Sevis, 2013) without following a guided procedure. As the SEeDS and Narration students tried to solve the story problem, they employed those strategies to help them make the right decision. While many studies examining the strategies that students use to create coherent stories have focused on developing narrative and language skills (Nicolopoulou, 2019; 2016; 2008; Nicolopoulou and Trapp, 2018), this research went a step further. It highlighted the contribution of problem-solving strategies in helping students to externalise and reflect on their understanding of the learning material.

Decision making is itself an explanation-based process (Jonassen, 2011) because students as decision-makers have to make sense of the story pieces presented to them to aid the selection process. SEeDS students had to make a sequencing choice among alternative

options, and Narration students had to make a content decision out of a given option. These decisions are part of learners' strategies to construct a coherent story (Nicolocopoulou, 2008). SEeDS and Narration students generated arguments to help them to resolve any rising conflicts regarding the different choices (Jonassen, 2011). Making arguments requires knowledge of the available options. Students' decisions depended on how they argued for and against each option based on their knowledge and how they combined those arguments to reach a joint decision (Jonassen, 2011). SEeDS and Narration students had to externalise and refine their prior knowledge about the topic of matter before sequencing the story events (SEeDS) or verbalising the story content (Narration). Students' final decisions resulted from the process of supporting or rejecting alternative claims/decisions (Jonassen, 2011) and were constructed as an explanatory representation in story form that contained causal accounts of the evidence (Jonassen, 2011).

Asking students to solve problem-based stories like SEeDS or Narration enabled them to control aspects of the story presentation (Moreno and Mayer, 2007) and thus take ownership of their creation and challenge their existing assumptions (Kucirkova, 2019). The sharing of ideas and information allowed the Greek and English students to share understanding and make meaning based on their collaborative interpretation. As the findings revealed, the two activities enabled the Greek and English students to interact critically with the content to determine its presentation (SEeDS) or define its content (Narration), relate the story parts to previous knowledge, and provide sufficient scientific explanations in their story commentaries. The open-ended nature of the two activities enabled students to think harder and uniquely apply their knowledge beyond the frames of the fragmented teaching sequence. That aligns with the widely accepted view that harder versions of the same task can generate better results (Brown *et al*., 2014), as students can learn more in the least preferred conditions (Kelly and Tangney, 2006). Beyond what Brown *et al.* (2014) and Kelly and Tangley (2006) noted, this research highlighted that there were occasions that students felt tired and confused by the harder version of the SEeDS activity, which might have acted as an off-putting factor for some students (see later section 7.4.2) That could be due to the open-ended, not predefined nature of SEeDS, which made students' collaboration more stressful because there was no clear script on how to proceed (Azmitia, 2000).

The ordering strategies that SEeDS students employed indicated how students conceptualised matter by matching together chunks of information based on their shared collaborative understanding. The learning strategies that Narration students used to make sense and verbalise the content of a predefined story indicated whether (or not) students' externalisation of prior knowledge about matter followed the hierarchical teaching sequence proposed by the science curriculum. The problem-based nature of each activity posed different challenges for students, which could, in turn, prove to be either positively thought-provoking or detrimental to students' understanding of matter. The SEeDS and Narration activities were not just story problems students had to solve. The two activities were based on problems carefully broken down for each activity to capture what the Tricky Topic and Stumbling Blocks were. Meaning that the design of the story problems relied on the careful scaffolding of the learning experience, making the contribution of this research unique. The important role of scaffolding the learning environment in terms of task features (e.g. sequencing) and a problem-based learning context is also found in Leuchter, Saalbach and Hardy's (2014) study. However, the current research stepped beyond what Leuchter and his colleagues (2014) did – measuring students' success or failure in understanding scientific concepts using scientific reasoning – and evaluated students' interpretation of scientific concepts through the carefully scaffolded learning experience found in SEeDS and Narration. As the students worked through the two ill-structured problem-based activities, they had the opportunity to think about new ideas (Linn and Eylon, 2006), resolve opposing views (Amigues, 1988); explain one's thinking (Webb *et al.*, 1995), receive explanations and make critique (Chi, 2008). As the Greek and English students sought to make sense of the context and the content, they actively interpreted the ideas they encountered in the story scenes (Osborne and Dillon, 2010). As a result, students shared a common way of understanding through collaborative efforts, aligning with the socio-constructivist learning perspective (Silcock, 2003). The suggestion, therefore, is that problem-based activities, including various challenges, can promote the instinctive use of fruitful learning strategies by positioning students as problem solvers.

7.2.2 The use of digital storytelling in science

Drawing on evidence from this research, it could be argued that the two digital storytelling activities provided an interesting way for the Greek and English students to show their understanding of matter and an opportunity for them to organise and present their knowledge. The process of abstracting and organising data is an effective way of engaging students in higher-order thinking (Chu, Hwang and Tsai, 2010) and critical thinking (Dewi *et al.,* 2019; Nanjappa and Grant, 2003). Whilst this research did not seek to assess students' communication skills like O'Byrne, Stone and White (2018) did, it highlighted students' sharing of ideas, asking questions, expressing opinions, and constructing stories while interacting with others and the iPads. Trying to access information, interpret and organise their prior knowledge and then (produce and) represent what they knew to others is linked to meaningful and transferable knowledge (Jonassen *et al.* 1993). As the SEeDS and Narration students worked in a collaborative learning environment, it helped them to engage in reflective thinking and evaluation (Nanjappa and Grant 2003).

Findings from this research are in accordance with the study of Hung *et al*. (2012) and Sadik (2008) on the benefits of using digital storytelling in the science class in promoting learning motivation and problem-solving capability (Hung *et al*., 2012; Sadik, 2008). The study of Hung and his colleagues (2012) also provided valuable information about digital storytelling in improving learning performance. In doing so, Hung *et al.'s* (2012) study fell into the trap of assessing context-bound performance, missing out on two vital points. First, it focused on the learning outcome than on the learning process, not considering that "learning, or at least aspects of it, occurs in mind; and second, the behaviour is not *a priori* a reliable indicator of cognitive processes" (Adams, 2006a, p. 244). It could be argued that students' good or poor performance at the specific project-based activity, used by Hung and his colleagues (2012), accurately indicated cognitive development. Yet, it could be inferred that such performance was nothing more than an indication of the students' ability to carry out the task's requirements. The study by Hung et al. (2012) failed to recognise how students constructed their knowledge of a specific topic to evaluate it accordingly, and this is where this research came in contrast. Researchers need to acknowledge that students previously failed to understand or inadequately synthesise information. Thus, any new interpretation of

information could be insufficiently based (Adams, 2006a). Therefore, research must focus on how the activities can help students to reflect on their understanding, as in the case of this research. Science (digital) storytelling research needs to focus on how learners construct knowledge individually and shift from assessing performance to learning. As such, there will be a thorough evaluation of the various ways in which individuals acquire, select, interpret and organise information (Adams, 2006a) - that is, students' thinking.

This research found that the two digital storytelling activities encouraged students to express their ideas and knowledge in an individual and meaningful way (Robin, 2016; 2008; 2005). Students tried to personalise their stories by adding name recognition (Fitzgerald *et al*., 2017) and human-like personalisation. The personalisation of stories (Hu, Gordon, Yang and Ren, 2021) helps students to externalise and reflect on their understanding of scientific concepts and engage with the content and context of the story (Hadzigeorgiou, Klassen and Froese Klassen, 2012). Putting a personal touch to the stories adds a layer of playfulness, authenticity, and immediacy to the story (Kucirkova, 2013; Kucirkova *et al.,* 2010). That could also be attributed to the use of animations.

The animations in the two activities were carefully selected to connect to the curriculum content and encourage active learning and collaboration, helping students to conceptualise the science content (Barak *et al*., 2011; Barak and Dori, 2005; Najjar, 1998). Moreover, the choice of the animations sought to address the educational needs of students in the topic of matter. Considering that participants were middle- to low- attainers, animations helped them to enrich challenging cognitive processes, such as abstraction or imagination that could be short of. The findings showed that students understood better concepts and events, such as particles' movement in temperature changes. This research extends the work of Barak and his colleagues (2011), highlighting the value that thoroughly selected animations had on learners with different learning styles.

Studies found that the use of animations and visualisations could improve students' conceptual understanding (Barak and Dori, 2005), learning achievements (Dori et al., 2003), and motivation to learn science (Rosen, 2009). The studies mentioned enriched evidence supporting animations' ability to create mental pictures among students that were similar to

the mental model of scientists, based on the construction of computerised molecular models (Barak and Dori, 2005; Dori *et al*., 2003). Also, anthropomorphism – adding human qualities to the substances – can aid the retention of scientific concepts (Banister and Ryan, 2001). Despite their essential contribution to the field of science learning, these studies sought to review and assess the impact of technology on an otherwise traditional lab experiment. Doing so, they failed to acknowledge the importance of students' thinking during the learning process of the activities.

Similarly, Rosen (2009) examined the impact of narrated animations in online stories on the transfer of knowledge and motivation to learn science and technology. The focus again was on students' performance before and after using the digital medium. Although Rosen (2009) recognised knowledge transfer as one of the key components of higher-order thinking skills, he ignored the learning process through which students unfolded their thinking. This research accepted the value of carefully selected animations on the transfer of knowledge and proposed the use of inaudible animations as equally motivating and engaging. Apart from being enjoyable, animations are believed to help students to visualise individual concepts and the relationships between them to gain an idea of the whole then. In such a way, abstract concepts become more concrete (McCartney and Samsonov, 2011).

On the other hand, animations could be underwhelming and lead to excessively passive information processing. The dynamic and vibrant nature of videos and animations could pose a threat to novice learners, as the processing of visual materials required "high levels of mental abstraction and synthesis of the procedures modelled that could overload students' cognitive capacity" (Moreno, 2007, p. 766). That would prevent learners from performing effortful cognitive processes required for deep understanding (Schnotz and Rasch, 2005). That could be the case when the chunks of information exceed students' cognitive load capacity (Sweller, 2007). Considering that Grade 5 students were taught the topic of matter two months before conducting this research, it was expected that they might lack sufficient content knowledge to guide their attention (Moreno, 2007). Learners' cognitive capacity develops with age (Flavell, 1963), which could explain why older students (Grade 6) were confident in handling all that information. In addition to the fact that they relied on retrieving knowledge and past experiences to help them understand relevant information (Anderson,

1983). In either case, knowledge is not memorising single chunks of information, which could confuse students if presented in a greater number than the proposed teaching one. Meaning that if students lacked appropriate domain knowledge to guide their attention (Moreno, 2007), they might easily get distracted from the vibrant nature of the animated videos. Learners have their schemes of understanding, which are constructed through mental representations rather than chunks of information fitted into their brains. In contrast to that behaviourist view, in social constructivism, learning is a mindful activity that occurs in the mind (Adams, 2006b). There is a need, thus, for embracing a socio-constructive approach to teaching and learning science that does not primarily rely on performance scores to identify students' understanding of science.

The use of animations in both activities drew reference from the second principle of the Cognitive Theory of Multimedia Learning (CTML), that of *limited capacity* (see section 2.4.3). According to this principle, each of the two information channels, the visual and the auditory, have limited capacity for processing information at one time (Mayer 2014). For example, information that was initially presented to the visual channel could also be represented in the auditory one if learners had devoted sufficient cognitive resources to the task (Mayer, 2005). As in the case of this research, the Greek and English students across the two activities received information only from the visual channel, and they had to construct the corresponding verbal description in the auditory channel. That was not an easy task for the Greek and English students to achieve due to the absence of what Clark and Mayer (2011) called *the contiguity principle*. That principle states that "the effectiveness of multimedia instruction increases when words and pictures are presented contiguously (rather than isolated from one another) in time or space" (p. 444). That suggests that separating the animation from the commentary (spatial non-contiguity) may disrupt the building of referential connections needed to support problem-solving transfer (Clark and Mayer (2011). In other words, if SEeDS and Narration students viewed animations along with concurrent annotations, they could have provided richer descriptions of the depicted scientific concepts. Despite the cognitive difficulties a single-channel presentation entails, this is often the case with storytelling tasks. Learners are asked to produce a fictional story based on information presented to only one channel – to the visual channel, for example – using a written prompt

(Merritt and Liles, 1989), one picture (Coelho, 2002), several pictures (Hickmann and Hendricks, 1999), a wordless storybook (Botting 2002), a video (Eaton *et al.,* 1999).

Finally, there were occasions in which some story scenes looked alike that made students feel confused and tired and led them to mistaken scientific explanations. Students often might face deep-rooted difficulties in certain concepts, even though they previously scored high in formal tests. The complexity (confusion) and tiring elements found in SEeDS and Narration could aid to uncover these misconceptions rather than promote the repetition of superficial knowledge. The two activities offered a new way of thinking and organising information, contrary to the traditional teaching methods of feeding students with information carefully created to compile the right memorisation (Adams, 2006a).

7.2.3 Students' scientific explanations about matter

Engaging students in creating their digital stories through SEeDS and Narration revealed how the Greek and English students interpreted and scientifically explained the relevant concepts. As findings (section 6.2) revealed, the Greek and English students showed their understanding of matter by providing explanations about many relevant concepts, such as the *particles' movement in all three states of matter, changes of properties when heat is added or removed, the processes of melting, freezing and evaporation.* It could be argued that the two activities, SEeDS and Narration, provoked students' cognitive processes, such as abstraction, imagination, and creativity (Barak *et al*., 2011), by enabling them to think out of the box and make a story based on their shared understanding. Doing so triggered students' thinking about the depicted scientific concepts and gave them time to think about and provide scientific explanations.

The affordances of significant others, such as peers, also bears influence on the students' scientific explanations, for example, through the joint construction of understanding (section 6.3). The discursive nature of social constructivist learning environments highlights the need to give students time to talk. While the ideas that students exchange during peer interaction may be right or wrong, existing research (Leuchter, Saalbach and Hardy, 2014; Inel and Balim (2010) fails to acknowledge that interactive process by focusing on the measurement of

individual students' concept knowledge. These studies focused solely on students' learning performance after receiving problem-based instruction, without reference to peer interaction. The current research moves beyond the assessment of science performance, recognising the value of peer interaction in offering students the opportunity to scaffold their understanding through the immediacy of shared interrogation (Torrance and Pryor, 1998).

The findings identified (section 6.2) that students' scientific explanations might not have always been rich in description, but they were precise and sufficient. According to Mercer and his colleagues (2004), it is expected that primary students' talk is often quite simplistic and minimal because of their young age. Also, students up to the age of 12 are less able to produce rich story plots and coherent events than older students over the age of 12 (Stamouli, 2012).

Another reason could be that students lacked substantial knowledge (Clough *et al.*, 2013) or had an incomplete or mistaken one. The fragmented way (*hierarchical sequencing,* section 2.3.2) in which matter was taught at school (ΥΠ.Ε.Θ, 2018), might have left students with incomplete or insufficiently constructed knowledge. The findings from this research concur with what Tan, Lee and Hung's (2014) concluded, that students' knowledge – whether it is hierarchical or horizontal – influences the creation of digital stories and the purposeful integration between the narrative context and the knowledge content. Other studies have shown that school science is disconnected from everyday life and learners find it difficult to conceptualise and understand the connections of science (concepts) to the natural world (Osborne *et al.*, 2004). This disconnection gets bigger when students experience and speak about scientific phenomena in an "everyday, or common-sense way of talking and thinking" (Leach and Scott, 2000), which differs from the one presented at school. Therefore, students' understanding is heavily influenced. From this perspective, participants tried to relate the new information taught at school to existing ideas that were inappropriate (Taber, 2001). Such a mismatch is seen as a 'learning block' that occurs when students bring in "aspects of their 'life-world' experience that are not understood in scientific terms. Or it may derive from prior classroom learning, which does not adequately reflect the pre-requisite learning needed to make sense of the new topic" (Taber, 2001, p.130). In this case, it is the teacher's role to identify the situation and adjust their teaching methods accordingly to help learners reconstruct the conceptual structures. On occasions, there may be "a mismatch between the

ideas the teacher believes the student has available, and those they bring to mind in the context of instruction" (ibid). That results in teachers' failure to address students' needs adequately.

Also, certain concepts (e.g., *condensation, particles' movement in gases and/or liquids, heat and coldness*) were troublesome enough for students to understand and explain, unlike others, such as *evaporation* or *melting* and *freezing*. Subsequently, students' understanding of specific concepts is sometimes superficial, regardless of whether they can associate the correct technical term with the event or phenomenon (Osborne and Cosgrove, 1983). Students may use labels like *evaporation* and/or *condensation* precisely but accepted scientific explanations do not underpin their understanding of these terms. The concept of *condensation* was the most difficult to explain, and SEeDS nor Narration helped students to reflect on and identify that difficulty (or gap) in their knowledge. Considering that this research stands by the socio-constructivist view that understanding should be developed by the learner and not predefined by the teacher, it is worth discussing the nature of that concept.

Studies examining students' conceptions about the changes of states (Osborne and Cosgrove, 1983) found that at the age of 8 – 17 years, students' understandings of *evaporation* and *condensation* were most of the times superficial, regardless of whether they could associate the correct technical term with the event or phenomenon. Students tend to use labels like *evaporation* and *condensation* precisely, but these do not underpin their understanding of these terms. In this research, the Greek and English students mentioned the term condensation across the two activities, but they could not describe its process. It is common for students at the age of eight to eleven years to face difficulties explaining *condensation*. Considering that young students' "thinking is perception bound" (Hadzigeorgiou, 2015, p. 74), they have difficulty accepting the idea that water in its vapour state can be present in the air. The air is perceived as a "conduit for the water (formed), but there is no sense that the water can be in the air as a vapour" (Bar and Travis, 1991, p. 704). Students' common-sense views about certain concepts persist even after receiving formal instruction (Talanquer, 2009). The implication here is that the difference between matter and its forms are difficult concepts to grasp at all levels and ages (Adbo and Taber, 2009) and

across different countries (Hatzinikita *et al*., 2005). Not only has the current research verified these findings but identified more detailed aspects of that occurring across different types of engaging activities, such as SEeDS and Narration.

7.2.4 Summary

This section highlights the need to develop proper assessment tools to evaluate students' learning needs beyond the test scores and the performance tables. The open-ended nature of the two digital storytelling activities brought to the surface the deep-rooted difficulties that many students under the age of 12 still had about certain scientific concepts, such as *condensation.* That raises the concern about the proposed-by-the-curriculum teaching sequence, the limited timetables, and the teachers' view of learning. Teachers who view teaching as the transmission of knowledge believe that teaching ways of thinking or presenting problems that require students' independent thinking is inappropriate because it brings frustration and confusion (Zohar, 2008). This view of learning as a transmission process is believed to promote standardised understanding that does not deviate from the prescribed science syllabus set out in the curriculum (Entwistle *et al*., 2002). Teachers need to set open-ended tasks that require students to think independently and critically, giving them the opportunity and incentive to construct personal meaning (Adams, 2006b).

7.3 Student's types of talk that support science learning (RQ 2)

As highlighted throughout Chapter Six, students' recorded interactions provided unique insights into the types of talk the Greek and English instinctively used while working together to implement SEeDS or Narration. As the students were not trained to use *exploratory talk* (Mercer *et al*., 1999), examples from their coordinated ways of arguing, reasoning, and ideas' sharing, together with the other types of talk often found in collaborative learning environments (*cumulative* and *disputational)* allowed exemplifying how they supported students' science learning. The typology of peer talk developed by Mercer and his colleagues (1999) refers to exploratory talk after training. Also, it highlights that *cumulative* and *disputational talk* appear naturally and require no training.

Consequently, the intention, in answering the second research question, is to draw together and discuss students' natural use of exploratory talk to determine:

"Whether, and, if so, how do the SEeDS and Narration activities facilitate the types of peer talk that research suggests can support science learning in each of the two contexts?"

It was evident from the findings (section 6.3) that while Greek and English students worked together to implement SEeDS or Narration, they engaged in the construction of meaning, as participants' existing ideas met the new ideas presented in the talk (Mortimer and Scott, 2003).

7.3.1 The use of *exploratory talk*

The reinforcing nature of open-ended, exploratory talk provides mechanisms and opportunities for mediating knowledge construction into the social space (Adams, 2006). Teachers need to devise more open-ended activities, such as the SEeDS (section 4.3.1) or Narration (section 4.3.2), that require students to get actively involved with the content, think critically, solve complex problems and apply their knowledge in and to the world (Shepard, 2000). The results from this research align with research showing that when students work together in complex tasks with ill-defined problems, they are more likely to exchange ideas and information (Arvaja and Häkkinen, 2010). They may also use higher-level reasoning strategies, such as category search and retrieval and formulation of equations from story problems (Nastasi and Clements, 1991). Thus, students take responsibility for every step of the task, selecting the steps for its solution.

Evidence drawn from the Greek and English students working through SEeDS (sections 6.3.1 and 6.3.2, respectively) and Narration (sections 6.3.3 and 6.3.4) highlighted that the students engaged in exploratory talk by offering opinions and giving reasons to support them and seeking each other's agreement before deciding about the ordering (SEeDS) or the content (Narration) of their stories. Results from Mercer, Wegerif and Dawes's (1999) study with 9-10 years old British children support these findings. Their study was designed to improve the quality of students' scientific reasoning and collaborative activity by developing their

awareness of language use and promoting certain 'ground rules' for talking together. Results from their study on the use of language through collaborative activities in the science classroom applied to this research. When students used the kind of talk that Mercer and his colleagues (1999) termed as *exploratory talk*, it improved their cooperation on problem-solving tasks, as well as their reasoning. This research also found that exploratory talk provided mechanisms and opportunities for individual reflection on and (re)shaping existing knowledge through constructive arguments that co-reasoned in language. Where this research differed was that none of its participating students, neither the Greek nor the English ones, were trained to use the specific ground rules for talking together, as did participants in the studies by Mercer and his colleagues (Mercer *et al.,* 2004; Mercer *et al.,* 1999). Providing teaching guidance was not the purpose of this research. Mercer and his colleagues (2004; 1999) explained that the implementation of the ground rules of *exploratory talk* refers to the frequent use of some specific forms of language, such as the verb *I think* to denote a hypothetical claim (section 6.3.2), the conjunction *because* to support a claim (section 6.3.1), or the question *do you agree* to seek agreement. Throughout students' interactions, there were occasions that these forms of language appeared but at a very low frequency, which was expected as students were not trained to use them.

The findings align with those from the SLANT (Spoken Language and New Technology) project, which explored British primary students' use of talk when engaging in computer-based joint activities (as described in Mercer, 1994). Mercer (2008) maintained the view that (naturally occurring) exploratory talk during group work is uncommon, while it is hard to find "examples of explicit reasoning, and co-reasoning, as exemplified by the use of requests for information, challenges, and attempts to seek agreement" (p. 32). This research stands against Mercer's (2008) view and supports that instinctive exploratory talk can appear less, often in a simplistic way, if students are not trained and guided appropriately.

The problem-based nature of the two activities allowed the Greek and English students to be further ranging in their discussions, throw out ideas and add to each other's thoughts (Hogan *et al*., 1999). While engaging in exploratory talk, students were given the opportunity to construct new ways of understanding through a collaborative negotiation of their meanings (Howe *et al*., 1990; Brook and Driver, 1986). Negotiating a shared understanding

involved engaging critically but constructively with each other's ideas and solving the problem together. Drawing on evidence, SEeDS and Narration allowed students to argue more, seek each other's ideas before reaching a final agreement, and embark on a continuous discussion. These findings are also in line with the studies of Morais (2015) and Kokkotas, Rizaki, and Malamitsa (2010), which recognised the beneficial role of storytelling in science, helping primary students to make connections to their existing knowledge and contextualised gaps in students' knowledge. These studies captured students' understanding of scientific concepts through a combination of storytelling with follow-up hands-on activities. In contrast, this research proved that problem-based stories like SEeDS and Narration could do so without additional pedagogical techniques.

In conclusion, the research findings identified that the problem-based nature of the two activities, SEeDS and Narration, promoted *exploratory talk*. Whether students had to create their story by ordering its events (SEeDS) or by defining the content of the story (Narration), there was a "conflict and an open sharing of ideas in pursuit of rational consensu*s"* (Mercer, 1996, p. 370). According to Mercer and his colleagues (1999), *exploratory talk* is more effective for solving problems through a collaborative activity and is linked to meaning making in science. This research has identified that sharing ideas to reach consensus does not require training the students to conduct this type of exploratory talk but requires carefully scaffolding the activities to elicit this type of talk.

7.3.2. The use of *cumulative* and *disputational talk*

A less frequent type of talk that the Greek (section 6.3.3) and English (section 6.3.2) students used whilst working together on the two activities was *cumulative talk*, which resembled a friendly but uncritical discussion (Mercer *et al*., 1999). It is not uncommon for young students to have an unconstructive exchange of ideas while working collaboratively. That is shown by a tendency to exchange and build information uncritically (Mercer *et al*., 1999). Findings from this research illustrated that there were occasions when students would discuss the scenes' content but uncritically and passively. That would involve accepting each participant's ideas, often repeating the proposed ideas without questioning them. Even when there was disagreement, students would not provide any reasoning or justification for it.

There was an uncritical, sequential continuation of the conversation that failed to address the learning purpose of each activity. That, again, would be very common according to Mercer's (1996; 1994) studies. There might be an exchange of ideas and information in cumulative talk before any joint decisions are reached. Yet, there would be a little challenge or constructive conflict in the process of constructing knowledge. The interaction, in this case, is naturally more like helping each other understand concepts without a need for deeper-level discourse (Arvaja and Häkkinen, 2010).

The last type of talk that the Greek (section 6.3.1) and English (section 6.3.4) students appeared to use occasionally was the type that Mercer and his colleagues defined as *disputational*, characterised by uncooperative and competitive interaction (Mercer *et al.,* 1999; Mercer, 1994). There were instances in which students had a strong disagreement about the content of some scenes, but they would not provide sufficient evidence to support their claims. In these cases, students' statements would be mainly assertive or defensive. Mercer (1996) pointed out the fact that in *disputational talk* the relationship is competitive; information is flaunted rather than shared, differences of opinion are opposed rather than resolved, and the general orientation is defensive" (p. 370), which are in line with this research's findings.

The appearance of *cumulative* and *disputational talk* in the Greek and English students' collaborative interaction could be attributed to students' tiredness, limited attention, lack of knowledge, limited collaboration and/or communications skills, and so more than to the nature of the two activities. Collaborators' interaction and their personalities and relationships can also play an important role in managing collaboration (Arvaja and Häkkinen, 2010).

7.3.3 Summary

To conclude this section, this research has stepped beyond Mercer's work (1996; 1994), showing that the careful scaffolding in the digital problem-based stories of SEeDS and Narration helped students to use *exploratory talk* without having received any training. The

occasional appearance of *cumulative* and *disputational talk* elements established the range in talk types that students instinctively use while working collaboratively. It should be noted that any judgements made about the educational value of any observed talk (*exploratory, disputational or cumulative*) require an additional level of analysis. That is the cultural level, which "inevitably involves some consideration of the nature of educated discourse and the kinds of reasoning that are valued and encouraged in the cultural institutions of formal education" (Mercer, 1996, p. 370). This research will not concern itself with these cultural factors further, as it goes beyond its scope and rationale. Further research is needed to investigate the issue in more depth.

7.4 Engaging and challenging learners (RQ 3)

Underpinning the final research question is exploring whether the structure of the two activities, SEeDS and Narration, engaged and challenged learners in the two contexts (section 6.4). The wording of the question attempts to consider this relationship by asking:

"Whether, and, if so, how do the SEeDS and Narration activities engage and challenge learners in the two contexts?"

Specifically, the findings suggest two things. First, the Greek and English students found the two activities enjoyable, fun, and challenging because they enabled them to work independently and use their imagination. Second, students in the two contexts found the SEeDS activity hard and often confusing and tiring because they first placed the story scenes together and then thought of the plot. Regarding the Narration activity, the Greek and English students felt it was easy to implement because all the story pieces were connected, and they had more time to focus on inventing the plot.

7.4.1 Ownership and enjoyment

The analysis of findings (section 6.4) in the previous chapter indicated that the Greek and English students expressed feelings of pleasure and enjoyment about the two activities. More specifically, they felt like they owned the creation process of the two activities, even though

they had a different level of ownership over each one. Having students involved actively in creating their story, either by sequencing the story events (SEeDS) or by adding narration to a predefined story (Narration), enabled students in the two contexts to use their imagination to invent the story plot. This overarching finding of ownership through creativity aligns with the findings from Siew, Chin and Sombuling (2017) study, who found that the combination of PBL with cooperative learning had fostered children's scientific creativity and understanding of scientific concepts. This research differed in evaluating students' experience of scientific creativity through digital story problems, moving beyond typical science tasks.

SEeDS students felt like they had better ownership of their activity because they first had to determine the ordering and sequencing of events and then invent the plot. That could relate to the third principle of CTML, *active processing* (Mayer, 2014; 2005), which proposes that learners actively engage with learning content to comprehend new information. That is likely to happen using interactive learning environments, in which the learner can actively and directly influence their learning processes (Hillmayr *et al.*, 2020). One way to achieve interactivity in learning settings is by enabling learners to define the preferred order of presentation (Hillmayr *et al.*, 2020). SEeDS, for example, offered participants the opportunity to manipulate – to a certain extent – the presented information, determining thus the preferred order of their story. The physicality of manipulating and methodically arranging digital scenes to match and make sense pushed students to think not only harder but also differently (Matthews-DeNatale, 2013).

The Narration activity did not include such interactive features, so students could not determine the preferred order of presentation. However, the Narration students across the two contexts also felt that they owned the creation of their story because they were free to define its story plot by adding narration. Adding their narration onto the story served as a signal that helped the Greek and English students to "build cause-and-effect relations among the pieces of verbal and visual information" (Mayer, 1997, pp. 18-19). That, in turn, enabled students to build one-to-one connections between actions in the visual and verbal representation (Mayer, 1997).

Apart from owning the creation of the story, the findings of this research documented that the Greek and English students enjoyed the two activities, and they favoured the use of iPads and teamwork. The use of technology-supported activities in science (and other subjects) is a common practice in Greek (ΥΠ.ΕΘ, 2018; Π.Ι, 2011) and English schools (DfE, 2014), especially if schools are equipped with contemporary electronic devices (computers, laptops, tablets, interactive boards and many more). Research provides supporting evidence in favour of such technologies in science learning relating them to secondary students' enhanced interest and motivation (Nikolopoulou and Kousloglou, 2019), primary students' positive reactions about the integration of digital technologies in the classroom (Silva *et al*., 2019) and collaborative learning strategies/collaboration (Fu and Hwang, 2018). Although the use of iPads is not referenced explicitly in either country's science curriculum or the selected schools' regular teaching approaches, the findings suggest their use. IPads in a collaborative setting helped the SEeDS and Narration students across the two contexts to engage creatively with the science content while it enacted their understanding of scientific concepts. It is suggested that teachers use their judgement about when such tools should be used in the classroom (DfE, 2014) and always in accordance with the safety rules (protection of personal data of pupils and teachers) (Nikolopoulou and Kousloglou, 2019).

Lastly, the Greek and English students favoured the animated videos/scenes included in the two activities. Animations in learning are found to support students' motivation in learning science in terms of self-efficacy, interest and enjoyment and connection to daily life (Barak *et al*., 2011). Solomon (2002) highlights the impact of pictures and cartoons in a science story because individuals have a much larger capacity for in-built attention to moving objects. The findings from this research align with Barak *et al.* (2011) study results. It would be safe to argue that both the SEeDS and Narration activities kept students engaged in implementing their science activity. That could be explained in terms of students' engagement in three important cognitive processes – selecting, organising, and integrating (Mayer, 1997). As the findings from this research revealed, these cognitive processes in which students engaged to solve the two digital story problems, SEeDS and Narration, proved to challenge students' understanding and engage them in a way that they wanted all their classes to be structured in this way. The SEeDS and Narration activities did not require students to simply watch the animations. The uniqueness of this research is found in that its two activities enabled students

to create their interpretation of the animations and, subsequently, the scientific concepts they represented.

Overall, the SEeDS and Narration students across the two contexts felt personal ownership of the activity because they could contribute to the story creation. Creating a digital story does not necessarily require a new story because authoring or editing existing stories (Kucirkova, 2018) combines physical and mental intensity, attention to detail and reflection. Students' active participation in story creation helps them negotiate their understanding of stories (Kucirkova, 2018). It could thus be implied that choosing the right tools could help students engage in the construction of knowledge both individually and collaboratively while giving space for personal development of knowledge and meaningful and critical thinking. Taking into account that "deep learning depends on cognitive activity" (Moreno and Mayer, 2007, p. 312), ownership of the creation of a story aids students in making connections between their creation and their sense of learning (Alexander, 2017). As such, digital storytelling could be a valuable educational tool that gives voice to students' thinking. This comes along with Papert's perspective on emphasising students' agency in making choices, thinking independently, and seeking answers (Kucirkova, 2019). Teachers need, thus, to carefully select (interactive) digital tools that match their students' learning needs (Nanjappa and Grant 2003; Jonassen *et al*. 1993).

7.4.2 Levels of conceptual complexity

Further to the notion of ownership and enjoyment that the Greek and English students felt about the two activities is the repeated reference to the different levels of conceptual complexity that students experienced through SEeDS and Narration. In particular, students across the two contexts felt that the SEeDS activity required hard thinking, and it often confused and tired them. Some students were intrigued by that level of complexity and favoured the fact that it pushed them hard first to determine the sequencing of events and then invent the plot. Others were discouraged by this. Regarding the Narration activity, students found it easy and uncomplicated because it offered them enough time to focus on the story content and not on its order of presentation. The Narration activity could also be a challenging task, assuming it was harder for students to produce a technically accurate story

plot by following a predefined sequence than to have the flexibility to build their sequence around the concepts they could recall and were confident they knew. However, the results from this study highlighted that the predefined story order of Narration made students experience it as an easy task.

A possible explanation for that can be found in Jonassen's (2011) statement about structured stories. When people receive information that is not predefined, they are likely to construct a story out of the given evidence to make sense of it. When information is given in a story, it is more relevant and easily understandable. When the story events are ordered and sequenced, it helps individuals mentally organise the given information and make sense of its plot (Bruner, 1990). One might argue against this because by narrowing the scope and sequence of the information supplied and specifying a single order of presentation, the story's designer intentionally leads the learners to arrive at a predetermined plot (Mahnaz, Hung and Dabbagh, 2019). That means different story events could create a very different experience (Szurmak and Thuna, 2013) for the Narration students. Reciting a series of events does not constitute a story (Cobley, 2001) because all parts must be structured so that the entire sequence of events is meaningful (Nicolopoulou, 2008) to the story creator. Providing the Narration students with a predefined sequenced story did not necessarily make it easy for them to understand the science concepts or invent its plot. The Narration activity was based on one identifiable story plot, which single individuals could also accomplish (Chizhik, 2001). That implies students' collaborative interaction could end up more like helping each other understand concepts without a need for deeper-level discourse (Arvaja and Häkkinen, 2010).

The SEeDS activity was considered hard and occasionally confusing and tiring because it required students first to determine the story order and then invent its plot. That could be attributed to the fragmented presentation of the story content. The process of creating a story is heavily dependent on how one could see their understanding of something come together and make sense. SEeDS students in the two contexts had to make the fragmented elements of what was not yet fully understood hang together to have a coherent story (Clark and Rossiter, 2008). The absence of connections and logical relationships among the story elements in SEeDS made it hard for the students to determine its overall plot (Dettori and Paiva, 2009). Thus, students had to think hard, essentially trying to make sense of the story

scenes, discern the story internal logic, and figure out how it is related to what is known already (Clark and Rossiter, 2008). Seeking to relate the fragmented story pieces to their previous knowledge and experience, students employed higher-order strategies such as looking for patterns and underlying principles, checking the evidence and relating it to conclusions; whilst arguing cautiously and critically (Entwistle, 1996). Looking for patterns and examining cautiously and critically are indicative features of critical thinking and making meaning (Entwistle, 2018).

The fact that SEeDS presented the story scenes in an order that was not predefined would not explain the hardship, confusion, and tiredness that the Greek (section 6.4.1) and English (section 6.4.2) students occasionally felt when implementing the SEeDs activity. Another justification could be found in the animation's transitory nature. That is, SEeDS students had first to investigate the information delivered by the story animations, then relate it to existing knowledge (Lin and Atkinson, 2011), and finally sequence that information in a coherent plot. In doing so, SEeDs students might have experienced a high level of extraneous load, which frustrated them. It could also be that SEeDS students found it difficult to construct a sustained plot because the story content was fragmented (Laurillard *et al.*, 1999) and not presented in a predefined manner. An argument against that would be that the techniques of segmentation and interactivity found in the SEeDS activity might have provided learners with greater control over the learning process (Mayer and Moreno, 2003). For instance, Mayer and Chandler (2001) found that learners who studied segmented, controlled animations understood the lightning formation better than their peers, who viewed a whole, continuous animation unit. Through the SEeDS activity, students took control of the segmented story scenes and organised and determined the story plot by deliberately placing its events in a meaningful-to-them sequence. Doing so helped the SEeDS students demonstrate their understanding of the context in which the decision was made and the specific topic. It also highlighted the value of students' involvement in creating the story in terms of authorship, autonomy, authenticity (Kucirkova, 2018; 2017). Therefore, it could be argued that to mitigate the transitory nature of animation, learner control should be available to learners (Ayres and Paas, 2007).

The absence of auditory information (section 2.4.3) combined with the fragmented story content could also justify the level of conceptual complexity found in the SEeDS activity. Mayer (2014; 2005) has stressed that for learners to transition from the visual to the auditory channel, they have to rely on adequate existing knowledge. Therefore, learners' prior knowledge influences how new or existing information is processed (Anderson, 1983). The study of Clark and Mayer (2011) found that animations alone did not improve students' understanding of creative problem-solving performance. However, Clark and Mayer's (2011) study was concerned with the practical application of instructive animation. That is, they examined how students could learn about the operation of a bicycle tire pump (or a car's braking system) by studying narrated animations describing each step in the process. The current research differentiates itself from the study of Clark and Mayer (2011) as it did not investigate students' practical application of scientific knowledge after instruction. Instead, this research used educational animation to evaluate students' understanding of a specific science topic following traditional teaching methods.

Finally, SEeDS students might have faced a variety of possible solutions to understand the activity (Mayer, 2002). That involves the invention of alternative hypotheses that can often exceed the boundaries or constraints of prior knowledge and existing theories, resulting in divergent thinking (Mayer, 2002). This divergent phase required harder thinking about changing a situation from its given state into a goal state (Mayer, 1989). The more students thought about how to order and sequence the story scenes, the more "strategies they used for representing and processing new information" (Mayer, 1989, p. 206). That is the essence of using harder versions of the same task to generate better results (Brown *et al.*, 2014), as students can learn more in the least preferred conditions (Kelly and Tangney, 2006). The hard-thinking nature of the SEeDS activity pushed students to pay attention to the relevant information and mentally organise and present that information into a coherent representation (Mayer, 1999). SEeDS students had to work out a story structure for themselves to make sense of the content (Entwistle, 2018), which required autonomous decision-making (Barell, 2007).

Moreover, the process of abstracting and organising data has been recognised by researchers as being an effective way of engaging students in higher-order thinking (Chu, Hwang and Tsai, 2010) and critical thinking (Nanjappa and Grant, 2003). The current research stepped beyond

the existing literature by linking an engaging animated process that the above studies did not use. This research did not seek to assess learning but to explore how students externalised and reflected on their prior learning and what thought they had learned.

7.4.3 Summary

To conclude this section, both activities were an opportunity for students to engage in science learning and develop their cognitive skills, such as thinking, explaining, making sense, and understanding (Chen *et al.,* 2003). Findings from this research revealed that predefined activities, like Narration, offer the opportunity to students to become creative and own the learning process. The Greek and English participants of this research did not feel like their creativity was limited because they were not allowed to determine the order of the story's presentation through the Narration activity. On the contrary, they expressed their preference for such a structured activity because it gave them more time to focus on the content and think about the plot. SEeDS students, some of whom found their activity hard and occasionally tiring, were not discouraged, disengaged from the activity's difficulty and also enjoyed the process of creating it. The implication, therefore, would be that teachers should have their judgement to decide on the type of digital storytelling activities they can use in their science class, based on their students' attainment levels.

7.5 Chapter Summary

The purpose of this chapter was to discuss the findings of this research seeking to address its two research questions while linking them to international literature. One of the principal findings was the two digital storytelling activities helped the Greek and English students to reflect on and externalise their prior knowledge about many concepts relevant to matter. The problem-based nature of the two digital storytelling activities brought to the surface the deep-rooted difficulties that many students under the age of 12 still had about certain scientific concepts, such as *condensation, heat* and *(gas and/or liquid) particles' movement when the temperature changes.* Another important finding was the careful scaffolding of the digital problem-based stories, SEeDS and Narration, which helped students use *exploratory*

talk without training. The occasional appearance of *cumulative* and *disputational talk* elements established the range in talk types that students commonly use while working collaboratively. Finally, the two activities allowed all students to become creative and have personal ownership of the story creation. The findings indicated that the SEeDS activity was challenging, making it hard to complete and at times tiring and confusing. The Narration activity was easy to implement, allowing students to focus mainly on inventing the story plot.

The last chapter, Chapter 8, discusses the implications and contribution of this research both to research and practice and concludes with suggestions for further research.

CHAPTER 8: IMPLICATIONS AND CONCLUSIONS

8.1 Introduction

The final chapter of this thesis discusses the research's unique contribution to science teaching and learning and outlines the wider implications that concern all stakeholders. Finally, it presents some research limitations and concludes with recommendations for further research and practice.

8.2 Unique contribution of the research and implications

The present research makes its unique contribution in informing teaching practices and in enriching the knowledge base about novel activities in teaching and learning science through digital storytelling. It also has implications for research and practice, referring to the academic audience and those involved in education, such as teachers and researchers.

In terms of the academic audience, this research enriches the knowledge base of exploring the educational uses of digital storytelling in engaging students in meaning making while helping them externalise their understanding of a tricky topic in science. Despite the considerable work published on the importance of meaning making in learning (Vygotsky 1987; 1978) and the supportive role of digital storytelling in students' construction of meaning (Alexander 2017; Matthews-DeNatale 2013), the contribution of problem-based digital storytelling in the learning and teaching of science is largely unexplored. This research emphasises the role that problem-based learning in combination with storytelling plays in shaping students' understanding of specific tricky topics, providing, thus, a foundation for further research on the subject. The significance of such an in-depth exploration can be seen on the micro-level, expanding from a single-classroom level to school community levels, parents, and school practitioners. The uniqueness of this research is found in the construction of digital story problems that help students to externalise their understanding of scientific concepts and identify possible gaps in their knowledge while interacting collaboratively with their peers. An implication is that problem-based stories, with their hard-thinking and

challenging nature, and digital storytelling with its creative and playful format can engage students in meaning making in science.

The use of single prompts to the visual channel combined with students' active interaction with the content as they determined the preferred order of presentation (Mayer, 2014) makes the two activities, SEeDS and Narration, quite challenging. Providing information in one channel demands learners to devote adequate cognitive resources to the task to eventually process it in the other channel. When information is presented to the eyes through illustrations, videos, or animations, it is processed in the visual channel. When that information is presented in an order that is not predefined (like in SEeDS), it becomes more challenging for the learners to organise and visualise its order and sequence mentally. When information is presented to the ears, like oral or audio narration or nonverbal sounds, the processing takes place in the auditory channel (Mayer, 2005). Having students work collaboratively helps them process information to the auditory channel through social interaction. Yet, such information may or may not be congruent with what the representations are intended to show, causing a mismatch of the information processed simultaneously in the two channels.

In exploratory talk, students engage critically and constructively with each other's ideas, seek agreement before reaching a common decision and provide reasoning and explanation for their thoughts (Mercer *et al.,* 1999). Existing research (Mercer and Howe 2012; Mercer 2008; Mercer 2002; Mercer *et al.* 1999; Wegerif and Mercer 1997) on the use of exploratory talk is primarily concerned with teacher-led scaffolding and guidance. This research reveals that the two digital storytelling activities can promote the instinctive use of exploratory talk to a certain extent. When students work collaboratively and independently, without the teachers' guidance, they often engage in critical thinking and constructive arguments to produce a desirable outcome. However, students' collaborative interaction does not always run smoothly, as there are occasions in which students may engage in a positive yet uncritical interaction *(cumulative talk).* Or in a competitive and conflicting exchange of ideas *(disputational talk)*, which is expected during collaboration and verifies the existence of various types of peer talk found in students' interaction (Mercer *et al.,* 2004).

Moreover, this research makes its unique contribution regarding the methodological approaches used to evaluate students' (thinking about and) understanding of specific concepts. There is a significant gap in the practical construction of learning activities that help students externalise and reflect on their understanding of a science topic. Using the five Stumbling Blocks to build the two digital storytelling activities provides the basis for creating an evaluation rubric, which aids in identifying students' gaps in knowledge that no previous research has extensively done up to date.

In addition to closing gaps in current literature, this research provides practical information to schoolteachers about the beneficial use of problem-based digital storytelling activities. As an aiding tool for distinct teaching methods, digital story problems can be used not only in the subject of science but in Maths, geography, literacy and other school subjects. This research offers insight into how predefined and not predefined activities based on storytelling, supported with digital tools, can foster students' engagement in and ownership of the learning process. Depending on students' attainment level and knowledge background, teachers can opt for easy activities, such as Narration, or challenging activities, such as SEeDS that makes students think hard to facilitate critical thinking and constructive dialogue in science learning.

Lastly, the findings of this research inform the optimal design of science stories based on the animations. In terms of structure, cartoon animations fit the trends of current educational technology and students' familiarity with them. In terms of content, when animations are carefully selected to match the learning needs and purposes of the instruction, they can help students to externalise their understanding of science concepts. At the same time, they can also identify students' deep-rooted learning needs. The implication here is that the two digital storytelling activities can elicit students' conceptions about specific scientific phenomena to a great extent in a seamless way that differs from the traditional summative assessment. Findings reveal that students often think they understand a concept because they can articulate it with precision or do well in tests. Yet, they are to explain or justify it correctly when asked to do so. Students can use labels precisely, but scientific explanations do not underpin their understanding of these concepts. That is a significant implication for teaching practice. It stresses the need for (science) teachers to employ different strategies to identify

students' gaps in existing knowledge, based on children's reasoning for their answers and not the answers themselves (Driver, 1983).

8.3 Recommendations for teaching practice

This research has further practical recommendations for teachers' professional development and training. Its significance lies in the currently limited guidance that stems from empirical research about the use of problem-based digital stories in helping students to externalise and reflect on their understanding of science tricky topics.

Initially, the research findings highlight the need for teachers to receive more training in identifying tricky topics among the subjects they teach. Although the literature on tricky topics emerged in the last decade, this research provides further evidence to support its significance in the field. Identifying tricky topics in school subjects helps teachers and students to understand where and why they have difficulties teaching and learning specific topics, respectively. Teachers must get the opportunity to reflect upon their practice and become aware of their strengths and limitations. That will reflect their pedagogical practice and, thus, students' learning. There is, therefore, a need for regular pre-service (through university courses) and continuous in-service teacher training and CPD activities. It is also necessary that current teaching policies are often upgraded to improve the quality of teaching and effectively address the educational needs of students. Furthermore, there is a demand for continuous quality review procedures to monitor and advise on standards and excellence in teachers' education. It is vital to provide students with the highest education experiences they are entitled to expect.

Moreover, the analysis of students' interactions from both the SEeDS and Narration teams casts light on the value of problem-based digital stories in engaging students in meaning-making in science. SEeDS enables students to make their own sequence decisions about the plot based on their understanding of the order of story presentation and sequence of content. Narration allows students to define an unknown plot based on a predefined order of story events. Therefore, teachers must not evaluate student stories as good or bad by analogy with the original one. The significance of the two activities, SEeDS and Narration, is that it gives

students the freedom to think about, recall, externalise and reflect on their prior knowledge about a science topic.

In terms of engagement and challenge, students find both activities fun, enjoyable and creative, but they view SEeDS as challenging because it requires hard thinking and is difficult to complete. The process of ordering and sequencing, not just storytelling, makes students think hard not only about the story plot but also about the order of the story presentation. That poses questions about what learning is. If it is about just ticking a box, getting past some exam test and having fun in doing so or being challenging but transformative. This research concludes that learning can be fun and transformative simultaneously. Yet, it is up to each teacher (who understands their students' learning needs) to decide which type of problem-based digital storytelling activity they will use. Emphasis must be placed on designing learning environments that focus on students' thinking, not performance. The thinking in which students engage is vital to the learning process and shapes what is finally learned. In contrast, performance indicates no more than students' ability to read the requirements of a test (Adams, 2006b).

Findings from this research also confirm that students generally find technology-enhanced activities enjoyable. The teacher's contribution in creating such activities can be crucial for determining students' learning experience (Mercer, 1994). How teachers introduce and define activities to their students strongly influence how students perceive and interpret the requirements of the activity. The 'voice' of the teacher can be heard in the students' discourse when the teacher is not around (Mercer, 1994). That is also the case when presenting a complex idea or topic. It first needs to break down into smaller segments. Each segment must be first processed for meaning before the set is combined into the larger idea unit (Novak, 1988). From this aspect, teachers need to always consider students' attainment levels to create suitable activities that match students' educational needs. Peer mentoring and school support mechanisms, such as in-school consultation, are indicative methods for providing guidance and checking the quality of teachers' creative teaching strategies.

Considering the Greek and English participants' middle- to low- attainment level, students need to learn to use strategies that require constructive dialogue and explanations. This

research demonstrates how teachers can use the two digital storytelling activities to explicitly teach discursive strategies and raise students' communicative self-awareness (Mercer, 1994). Students need to understand the importance of challenging ideas, making arguments explicit, justifying them and reaching a joint agreement. If students are "to work effectively in groups with relatively infrequent teacher intervention, they must be helped to precisely understand what is expected of them, and why these expectations are being set" (Mercer, 1994, p. 30).

Lastly, the constitution of groups is of great importance to the learning process. Teachers need to consider their specific aims when using disparate groupings, mainly where the groups work autonomously for extended periods (Mercer, 1994). Different learning skills and personal styles of working can overwhelm other aspects of the design of an activity (Mercer, 1994). The suggestion for teachers is to set up collaborative learning environments that involve heterogeneity, such as high-attainers with middle-attainers or middle-attainers with low-attainers to enhance students' understanding of the learning material.

8.4 Limitations of the research and recommendations for future research

Like any other research including qualitative – and not only – methodology, this research has limitations and recommendations for future research.

First of all, coming from a different educational and cultural background than the one in which the first pilot and one study were undertaken means that my understanding of how things work within UK schools was limited. Unfortunately, there was no time to visit the English school in advance to observe and explore the characteristics of the different settings and understand the UK educational system's purposes and teaching approaches. Therefore, gaining an understanding of the educational system, teaching, and learning was that of someone 'outside' the system – something that could be considered positive as well, in terms of unpacking observations that an 'insider' could not.

A second limitation relates to the cultural background and the language used. Some of the primary data sources were audios and transcripts from English students' interactions, in which the language used differed from the researcher's native Greek language. It was

recognised that each language had its metaphors, expressions, cultural norms, words and idioms, which could not be precisely translated. As such, an attempt to translate the whole dataset in advance could undermine the accuracy of the data, not giving an accurate representation of the participants' opinions and views. The purpose was to have a clear picture of data to code the transcripts without loosing any critical information that emerged from the language itself and the implicit meanings of participants' answers. The researcher's bias was one of the most severe threats to the research's trustworthiness (Johnson and Christensen, 2004). Transcripts were kept in Greek to prevent it, thereby minimising the mediation and the danger of bias. Thus, help was sought from other native English-speaking researchers and the supervisory team to translate and understand words and expressions in the selected datasets. That proved to be an advantage for the transcription and analysis processes (English to English). The same, however, could not be argued for the Greek data (Greek to English), as it allowed for translation errors and points missing in both transcription and analysis. Being an insider in the Greek context, speaking the language of instruction, benefited from the English study. There were times that only through the analysis of findings with supervisors, concepts, norms and practices accepted in 'the cultural insider' were noted as unusual and unique.

Another limitation the reader should be aware of is that data was collected for a particular science topic. Therefore, it is difficult to generalise findings to other courses or subjects. Digital storytelling covers a broad spectrum of school subjects. Teachers can use story-sequencing to create digital stories (with educational material available online) and present them in maths, history, geography, literacy and many more.

In this context, there is also the limitation in the choice of schools and teachers. The target school originally planned to be in the research involved primary school children from a UK school. However, as often happens with school-based research, some initial engagement and data capture issues were encountered. That included establishing connections with a primary school in Milton Keynes that later withdrew due to pressures from current educational curriculum changes. Then, follow-up contacts with an old colleague working in a primary school in Athens, Greece, were made.

Similarly, the research concerned itself with two different groups (one Greek and one English) within two different schools. The population in each group/school had different learning and socio-cultural backgrounds and attainment levels. Findings, therefore, cannot be considered universal truths but merely an interpretation of how the specific case indicated students understanding and formed working hypotheses about the issue. In sum, the generalisability of the study's findings to other classes or schools with similar populations is hard.

A fifth limitation is linked to the design of the research. It should first be acknowledged that the composition (selection, editing, ordering and sequencing of the animated videos) of the two digital storytelling activities was based on the individual understanding of me as the creator, being both a researcher and teacher. Meaning that a different teacher or researcher could make a different selection of sources, combine scenes differently and generally determine a different plot. In addition to that, the design of the two activities relied on the five Stumbling Blocks that the English and Greek teachers identified as students' barriers to understanding matter. That was limited by the possibility of inappropriate delivery of teaching or the teachers' knowledge or specialism limitations. In other words, the SBs occurred from reviewing teachers' understanding of students' problems and applying them in practice through the two activities.

A sixth limitation refers to the story application used (OurStory), which guided students to edit their stories using a specific step-by-step procedure. The *Our Story* application produced some technical difficulties when students were viewing the scenes on the app, which frustrated and got them complaining. That could be because some iPads were of older technology than others. The app, nonetheless, was checked the day before and was working properly on all the iPads. Another technical issue concerned the recording apps and devices used in the English study. A few of them stopped recording at one point without, however, risking the integrity of the project as they were immediately identified and fixed. In other words, more experiments are needed to investigate the effectiveness of different applications with more flexible functions.

Attention should also be given to the occasions when both Greek and English students could not focus on the activity because the animated videos amused them. That could be because

students were middle- to low- attainers and perhaps needed more support and guidance from their teachers. Or because they saw the activity as a chance to enjoy some playful learning time other than writing and listening.

Finally, in qualitative research, the researcher becomes the research tool, meaning that attention should be given to the possible bias of the researcher due to her professional identity as a teacher. That is, my involvement in the creation of the two digital storytelling activities and the collection and analysis of the data could have been influenced by my expectations for the effectiveness of one activity (SEeDS) over the other (Narration). This research uses the 'audit trail' method to avoid that, providing detailed accounts of the data collection process, data analysis and presentation of the findings. Considering the subject nature of qualitative methodology, which relies on identifying patterns "located in the subjective interpretation of data" (Levitt, 2015, p. 456), any qualitative research needs to be "assessed on its terms within premises that are central to its purpose, nature and conduct." (Spencer *et al.*, 2003, p. 4). The 'audit-trail' method, thus, describes the research plan, from planning to implementation and links the research questions to the research conclusions through the steps undertaken during data collection and data analysis. In this way, the research plan is discussed and justified appropriately to meet the research's purpose and be consistent with the overall approach. Yet, the transferability of results to other settings or from one context to another should be treated with caution.

8.5 Chapter Summary

This research has used digital storytelling to help students externalise and reflect on their understanding of the tricky topic of matter in science. The design and creation of the two digital storytelling activities, SEeDS and Narration, was based on elements from the socio-constructivist approach to learning, which views the construction of knowledge as the product of social interaction, interpretation and understanding (Vygotsky, 1962). It also used the notion of tricky topics, which referred to the topics containing difficult concepts that both students and teachers had difficulty learning and teaching. Students relied on prior knowledge to help them to determine the order of the story presentation and invent the plot or only invent the plot. Students engaged in meaning-making as they adapted information

and reflected on their existing knowledge. They provided necessary explanations and employed thoughtful and critical strategies while working collaboratively with peers.

Teachers should encourage and teach students to get actively involved in the sharing and building knowledge, shifting their focus away from the requirements of test and exam questions met by superficial and rote learning. At the same time, teaching should be not merely concerned with prescribed performance targets that supersede cognitive development. SEeDS and Narration required students to interact vigorously and critically with the content. However, the exceeding number of the chunks of information (scenes) along the lively nature of animated videos may have hindered middle- to low- attainment students' capacity for information processing, not helping them make congruent connections with prior knowledge. Teachers, therefore, should consider that when designing and implementing such activities, without being discouraged.

To sum up, this research acknowledged the challenges and difficulties of designing and implementing activities that seek to address tricky science topics with which students and teachers struggle. Identifying and understanding the origin of the problem is crucial before constructing any digital storytelling activity. Teachers need to be mentally and critically equipped to acknowledge the problem before meeting students' learning needs. Thus, extensive support and continuous guidance in teachers' professional development must be provided. Finally, designing and implementing this research, creating the two digital storytelling activities, analysing the data and writing this thesis provided valuable gains for addressing the need to focus on students' thinking and understanding in teaching practices.

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Appendices

Appendix 1: The Science Programme of Study for the fifth and sixth Grades (Π.Ι, 2011)

Programme of study for the fifth Grade: Physical Sciences and Technology				Programme of study for the sixth Grade: Physical Sciences and Technology			
Thematic Units		**Sub-units**	**Didactic time/ hours**	**Thematic Units**		**Sub-units**	**Didactic time/ hours**
1st Unit	Matter	1.1: Living organisms - Life around us 1.2: Materials and technological objects around us – Raw materials 1.3: Density of the materials around us 1.4: Mixtures, solutions, air, water 1.5: Acids, bases, salts	6 5 5 5 3	1st Unit	Structural Organisation of the Human Body – Getting to know my body	1.1: Reproductive system 1.2: Respiratory system 1.3: Relating functions of the respiratory - digestive - circulatory systems: blood	4 4 6
				2nd Unit	Sound phenomena	2.1: The hearing system 2.2: The ear 2.3: Construction of simple musical instruments and acquaintance with	2 2 2

Unit	Title	Topics	Hrs	Unit	Title	Topics	Hrs
						the musical instruments of different cultures	2
						2.4: The production of sound	
						2.5: Reflection and absorption of sound	4
						2.6: Effects of modern technological advances on human hearing	4
2nd Unit	Heat in our Lives	2.1: Heating and cooling of indoor rooms and houses	2	3rd Unit	The light around us	3.1: The sun, a source of light	2
		2.2: Temperature measurement	1			3.2: The travel of light: the ray aspect	4
		2.3: The effect of thermal interaction - Thermal conductivity of materials	2			3.3: Reflection and refraction of light	3
		2.4: Changing the condition of materials	4			3.4: Rainbow	1
		2.5: Technological applications - protection	1			3.5: Plants "turn" to light	1
						3.6: Vision and the eye	2
3rd Unit	Technological Applications of Energy	3.1: Manufacture of simple machines	2	4th Unit	Creating forces	4.1: Forces	3
			4			4.2: Measuring forces	2
			2			4.3: Contact and non-contact forces	1

		3.2: Less energy for the same needs and desires 3.3: The energy wealth of our country now and in the future 3.4: Energy in living organisms 3.5: Ecosystem: food relations, food chains 3.6: The journey of energy in the human body: the circulatory and digestive systems in humans.	12 5 7			4.4: Gravitational attraction 4.5: Friction 4.6: Pressure 4.7: Moving around safely 4.8: Gravity attracts plants	2 2 6 8 1
4th Unit	Electric and Magnetic Phenomena	4.1: From toys with magnets… to experiments with electrical and magnetic phenomena 4.2: In… the avenues of charges 4.3: Electromagnetism 4.4: Great discoveries that changed our world - Faraday	4 4 4 6	5th Unit	Energy Transfer	5.1: Energy in objects 5.2: Energy transfer and stores 5.3: Can energy have many "faces"? 5.4: Energy dissipation 5.5: Energy in plants 5.6: Energy in fuels and food	2 2 2 2 8 2

There are four main units break down into sub-units, which, in turn, match nine different chapters in the science textbook[9]: *Chapter 1: Materials; Chapter 2: Mixtures; Chapter 3: Energy; Chapter 4: Digestive System; Chapter 5: Heat; Chapter 6: Electricity; Chapter 7: Light; Chapter 8: Sound;* and *Chapter 9: Mechanics.*

For the sixth grade, there are five basic units with their sub-units, which correspond to thirteen chapters in the science textbook: *Chapter 1: Energy; Chapter 2: Heat-Temperature; Chapter 3: Living and non-living organisms; Chapter 4: Plants; Chapter 5: Animals; Chapter 6: Ecosystems; Chapter 7: The respiratory system; Chapter 8: The circulatory system; Chapter 9: Electromagnetism; Chapter 10: Light; Chapter 11: Acids, Bases and Salts; Chapter 12: Transmitted Diseases; and Chapter 13: The reproductive System.* As it appears, there is a continuity and coherence in the themes presented in the instructional units of the science programmes of study for Grade 5 and Grade 6. In Grade 6, these themes are gradually developed and explored in more detail through additional units.

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[9] The teacher book and student textbook and activity books can be found online at http://digitalschool.minedu.gov.gr , and are available only in Greek.

The four stages of the research developing model

1) **_Introductory hook – formulating hypotheses_**: at this stage, the teacher tries to orient students towards the phenomenon under study through a problem, followed by brainstorming and discussion in the classroom. At this point students may formulate hypotheses about the phenomenon based on prior knowledge.

2) **_Experimentation_**: at this stage, students carry out one or more experiments, make systematic observations and keep notes. If a unit does not require experimentation, then students continue with the textbook activities. The teacher orchestrates the experimentation process and assists where necessary. Given the available time and availability of resources in the science laboratory, the teacher decides about the type of the experiment – demonstration experiment (the teacher conducts the experiment with the help of a few students) or group experiment (all students divided in small groups participate in the experiment).

3) **_Drawing conclusions_**: this is the stage where students draw conclusions and make inferences about the results of the experiments, and so they validate or reject their initial hypotheses. There are also attempts to make abstractions and generalisation about new knowledge.

4) **_Comprehension - generalisation:_** in this final stage, students consolidate the new knowledge that occurred from the previous stages and generalise the outcomes.

An example of the proposed teaching sequence for section 5.1 _Heat and Temperature: two different concepts_ based on the research-developing model

1) _Introductory hook – formulating hypotheses_: The teachers asks students to observe and comment on the first three photos found in the student activity book, WorkSheet1: The Thermometer, p. 70. To help them engage in a whole-classroom discussion, the teacher can give verbal prompts, by asking:

- _In what way is someone usually trying to check if he/she has got fever?_
- _What would you do to check if the oven or a cooking plate is hot?_
- _What do you think about the temperature of the rivet in the picture?_

ΦΕ1: ΤΟ ΘΕΡΜΟΜΕΤΡΟ

Πολλές φορές εκτιμάμε τη θερμοκρασία με τις αισθήσεις μας. Ακουμπάμε κάποιον στο μέτωπο, για να καταλάβουμε αν έχει πυρετό. Πλησιάζουμε τα χέρια στον φούρνο, για να καταλάβουμε αν λειτουργεί. Από το χρώμα ενός μετάλλου μπορούμε κάποιες φορές να καταλάβουμε αν είναι πολύ ζεστό. Είναι όμως η εντύπωση που σχηματίζουμε πάντα σωστή;

Then a student may read out loud the introductory question and the teacher asks students to start formulating hypotheses, which he/she then writes on the board without commenting on their validity.

1) *Experimentation*: Students have to carry out the following experiment as depicted in the pictures of the worksheet.

Γέμισε τρεις λεκάνες με νερό. Στην πρώτη βάλε κρύο, στη δεύτερη χλιαρό και στην τρίτη ζεστό νερό. Βάλε το ένα σου χέρι στη λεκάνη με το κρύο και το άλλο σ' αυτή με το ζεστό νερό. Μετά από λίγο βύθισε και τα δύο χέρια σου στη λεκάνη με το χλιαρό νερό. Τι παρατηρείς;

In this experiment, students have to fill three different bowls with cold, lukewarm and hot water. First, they place one hand in cold water and the other hand in hot water. After a while they sink both hands in the bowl with lukewarm water. They need to write down what they observe. With this experiment students need to realise that measuring temperature with

their senses is not precise. The recommendation is for the teacher to conduct a demonstration experiment with the help of two-three students, who will report the results back to the classroom. Group experiments are not suggested because they take a lot of time, and it is very possible for students to get wet. To save time, the teachers need to fill the three bowls with water and place them on the teacher desk. Students write down their observations from the experiment in the indicative place (shown here) in the activity book.
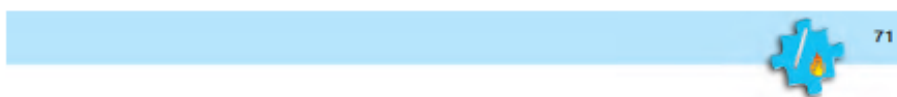
Παρατήρηση

_____
_____
_____

1) *Drawing conclusions*: the teacher initiates a discussion in the classroom, during which students generalise their observations about the experiment and make conclusions. The teacher may also encourage students to draw examples from their swimming experience at the sea. He/she can ask students how they feel the water temperature when they get in the sea, after having sunbathed for a long time and their body is warm, and after being in the shade for a long time. Students write their conclusion in the activity book (section shown here)

Συμπέρασμα

_____
_____
_____

The teacher then asks students how they can precisely measure the temperature of a body to get students discuss about the use of thermometers. He/she gives students a thermometer (alcohol or mercury) and asks them to observe it carefully. Then the teacher asks them to compare the alcohol and mercury thermometers as shown in the pictures of their worksheet.

314
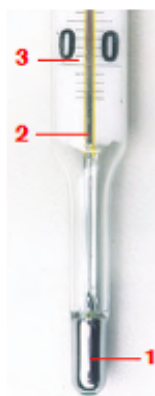
Για να μετρήσουμε τη θερμοκρασία με ακρίβεια, χρησιμοποιούμε ειδικά όργανα, τα θερμόμετρα. Στις εικόνες βλέπεις έναν γνώριμο τύπο θερμομέτρων, στα οποία η ένδειξη δίνεται από κάποιο υγρό. Συνήθως χρησιμοποιούμε υδράργυρο ή χρωματισμένο οινόπνευμα. Τα θερμόμετρα υδραργύρου και τα θερμόμετρα οινοπνεύματος μπορεί να περιέχουν διαφορετικό υγρό και να έχουν διαφορετικό σχήμα, έχουν όμως όλα:

1. _____
2. _____
3. _____

Finally, students, with the help of the teacher, complete the written activity about the thermometers.

Then the experimentation process (steps two and three) is repeated, as students have to conduct two more experiments about the measurement of temperature, before reaching step four *Consolidation of knowledge – generalisation*.

2) *Experimentation*: The first experiment is now complete, and the teacher continues with the second experiment regarding temperature measurement (shown below).

Βάλε μερικά παγάκια σε ένα δοχείο με λίγο νερό. Ανακάτεψε καλά με ένα μολύβι. Αν λιώσουν όλα τα παγάκια, πρόσθεσε μερικά ακόμη, ώστε να υπάρχουν στο ποτήρι συγχρόνως παγάκια και νερό. Χρησιμοποιώντας το θερμόμετρο, μέτρησε τη θερμοκρασία του πάγου που λιώνει.

For this group experiment (students team up), students have to add ice cubes (six to eight) in a glass of water (about a quarter of water) and stir them with a pencil. The glass must contain both water and ice-cubes so that students can use a thermometer to measure the temperature of the ice-cubes while melting. With this experiment, students will learn that the melting temperature of solid ice is the same as the freezing temperature of liquid water, thus

water and ice exist in equilibrium at 0°C. A whole-classroom discussion follows, and students make notes again of their observations.

✎ Παρατήρηση

_____
_____
_____

When the second experiment is complete, the teacher continues with the third and last experiment. This is a demonstration experiment, where the teacher boils a pot of water and students must realise that boiling temperature is approximately at 100°C.

Πείραμα

Η δασκάλα ή ο δάσκαλός σου βράζει νερό σε ένα δοχείο. Με ένα θερμόμετρο μετρά τη θερμοκρασία του νερού που βράζει.

✎ Παρατήρηση

_____
_____
_____

At this point the teacher can explain to students that tap water contains dissolved minerals and chemicals that have the effect of slightly raising the boiling point. Instead, pure water's boiling temperature is closer to 100°C.

In the conclusive activity of the worksheets (shown below), students have to calibrate an uncalibrated thermometer, while the teacher explains how Celsius worked to define the temperature scale.

Συμπέρασμα

Με τη βοήθεια της δασκάλας ή του δασκάλου σου συμπλήρωσε την κλίμακα Celsius στο θερμόμετρο.
Τι θερμοκρασία δείχνει το θερμόμετρο στο σκίτσο; _____ °C.
Μπορείς τώρα να περιγράψεις με λίγα λόγια τον τρόπο με τον οποίο εργάστηκε ο Celsius;

_____
_____
_____
_____
_____
_____

◄ Θερμοκρασία στην οποία βράζει το νερό

◄ Θερμοκρασία στην οποία λιώνει ο πάγος

316
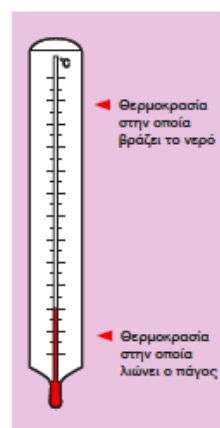
1) *Drawing conclusions:* When all three experiments are completed, the teacher recaps by asking a few students to describe verbally the invention of the Celsius scale and ensures that all students have written the correct answer in their worksheet.

2) *Comprehension - generalisation:* Students can deepen in their understanding of temperature measurement and the use of thermometers by having the following activities from *WS1: The Thermometer* as homework.

ΕΡΓΑΣΙΕΣ ΓΙΑ ΤΟ ΣΠΙΤΙ

1. Μπορούμε να εκτιμήσουμε με τις αισθήσεις μας τη θερμοκρασία, έστω και με μικρή ακρίβεια, σε όλες τις περιπτώσεις; Μπορείς να εξηγήσεις την απάντησή σου;

2. Στα θερμόμετρα της φωτογραφίας η στάθμη του υγρού δεν είναι στο ίδιο ύψος. Δείχνουν τα θερμόμετρα διαφορετική θερμοκρασία; Μπορείς να εξηγήσεις την απάντησή σου;
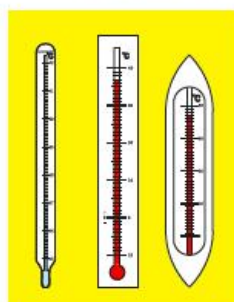
3. Ο Γιάννης και ο Νίκος θέλουν να μετρήσουν τη θερμοκρασία του εδάφους. Ποιος από τους δύο εργάζεται λανθασμένα; Ποιο είναι το λάθος που κάνει;

Γιάννης   Νίκος

In summary, the research-developing teaching model, comprised of the four steps just described, is the proposed one for teaching science in the Greek primary school. Usually step *2: Experimentation* involves more than one experiment. The four-step teaching sequence followed for teaching *Chapter 5.1 Heat and Temperature: two different concepts* is an indicative example and applies to all the chapters that involve experiments.

INTERVIEWER: What I 'd like to do now is to take an exam, question… have you got anything in here that you might be able to…?

B (biology teacher): I 've got a really hot topic we could really look into the particle theory of liquids, solids and gases… they don't understand that …

INTERVIEWER: so, the particle theory…

M (chemistry teacher): there is so many misconceptions in that, it's very simple, we understand it, but kids don't

INTERVIEWER: that's also chemistry, isn't it?

C (chemistry teacher): yeah…

INTERVIEWER: so assuming that it's our tricky topics… could you, between you, if you would like to break that down, break this particular subject down into up to 8 different bits, we 'll call them stumbling blocks, not more than 8, or from between 4 and 8… and you to identify some key parts to that, that might be assessable?

C: kids put these things into words 'cause they are usually quite into drawing pictures, and they can see what's happening in the pictures but then they actually can't put these in words, looking for words to put into these pictures in verbalising what happens … they 're used to seeing pictures and themes and I can recognize different stages usually

M: yeah, from the pictures… but what I noticed is that with the liquids… liquids is where the stumbling block comes for me, because they assume that the liquid molecules are just here and here … miles away from each other, just rather than sliding over each other, and they think that there is lots of space between them and they don't..

C: misconceptions?

M: yeah… I think it was you with the marble traders that kind of I used to get over this… it was you I got the idea from when I spoke to you when I've first come in to model this

C: to model the spaces?

M: yeah

B: then they can't link the model to key events like rapture and [inaudible]

C: so, linking…

INTERVIEWER: It's alright, do a bit of a sketch and link in the model…

C: how about understanding things like density ... what about evaporation as well... because I find when you get them to [...] about evaporation

M: they already can't do it... and then conduction not linking to convection... because I was surprised that they could actually describe conduction quite well and then they really struggle with describing convection ...

C: it is this transfer...

M: yeah... and evaporation and then it just relies on more complicated...

M: language, isn't it?

C: concepts are difficult [inaudible] I used to be at the start with skimming words ... and I thought it was quite difficult

M: yeah, so do I... because they can link it back into why they need to understand this...

C: yeah, so that's underpinning it's not the fundamental ... in fact this is really basic, it's not going to affect this, it's not the occasion, it's like the other things

M: or its not given the time or the worth it should do ... because this is actually having a lot of misconceptions in and that builds on through the key stages

C: even though it is done over and over again, it's never done properly and then they switch off completely ... what about practical work? Do you think they can do that?

M: so, do you remember this kind of stuff? Even though they never link it to the density, do they? there is like... when you kind are, the table with the differences between solids, liquids and gases, whether they flow or they take a shape ... they seem to remember that... they don't know what it is, so they don't understand that last column ... that's like a chain... because density doesn't come down until Y9... they should have a better understanding of what density is so then link back into this ...

INTERVIEWER: so how many things have you got so far?

C: application that is application of the more fundamental things which is being addressed in the curriculum. They are used to seeing diagrams and they should recognize pictures but actually verbalizing what's going on and understanding its phases...

B: there's a six-mark question based on this and they don't get it very well ... it's in one of our internal exams... probably P1

C: they tend to look things in isolation rather than putting everything together... they are remembering things than understanding the relationships between them... we 've got that

the misconceptions they develop very young, and then we can't correct them because they do it too often...

INTERVIEWER: so, the particle spacing in the liquids is one...

C: yeah... it's like when you ask them why your hand feels cold when evaporation is going on

M: yeah, they don't understand that it's actually cooling it down, do they? [...]

M: I think that's the key bit, think they are trying to rote learning rather than understanding ... they never go fast at very top level, do they?

INTERVIEWER: **so, what you 've got here?**

A (Grade 5 teacher): I 've already got two topics, electricity and matter. In electricity, you know they find it hard to understand when the circuit is off and on, and how it relates to the light switches on the wall. In matter, they 've got lots. One thing is that they don't think that gases exist because they can't see them. They think that boiling and evaporation are the same thing. And then they can't tell the difference between heat and temperature.

INTERVIEWER: ok! could you then define what their basic misunderstandings are, in a more concrete way that you might be able to start pulling apart, saying ok this is a specific source of problems that students have with those, I am going to call them stumbling blocks, on this topic?

A: I think that students found it hard at the beginning, about the particles, the atoms… these were concepts that they had not come across before.

INTERVIEWER: did you notice anything in particular?

A: They had difficulties with some words, for instance they couldn't understand what the particles of the three states were. But they are doing really well in the class, they participate, they really like the experiments … it's just that they can't understand and verbalise some scientific concepts.

INTERVIEWER: why do you think is that?

A: because they were not familiar with these lessons before, with this topic I mean, which refers to things they can't see, and they deal with things that they can't see in reality. They believe that matter exists only when there is proof of it. That is, gases have neither mass nor volume. So, they can't be heated either.

INTERVIEWER: **ok**

A: To give you an example, most of my students, I am referring to the ones I have this year, they had never observed the phenomenon of condensation. They have probably taken it for granted. So, when they [students] were asked to explain why there were droplets on a glass full of ice, they could not answer. I think perception is a problem, they don't usually understand the process of what's happening.

A: the same happens with evaporation, they confuse boiling with evaporation, they think it's the same thing. This is the kind of stuff I am talking about.

INTERVIEWER: so, the problem is not only perception you think?

A: then there's communication. They don't use the right sort of language... there is this language and common language... and they don't use the right vocabulary... and then they have difficulties to actually say what they want to say.

A: science has a difficult vocabulary. Every time I teach science to 5th or 6th graders, they all have the same problem this problem. They can't really describe a phenomenon using proper scientific phrases.
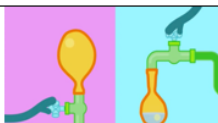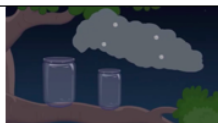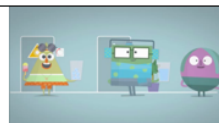
INTERVIEWER: so, they don't have the language they want?
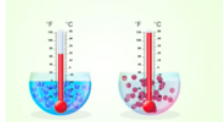
A: actually, some have the words… but they can't put those words together, they can't actually express it, as an expression. The way that students verbalise science events and phenomena … it is different from their daily talks… a different vocabulary, not so comprehensible… and they get confused trying to remember things and words

INTERVIEWER: how would you explain that though? I mean some of them have the words you say and still they can't get hold of a proper explanation

A: Because they are children, first of the image, second of the printouts, of the instructions… that is "do the exercise like in the example" and so kids have not learned to read [instructions] on their own and to think about what they should do. This is where the bad thing begins. And finally, we have reached a point where they [students] don't know how to read and comprehend in literacy. And then we expect them to understand science!

Appendix 5: The original story script/scenario as taken from its sources

Scene 1	Scene 2	Scene 3	Scene 4	Scene 5
-Alright guys what have you got there? -Ah, you've each got one of the three states of matter. Solids, liquids and gases. -Solids, like this block of ice or this ball retain their shape and volume. You can hold them and cut them into pieces and they always take up the same amount of space.	-Solids can be hard, like a toaster, a pencil or a cricket bat or they can be soft like a rubber toy or a piece of clay. -A solid means that the particles are packed in really close together and they can't move which means the object holds its shape.	-Liquids like water or honey can flow or be poured. And they are pretty tricky to hold. -They change shape depending on the container but always keep the same volume.	-A liquid can flow which means it can be poured, so if you pour water into a fish bowl it moves to become the shape of the fish ball. -Liquids are sometimes thick like honey or thin like water but no matter what they 'll always flow. Particles in a liquid can move around but they 'll stay together.	-Gases are crazy and don't keep their shape or volume. They spread out and can fit any container they are put in. Often you can't even see them. -Gas is put into some drinks to make them fizzy, and when we drink them the gas can sometimes try to uh…escape from our bodies. -Oh, delightful.

Scene 6	Scene 7	Scene 8	Scene 9	Scene 10
-Gas, like a liquid, takes the shape of the container it's in but it will also spread out to occupy the container. When a balloon fills with water, water fills up the bottom first, but when you fill it with a gas, gas fills the whole balloon.	-In gases the particles of matter are far apart from each other and have space to move into. Gases flow and they occupy all space in their container.	-Hey there, looking sharp. You are going to show us how to change the state of a substance by heating or cooling it, with the aid of these temperature controlled rooms.	-When solids are heated, they can melt into liquids. And when we freeze a liquid it becomes a solid.	-Hadn't you better check on them? -Right. After being heated, the ice has melted into water. For water, this melting point is zero degrees Celsius. And it looks like you 've done a fair bit of melting yourself. -When we freeze water, it becomes ice. It's changed from a liquid into a solid. This happens when the temperature drops below zero degrees Celsius. Someone here has become a big icy too. -It seems like **freezing** and **melting** are reversible processes. So, who wants another go?

Scene 11	Scene 12	Scene 13	Scene 14	Scene 15
-So, I've heard a rumour that you can change some liquids to gases, and back again. -Right! Go on then. Let's see! -Nice shower square? -Whoa! Cheeky. When water is heated up it changes state from a liquid to a gas, called steam. And this process is called **evaporation**.	-When a gas cools down it can change state back into a liquid. So, when the warm steam hits the surface of, say, a cold mirror it turns back into water again. This change is called **condensation**. The process can be reversed again if we warm up the liquid. -Oh, hang on. Time to get out of here I think. You really should have really locked that door.	-A thermometer measures the temperature of a state. Temperature measures the energy a matter contains, that is how hot or cold it is. With the thermometer, you measure how fast or slowly particles in matter move.	-Water constantly changes states in nature. In very cold places like the mountains the water freezes into ice and snow. The sun then warms frozen water causing it to melt to liquid water. As the sun continues to heat it water begins to evaporate.	-In warmer places the sun heats up water causing water to evaporate more quickly. The warmer the environment, the quicker water will evaporate.

Source for scenes 1, 3, 5, 8, 9, 10, 11, 12: https://www.bbc.com/bitesize/topics/zkgg87h

Source for scenes 2, 4, 6, 14, 15 : https://www.youtube.com/watch?v=tuE1LePDZ4Y

Source for scene 7: https://www.youtube.com/watch?v=jmm1J2yI9tk

Source for scene 13: https://www.youtube.com/watch?v=xGKg3TSO4v8

«Μαθαίνοντας επιστήμη μέσα από τη δημιουργία ψηφιακών ιστοριών»

Επιστολή συναίνεσης/ενυπόγραφη συγκατάθεση προς γονείς και κηδεμόνες

Αγαπητοί Γονείς και Κηδεμόνες,

Σας εύχομαι καλή Σαρακοστή και ευελπιστώ στη θετική ανταπόκριση σας για μια εποικοδομητική συνεργασία με τα παιδιά σας.

Στο πλαίσιο των διδακτορικών μου σπουδών με τίτλο *«Μαθαίνοντας επιστήμη μέσα από τη δημιουργία ψηφιακών ιστοριών»*, στο Ανοιχτό Πανεπιστήμιο Αγγλίας, εκπονώ τη διατριβή μου και θα ήθελα την άδεια σας για να συνεργαστώ με τα παιδιά σας. Η πρωτοβουλία, για την εν λόγω εκπαιδευτική παρέμβαση, προέκυψε μετά από εκτενή έρευνα, σε πρωτοβάθμια και δευτεροβάθμια εκπαίδευση, στο θέμα των 'προβληματικών' εννοιών (troublesome topics) σε μαθήματα όπως η επιστήμη και τα μαθηματικά. Σύμφωνα με τα αποτελέσματα της έρευνας, κάποια θέματα στην επιστήμη όπως η Φωτοσύνθεση, ο Ηλεκτρισμός, οι Φάσεις της Σελήνης και άλλα θεωρούνται δύσκολα να κατανοηθούν εις βάθος λόγω του δύσκολου λεξιλογίου που χρησιμοποιούν, των λανθασμένα εδραιωμένων αντιλήψεων των μαθητών, της μη εύκολης ταύτισης τους με την καθημερινότητα των παιδιών κτλ. Σε αυτά τα πλαίσια, σκοπός μου είναι να βοηθήσω στην κατανόηση αυτών των 'προβληματικών' εννοιών μέσω καινοτόμων, διαδραστικών δραστηριοτήτων, όπως είναι η δημιουργία ψηφιακών ιστοριών σε iPads.

1. **ΤΙΤΛΟΣ ΕΡΕΥΝΑΣ:**
Μαθαίνοντας επιστήμη μέσα από τη δημιουργία ψηφιακών ιστοριών (μτφ. από πρωτότυπο τίτλο «Digital Storytelling in a science class: a lesson to be learned»).

2. **ΠΟΙΟΣ ΕΚΠΟΝΕΙ ΤΗΝ ΕΡΕΥΝΑ:**
Η έρευνα θα εκπονηθεί από την Πόπη Αναστασίου, υποψήφια διδάκτωρ στο τμήμα της Εκπαιδευτικής Τεχνολογίας (IET) του Ανοιχτού Πανεπιστημίου Αγγλίας (Open University UK).

3. **ΣΚΟΠΙΜΟΤΗΤΑ ΕΡΕΥΝΑΣ:**
Η έρευνας αυτή αποσκοπεί να βοηθήσει στην κατανόηση 'προβληματικών' εννοιών, όπως ο Ηλεκτρισμός και το ηλεκτρικό κύκλωμα, στο μάθημα της επιστήμης, μέσω της δημιουργίας μιας ψηφιακής αφήγησης. Οι μαθητές θα δουλέψουν συνεργατικά σε μικρές ομάδες των 3-4 ατόμων σε iPads.

1. **ΔΙΑΔΙΚΑΣΙΑ ΕΡΕΥΝΑΣ:**

Αν επιθυμείτε το παιδί σας να συμμετάσχει στην έρευνα, τότε η συμμετοχή του θα πραγματοποιηθεί εντός δυο (2) διδακτικών ωρών και περιλαμβάνει τα εξής:

- Συμπλήρωση δυο μικρών ερωτηματολογίων (πριν- και μετά- τη διδακτική παρέμβαση) σχετικά με την ενότητα του Ηλεκτρισμού
- Συνεργασία σε μικρή ομάδα 3-4 μαθητών για τη δημιουργία μια ψηφιακής ιστορίας, σειροθετώντας μικρά βίντεο-κλιπς και ηχογραφώντας την πλοκή της ιστορίας με δικά τους λόγια.
- Σχολιασμός και συζήτηση των ιστοριών όλων των ομάδων στην ολομέλεια της τάξης
- Συζήτηση μαζί μου για την εμπειρία τους αυτή, σε μικρές ομάδες (focus groups)

Κατά τη διάρκεια της διδακτικής παρέμβασης, εγώ, η ερευνήτρια θα ηχογραφήσω και θα βιντεοσκοπήσω τις δραστηριότητες των μαθητών, ώστε να μπορώ να καταγράψω και να αξιολογήσω τόσο τη διαδικασία όσο και τα αποτελέσματα. Σας ζητώ την άδεια για την βιντεοσκόπηση και ηχογράφηση των παιδιών σας κατά τη διάρκεια της διδακτικής παρέμβασης

2. ΑΝΑΜΕΝΟΜΕΝΑ ΟΦΕΛΗ ΑΠΟ ΤΗΝ ΕΡΕΥΝΑ:

Η ενεργή εμπλοκή των μαθητών στη δημιουργική διαδικασία επιτρέπει στα παιδιά να αποκτήσουν έλεγχο στη διαδικασία μάθησης, όπως επίσης εμπλουτίζει τις δεξιότητες τους στη χρήση των Νέων Τεχνολογιών. Ακόμη, το ομαδοσυνεργατικό μοντέλο μάθησης που ακολουθεί η έρευνα συμβάλει στη νοητική ανάπτυξη των παιδιών, ενώ παράλληλα ενδυναμώνει και τη συναισθηματική τους ανάπτυξη και ευνοεί ένα κλίμα αλληλοβοήθειας, αλληλοσεβασμού αλλά και κατανόησης για τη λήψη κοινών αποφάσεων,

3. ΠΙΘΑΝΟΙ ΚΙΝΔΥΝΟΙ / ΔΥΣΚΟΛΙΕΣ:

Η παρούσα έρευνα δεν εμπερικλείει φυσικούς ή άλλους κινδύνους καθώς θα διεξαχθεί μέσα στη σχολική μονάδα υπό την παρουσία της ερευνήτριας και την επίβλεψη του δασκάλου της τάξης. Οποιεσδήποτε δυσκολίες πιθανόν να προκύψουν από τη χρήση των iPads θα επιλυθούν από την ερευνήτρια και το δάσκαλο της τάξης, οι οποίοι θα συμμετέχουν ενεργά στην όλη δραστηριότητα.

4. ΑΝΩΝΥΜΙΑ / ΠΡΟΣΤΑΣΙΑ ΠΡΟΣΩΠΙΚΩΝ ΔΕΔΟΜΕΝΩΝ:

Τα δεδομένα της έρευνας θα φυλαχθούν με ασφάλεια, σύμφωνα με τον Νόμο Προστασίας Δεδομένων για 10 χρόνια και μετά θα καταστραφούν. Θα χρησιμοποιήσω αποσπάσματα για σκοπούς υποστήριξης/επιμόρφωσης/δημοσίευσης μέσω της διδακτορικής διατριβής μου. Τα αποσπάσματα θα είναι ανώνυμα, δε θα θίγονται προσωπικά δεδομένα και δε θα γίνεται προσωπική ταύτιση με

τους μαθητές. Τα ονόματα των μαθητών καθώς και η διεύθυνση του σχολείου θα αντικατασταθούν με ψευδώνυμα. Τα αποσπασματικά δεδομένα θα χρησιμοποιηθούν σε συνέδρια, άρθρα, online περιοδικά και αναφορές.

Προϋπόθεση: ότι δεν θίγονται προσωπικά δεδομένα όπως κάθε πληροφορία που αναφέρεται στο παιδί, για παράδειγμα το όνομα, τη διεύθυνση της οικίας, το τηλέφωνο επικοινωνίας (σταθερό ή κινητό) , τα ενδιαφέροντα, επιδόσεις στο σχολείο κ.ο.κ. σύμφωνα και με την Αρχή Προστασίας Δεδομένων Προσωπικού Χαρακτήρα.

6. ΑΡΝΗΣΗ / ΑΠΟΣΥΡΣΗ:

Εσείς και το παιδί σας είστε ελεύθεροι να αποφασίσετε κατά πόσο θέλετε το παιδί σας να συμμετέχει. Η συμμετοχή είναι εθελοντική και το παιδί μπορεί ανά πάσα στιγμή να διακόψει τη συμμετοχή του για οποιοδήποτε λόγο, χωρίς καμιά κύρωση. Αν το παιδί δεν ενδιαφέρεται να συμμετάσχει καθόλου στην έρευνα μπορεί να συνεχίσει με τις κανονικές δραστηριότητες που θα έκανε στο συγκεκριμένο μάθημα ή να κάνει παρόμοια (με αυτή της επέμβασης) δραστηριότητα στο iPad, ανεξάρτητα, και η οποιαδήποτε δραστηριότητα του δεν θα βιντεοσκοπηθεί/ηχογραφηθεί ούτε θα περιληφθεί στα ερευνητικά αποτελέσματα.

Για περαιτέρω διευκρινίσεις ή πληροφορίες, μη διστάσετε να επικοινωνήσετε μαζί μου ή με την επιβλέπουσα καθηγήτρια μου.

Σας ευχαριστώ για το χρόνο σας και την πολύτιμη συνεργασία σας,

Επιβλέπουσα Καθηγήτρια

Dr. Anne Adams

Πόπη Αναστασίου

Υποψήφια Διδάκτωρ,

Ινστιτούτο Εκπαιδευτικής Τεχνολογίας (ΙΕΤ)

Ανοιχτό Πανεπιστήμιο, Αγγλία.

Email: popi.anastasiou@open.ac.uk

Associate Director (Academic Professional Development)

Ινστιτούτο Εκπαιδευτικής Τεχνολογίας (ΙΕΤ)

Ανοιχτό Πανεπιστήμιο, Αγγλία.

Email: anne.adams@open.ac.uk

Με εκτίμηση,

Πόπη Αναστασίου

ΥΠΟΓΡΑΦΗ ΕΡΕΥΝΗΤΗ/ΤΡΙΑΣ   ΗΜΕΡΟΜΗΝΙΑ

....

2. ΥΠΕΥΘΥΝΗ ΔΗΛΩΣΗ / ΥΠΟΓΡΑΦΗ:

Δηλώνω υπεύθυνα ότι αποδέχομαι τη συμμετοχή του παιδιού μου στην έρευνα. Το παιδί μου διατηρεί το δικαίωμα να αποσυρθεί από τη διαδικασία της έρευνας σε οποιοδήποτε στάδιο της διεξαγωγής της.

ΥΠΟΓΡΑΦΗ ΓΟΝΕΑ Ή ΚΗΔΕΜΟΝΑ   ΗΜΕΡΟΜΗΝΙΑ

....

What I do:

I want to use digital storytelling as a learning tool to help school students understand science topics that they are having problems learning. I call them troublesome topics. These troublesome topics have already been identified with the help of the classroom's teacher and they have already been taught. I ask students to work in small groups to create a digital story that explains a troublesome science topic. The digital stories will include animated video, sound, text, pictures, and narration. I also work with teachers in school to help students to storyboard and review and comment on the stories of other students.

An invitation to take part in my research:

I would like to invite your son/daughter to take part in our research. This would involve:

- Completing a pre- and post- intervention quiz about their understanding of a troublesome science topic
- Learning about digital story-making on IPads and/or computers
- Working in small groups to create a digital story using prepared story clips
- Inventing their own story plot by ordering the animated story clips
- Narrating the story plot by making written commentaries
- Uploading and sharing their digital story with their classmates
- Watching and commenting on each other's digital story
- Talking to me after the classroom activities about their experiences

At the classroom activities, the researcher will take notes of what is happening. I will record audio, take photographs, and video record what the students are doing so I can look back to see which activities worked well and see if there were any problems during the process.

If you are not interested in your children taking part, they can either do the standard teaching activities they would normally have done or do similar-to-the intervention activities on an iPad, independently, and they will be neither recorded nor included in the data collected.

Confidentiality and data security:

I will store video data collected from the workshop securely in accordance with the Data Protection act for 10 years, and then it will be destroyed. I will put extracts into support/training/publicity videos for the PhD thesis. I might transcribe quotes from audio recordings, and I will then make them anonymous and use them for conferences, events, journal papers, online publicity and in written reports. I will make sure individuals cannot be identified by blurring or omitting faces and I may then use them for the purposes listed above.

Results of this research:

I will write up the results of this research for conference papers and peer-reviewed journal articles.

Contact details:

If you have any questions about this research or concerns about participating, then please email me or my supervisor:

Popi Anastasiou
PhD Student
Institute of Educational Technology (IET)
The Open University UK
Email: popi.anastasiou@open.ac.uk

Dr. Anne Adams
Associate Director Academic Professional Development
Institute of Educational Technology (IET)
The Open University UK
Email: anne.adams@open.ac.uk

Observations/Interviews Consent Form for Parents or Caregivers

Research project title
Digital Storytelling in science class: a lesson to be learned
I am collecting this consent as part of my PhD research undertaken at the Open University, UK.

I will store the data that I collect securely and will authorise only my supervisors to access it. This data will be retained by the project and will only be used for research, and statistical and audit purposes. By signing this form, you are consenting to the University storing your data for these purposes. The Open University will process the data in accordance with the provisions of the Data Protection Act 1998. I will not publish identifiable personal data without your separate written consent.

Statements of understanding/consent

I confirm that I have read and understood this consent form. I have had the chance to ask questions if necessary and understand and am happy with the answers.

I understand that my son/daughter is taking part in this classroom activity voluntarily and he/she can change my mind and withdraw at any time. If he/she withdraws, then his/her personal data will be removed from the project with immediate effect and destroyed.

Based upon the above, I agree to my son/daughter taking part in this research.

Name, signature, and date

Name of student

....

Name of parent/caregiver

....

Date ....   **Signature** ....

Two copies of the consent form should be given to the parent, one signed and dated copy should be returned and retained by the researchers to be kept securely on file.

What I do:

I want to use digital storytelling as a learning tool to help school students understand science topics that they are having problems learning. I call them troublesome topics. These troublesome topics have already been identified with the help of the classroom's teacher and they have already been taught. I ask students to work in small groups to create a digital story that explains a troublesome science topic. The digital stories will include animated video, sound, text, pictures and narration. I also work with teachers in school to help students to storyboard and review and comment on the stories of other students.

An invitation to take part in my research:

I would like to invite you to take part in our research. This would involve:

- Completing a pre- and post- intervention quiz about their understanding of a troublesome science topic
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- Working in small groups to create a digital story using prepared story clips
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- Narrating the story plot by making written commentaries
- Uploading and sharing your digital story with your classmates
- Watching and commenting on each other's digital story
- Talking to me after the classroom activities about your experiences

At the classroom activities, the researcher will take notes of what is happening. I will record audio, take photographs and video record what the students are doing so I can look back to see which activities worked well and see if there were any problems during the process.

If you are not interested in taking part, you can either do the standard teaching activities you would normally have done or do similar-to-the intervention activities on an iPad, independently, and you will be neither recorded nor included in the data collected.

Confidentiality and data security:

I will store video data collected from the workshop securely in accordance with the Data Protection act for 10 years, and then it will be destroyed. I will put extracts into support/training/publicity videos for the PhD thesis. I might transcribe quotes from the audio recordings and I will then make them anonymous and use them for conferences, events, journal papers, online publicity and in written reports. I will make sure individuals cannot be identified by blurring or omitting faces and I may then use them for the purposes listed above. Results of this research:

I will write up the results of this research for conference papers and peer-reviewed journal articles.

Contact details:

If you have any questions about this research or concerns about participating, then please email me:

Popi Anastasiou

PhD Student

Institute of Educational Technology (IET)

The Open University UK

Email: popi.anastasiou@open.ac.uk

Dr. Anne Adams

Associate Director Academic Professional Development

Institute of Educational Technology (IET)

The Open University UK

Email: anne.adams@open.ac.uk

Research project title

Digital Storytelling in science class: a lesson to be learned

I am collecting this consent as part of my PhD research undertaken at the Open University, UK.

I will store the data that I collect securely and will authorise only my supervisors to access it. This data will be retained by the project and will only be used for research, and statistical and audit purposes. By signing this form, you are consenting to the University storing your data for these purposes. The Open University will process the data in accordance with the provisions of the Data Protection Act 1998. I will not publish identifiable personal data without your separate written consent.

Statements of understanding/consent

-   I confirm that I have read and understood this consent form. I have had the chance to ask questions if necessary and understand and am happy with the answers.
-   I understand that I am taking part in this classroom activity voluntarily and I can change my mind and stop taking part at any time. If I decide to withdraw, then my personal data will be removed from the project with immediate effect and destroyed.
-   I understand that my personal data will be processed in accordance with the Data Protection Act 1998.

Based upon the above, I agree to take part in this research.

Name, signature and date

Name …………………………………………………………………………………………

Date ……………………………………   **Signature**…………………………………………

Two copies of the consent form should be given to the participant, one signed and dated copy should be returned and retained by the researchers to be kept securely on file.

Appendix 9: HREC proforma and Memorandum

Human RESEARCH ethics committee (HREc) Proforma

Open University research involving human participants or materials has to be reviewed and where appropriate, agreed by the HREC. To apply to HREC, please complete and email this proforma to research-rec-review@open.ac.uk. You will need to attach any related documents such as a consent form, information sheet, a questionnaire, consent form, or publicity leaflet, so that the HREC Review Panel has a full application. Ensure that if you have more than one group of participants, that the relevant documents for each research group are included. Omitting relevant documents may result in a delay to the review and approval process. No potential participants should be approached to take part in any research until you have received a response from the HREC Chair.

If you have any queries about completing the proforma please look at the Research Ethics website, in particular the FAQs - http://www.open.ac.uk/research/ethics/faq-questions-inline which includes sample documents and templates. You can also contact the HREC Chair or Secretary.

The submission deadline for applications is **every Thursday** at **5.30pm** when they will be assessed for completeness and then sent to the HREC Review Panel. Once an application has been passed for review you should receive a response within 15 working days.

All general research ethics queries should be sent to Research-Ethics@open.ac.uk.

Please complete all the sections below – deleting the inserted instructions.

Project identification and rationale

Title   of   project

Digital storytelling in science class: a lesson to be learned

Abstract

Digital storytelling as an aiding tool in the classroom has gained lot of attention in the past decade, because it can generate children's interest, attention and motivation and keep them engaged in the learning process. Researchers argue that, children can use digital storytelling to develop their cognitive skills, such as thinking, explaining, making-sense, understanding, and to improve their competence in collaboration, communication and creativity. The process of engaging children in the creation of a story allows them to interact not only as audience but also as makers of the experience. Digital storytelling spans the curriculum, though it is most commonly used in subjects such as literacy or history, whereas it rarely appears in science. Science topics are often described as 'troublesome knowledge' because they are considered conceptually difficult and they present a barrier to students' understanding of core concepts. This research aims to explore the use of digital storytelling to facilitate secondary children's understanding of a science topic. This research will not attempt to identify a 'troublesome' science topic; the intervention will be practiced on an already taught science topic. Where this research mainly focuses, is on testing the use of digital storytelling as a learning tool to improve children's understanding.

The sample will consist of 30 primary children, aged 11-13, who will be divided into small groups of 3-4 people and they will work together to create a digital story. A number of soundless animated story clips will be presented to participants, who will be then asked to place them in the right – according to them – order so that their final digital story will have a sequence of events and a story plot. Student's own narration of the story will be recorded and applied onto the digital story. The sample will be recruited from a secondary school in Oxford, UK. Data collection will be conducted using both qualitative methods: observations, focus groups, video and audio recording and quantitative methods: pre- and post-intervention quizzes.

Prior meetings with school teachers and any other stakeholders involved will be conducted in order for them to be informed about the research procedure and the ethical considerations involved. Once permission is granted, consent forms and information sheets will be sought from both children and their parents. Approximately 5 further meetings / workshops are planned at the school with 1-2 teachers taking part.

Participants will have discussions (the researcher taking notes on ideas that the teachers have for the particular science study), write and record with data pens concepts and activities that they use for teaching. All data collected when analysed will be fed back to be used by the school, the researcher and academics.

Ethics and ethical procedures have been built into key points throughout this project (e.g. ethics handbook Mth 6, Ethics review Mth 30, ethics feeding into the evaluation procedure) to maintain a clear understanding of the risks in multimedia usage with children and HE students. DBS checks have been completed for these meetings as well as completion of the data protection questionnaire. Ethical procedures detailed within the ethics handbook are being used for these meetings.

Project personnel and collaborators

Investigators

Give names and institutional attachments of all persons involved in the collection and handling of individual data and name one person as Principal Investigator (PI). Research students should name themselves as Principal Investigator and it is a requirement that a brief separate supervisor endorsement is sent to Research-Rec-Review@open.ac.uk to support the application. This needs to be received with the application or shortly after, as the application cannot be processed without it (see note for supervisors). Please include the relevant HREC reference number.

Principal Investigator/ (or Research Student):   Popi Anastasiou

Other researcher(s):

Primary Supervisor (if applicable):   Dr. Anne Adams

Research protocol

Literature review

The current study derives evidence from the theory of digital storytelling as narratives that generate students' interest, attention, motivation and creativity (Robin, 2006). Storytelling is a particular form of narrative that discloses someone's perspective on life and draws upon that person's emotions, theories, ideas, dreams, fears and hopes (McEwan and Egan, 1995 cited in McDrury and Alterio, 2002). Narrative emerges early in communicative development of humans and is seen as a means of recounting, exploring and making sense of experience (Davis, 2004; McDrury and Alterio, 2002; Ochs and Capps, 1996). Narrative must be coherent, meaning that the events of the story are "meaningfully connected in both temporal and causal ways", so that people can understand their experience (Si, Marsella and Pynadath, 2009).

Stories are believed to have a pedagogical effect, namely by "embedding content within a narrative frame and communicating it through character actions and dilemmas" (Barab *et al.*, 2009, p. 333). However, stories are subject to "the author's ideological intent" (p. 334) and individual bias and they should be treated with consideration, especially in an educational setting.

A significant amount of recent changes in the presentation and delivery of stories have been made possible by emerging technologies (Chen, Ferdig and Wood, 2003). The rapid development of technology, alongside "the advent of relatively inexpensive" (Davis, 2004, p. 1) digital tools, has shifted the focus from traditional types of storytelling to a new form of more digital-computer aided storytelling: digital storytelling.

Digital storytelling "blends media to enrich and enhance the written or spoken word" (Frazel, 2010, p. 9). Like all storytelling, digital storytelling is a form of narrative expression, presented as a short movie for display on digital devices, enriched with digital graphics, text, video, sound and music (Davis, 2004; Robin, 2006). A digital story combines an original script with visual imagery, sound tracks and most importantly, a narration in the author's own voice (Weis, Benmayor, O'Leary and Eynon, 2002). Animation can also be used given that it attracts students' attention more easily. Digital storytelling is usually shorter that a typical oral presentation – between 2 and 10 minutes length – but it "makes up in content what it forgoes in length", stresses Frazel (2010, p. 10).

Teachers have always proposed storytelling to their students, from preschool to high school, in order to help the latter develop a variety of skills in communication, search, collaboration and task completion; storytelling is seen as a very common educational practice (Di Blas, Garzotto, Paolini and Sabiescu, 2009) that is generally practiced in school classrooms.

Digital storytelling in education can be used in a number of ways and it is primarily dependent on the educator's decision. Some educators may decide to create their own stories and then present them to students as a way of introducing new material. Others may have their students create their

own stories (Robin, 2006). And then there are those who may choose to co-create a story with their students, such as in this research.

Using digital stories in teaching new context at school is a great opportunity to engage students deeper in the subject being taught. Students' participation in the multiple steps of designing, creating and presenting of their own digital stories, enables them to increasingly develop their literacy skills, including those of research, writing, organisation, technology, presentation, problem-solving and interpersonal (Robin, 2006).

In addition, digital storytelling, as a technology-based instructional tool, can capture students' attention and increase their interest in exploring new ideas. A significant number of researchers support the use of such tools at the beginning of a lesson to help engage students in the learning process (Burmark, 2004; Ormrod, 2004) and as a bridge between existing knowledge and new material (Ausbel, 1978).

Methodology

The purpose of this research is to explore how the use of digital storytelling in science learning can facilitate students' understanding of a particular topic, and thus impact upon teaching practice. In particular, it aims to explore how digital storytelling can help secondary students improve their understanding of a science topic. More specifically, the driving research questions are:

1) How can story-making help students understand better a particular troublesome topic?
2) How do digital tools help students engage in the storytelling process, if so?

Based on the 'exploratory' nature of the inquiry and the requirements of the research questions, that are practice-based to inform teachers, this research employs a mixed-methods approach. The table below describes the data collection methods that provide the best fit to the needs of the research questions.

	Research Questions	Concepts within RQ	Data collection methods
		Perceptions of (digital) storytelling	Focus group with the whole classroom on the concept of (digital) storytelling

RQ1	How can story-making help students understand better a particular troublesome topic?	Creation of the story (story-making as the practical creative process of storytelling)	Initial interview with the teacher to identify children's difficulties in a particular STEM topic
			Science learning quizzes to identify and evaluate individual needs in a particular topic (pre- and post-intervention)
RQ2	How do digital tools help students engage in the storytelling process, if so?	Social interaction with digital tools	Video recordings of the groups while they engage in the creation of a digital story on iPads and laptops
		Use of digital tools (prepared story clips and ipads)	Reflections/feedback from classmates on the finished digital stories – observation and notes-taking
		Value of engagement in the story-making process	Focus group with children to evaluate their understanding of both storytelling and the particular topic after the creation of the digital stories

Table 1 shows the proposed methods that best fit to needs of the study's research questions

Participants

A series of up to 8 semi-structured meetings / workshops will be held from January 2017 – March 2018.

Approximately 1-2 teachers and about 30 children will be involved in each of these sessions. As they are not formal evaluation procedures the teachers will participate in alignment with their other activities. Informal meetings with the deputy head of the school (head of teaching and learning) will also be held to ensure that all procedures and activities fit with the school's wider practices.

Recruitment procedures

The teachers and children, will be recruited based on ease of access and their willingness to participate in the study. Some trainee science teachers from secondary schools in Oxford, have already expressed their interest in working with us on this research and we are in communication via emails. These trainee science teachers take part in the IAA project, led by Dr. Anne Adams, in which I am currently involved. The Department of Education at the University of Oxford has given its permission for its trainee teachers to take part *(see attached Letter of Support).*

An intensive series of meetings with supervisors, mentors and their trainee teachers will ensure that the study can fully understand the school's internal procedures, norms of practice and identify in advance appropriate student selections, research methods and design to ethically fit with the school's needs. The researcher has the current DBS check.

Consent

I have carefully looked through the issues of consent at a very early stage of the research because it is important to allow participants to make an informed decision if they want to participate in the research. With this is mind I have decided that:

- Informed consent will be sought from all participants in both verbal and written form.

- Participants will be provided with information sheets and consent forms in accordance with official ethical guidelines (BERA 2011). Taking into consideration that participants are children, written permission and consent must be sought from their parents/carergivers as well (BERA, 2011).

- Participants who are not interested in taking part they can either do the standard teaching activities they would normally have done or do similar-to-the intervention activities on an iPad, independently and they will be neither recorded nor included in the data collected.

- Participants will have the right to withdraw at any point during the research, if they wish to no longer take part, without any explanations necessary. If they decide to withdraw, then their personal data will be removed from the project with immediate effect and destroyed.

- The researcher will also provide stakeholders with detailed information about the study, and about what data will be used throughout the study and how it will be re-used.

- Feedback will be provided to stakeholders on the data collected and conclusions inferred from this information. Stakeholders" feedback will be collected to verify if these are accurate interpretations for developing system requirements and specifications.

Location(s) of data collection

Research will be conducted in school premises with utmost care so that the school environment and the students will not be insulted in any way. It is my duty as the researcher of this research to pledge that I am aware of all legislation and guidelines which concern this research and to make sure that any other individuals involved in the research are also aware of the legislations and guidelines.

The data will be collected at an institutional premise such as the secondary schools in Oxford. The research will be conducted in the chosen locations so as to avoid disrupting and distracting students from both their daily classes and school tasks.

To preserve anonymity, the names and locations of the schools will not be revealed and participants' identity will be replaced by pseudonyms.

Schedule

The aim is to complete the meetings in the period between January 2017 – December 2017.

Key Ethics considerations

Published ethics and legal guidelines to be followed

2.4.12 in CIRE"s list of "privacy and confidentiality issues":
http://ccnmtl.columbia.edu/projects/cire/pac/foundation/index.html#2_4_12

British Sociological Association Statement of Ethical Practice (http://www.britsoc.co.uk/about/equality/statement-of-ethical-practice.aspx)

Employment Studies - IES (2004) An EU Code of Ethics for Socio-Economic Research

http://www.respectproject.org/main/index.php

Data Protection and Data Security

All data collected will be dealt with according to the Data Protection Act 1998. Data will be kept securely in manual and electronic formats and only the researcher and her supervisors will have access to it. Upon completion of the research project, all data will be destroyed.

Recompense to participants

No recompense will be offered to participants.

Deception

N/A. A copy of the study proposal will be given to the school in advance of these meetings.

The risk assessment matrix has been reviewed and submitted to the ethics committee along with the HREC-proforma.

School teachers will conduct the meetings as part of their duties at their school.

Debriefing

These meetings will help to support the development of technologies to enhance students' engagement and understanding within science and technology. Feedback to those involved in the meetings will be given on notes and requirements data gathered. Everyone taking part in those meetings will have the opportunity to amend and exclude parts of the information before they are distributed.

Project Management

Research organisation and Funding

The study is funded by the Leverhulme Trust.

AMS reference number:

Other project-related risks

The researcher will conduct the meetings as part of her PhD funded study and at the school's premises. As such I should be covered by The Open University's insurance cover, which is for established members of staff, other contracted staff, full- time and part-time directly registered research students.

Benefits, knowledge transfer

State how the research may be of general benefit to participants and society in general (100 words maximum). For guidance on what to keep, for how long and where to keep it, visit the Research Data Management intranet pages http://intranet6.open.ac.uk/library/main/supporting-ou-research/research-data-management or contact the RDM mailbox (rdm-project@open.ac.uk).

Disseminating and publishing research outcomes

Data collected in this research will be used for the purposes of this research and findings will be disseminated in this PhD thesis as well as in future publications related to it. Data will also be disseminated to both the school teachers and school children who participated in the study. For the protection of participants, anonymity will be preserved and the names and locations of the schools will not be revealed and participants' identity will be replaced by pseudonyms. Additionally, no information and details that could possibly reveal the identity of the school or participants will be included in the final report for the university or in any future publications.

Declaration

I declare that the research will conform to the above protocol and that any significant changes or new ethics issues will be raised with the HREC before they are implemented.

I declare that I have read and will adhere to the following two OU documents:

- OU Code Of Practice For Research and at the Open University
- OU Ethics Principles for Research involving Human Participants

http://www.open.ac.uk/research/ethics/index.shtml)

In order to conform to OU governance guidelines, brief information on OU research approved by the HREC will be added to the Research Ethics website. The HREC will assume that you agree that the following data from your research can be made public via the website unless you   tick   the   box   below:

HREC reference number	Project title	Faculty	Approval date	Type of HREC approval

[X] No, I do not wish for details of my HREC approved research to be publicised.

Name:	POPI ANASTASIOU
Unit/Faculty:	IET – CREET
Telephone	07761260722
E-mail	popi.anastasiou@open.ac.uk
Signature(s) (this can be the typed name(s) of investigator(s) if an electronic copy is submitted (which is preferred)	Popi Anastasiou
Date:	24/10/16

End of project final report

Once your research has been completed you will need to complete and submit a final report to the HREC.   A   copy   of   the   template   can   be   found   on   the   Research   Ethics   website   at http://www.open.ac.uk/research/ethics/human-research/human-research-ethics-full-review-process-and-proforma#final report.

Proposed date for final report: June 2019

From	Dr Louise Westmarland
	Chair, The Open University Human Research Ethics Committee
Email	louise.westmarland@open.ac.uk
Extension	01908 652462

To	Popi Anastasiou, IET/CREET

Subject	Digital storytelling in science class: a lesson to be learned

Memorandum

| HREC Ref	HREC 2016 2179 Anastasiou
AMS ref	
Submitted	24/10/16
Decision date	23/12/16

This memorandum is to confirm that the research protocol for the above-named research project, as submitted for ethics review, has been given favourable opinion by the Open University Human Research Ethics Committee (HREC).

Please note the following:

1. You are responsible for notifying the HREC immediately of any information received by you, or of which you become aware which would cast doubt on, or alter, any information contained in the original application, or a later amendment which would raise questions about the safety and/or continued conduct of the research.

2. It is essential that any proposed amendments to the research are sent to the HREC for review, so they can be recorded and a favourable opinion given prior to the any changes being implemented (except only in cases of emergency when the welfare of the participant or researcher is may be effected).

3. You are authorised to present this memorandum to outside bodies such as NHS Research Ethics Committees in support of any application for future research clearance. Also, where there is an external ethics review, a copy of the application and outcome should be sent to the HREC.

4. OU research ethics review procedures are fully compliant with the majority of grant awarding bodies and their frameworks for research ethics.

5. At the conclusion of your project, by the date stated in your application, you are required to provide the Committee with a final report to reflect how the project has progressed, and importantly whether any ethics issues arose and how they were dealt with. A copy of the final report template can be found on the research ethics website - http://www.open.ac.uk/research/ethics/human-research/human-research-ethics-full-review-process-and-proforma#final report.

Kind regards,
Dr Louise Westmarland
Chair OU HREC http://www.open.ac.uk/research/ethics/

Appendix 10: Mapping Diagram (Stage 1 of the Tricky Topic Process)
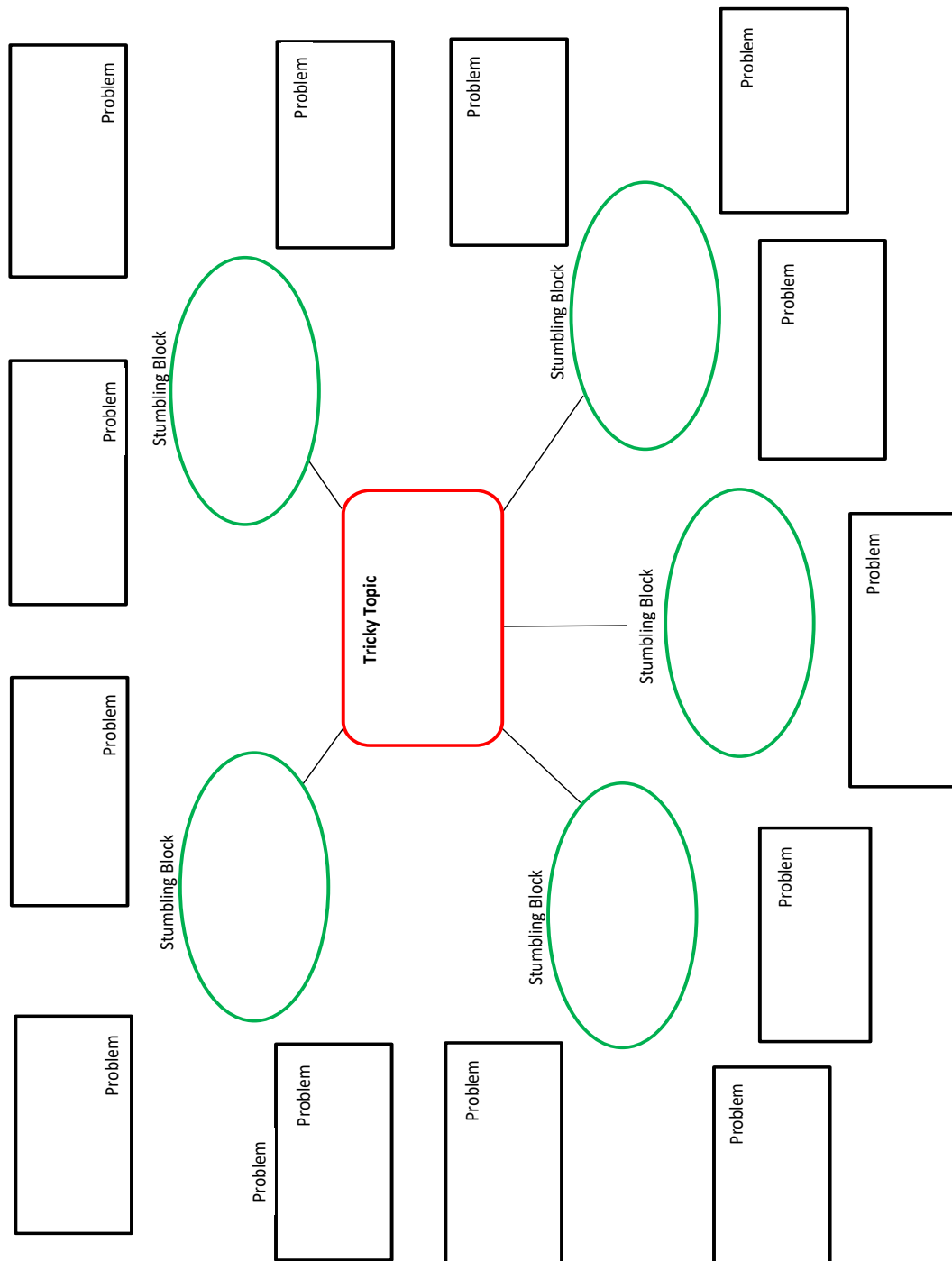
Appendix 11: Group interview questions with students

Group interview Protocol

- o Explain who I am and what I am doing in School.
- o Remind the respondent of their rights (Participant Information Sheet) and collect the Consent form.
- o Remind the respondent that the group interview will take approximately one hour.
- o Remind the respondent that I am asking them for permission to audio record. Remind them that their name will not be attached to the data. If any respondent does not give permission to have an audio recording, then I will take notes. If this is refused, then the respondent can leave the group interview.
- o I will ask the respondent if they have any questions before the group interview goes ahead.

1) What do you think of the activity you did today? How did you like it?

2) What kind of activity is the one you did today? How would you define it?

3) This activity was a story, broken down into small scenes which you had to put in the right order... How did you feel about ordering these clips? Why?

4) Was there anything that troubled you during the activity? If yes, can you explain what and why?

5) Would it be better if you created the story yourself? Meaning that you would have to create the characters, find the setting, edit the scenes, invent and record the plot etc?

6) How did you feel about working on iPads? Would you rather do it on a pc?

7) Would you prefer to have done this activity with paper and pencil? Why or why not?

8) How did you feel about working together with your classmates on this activity?

9) Would you rather do it on your own/individually?)

10) How would you feel about sharing your stories with the other Grade 5 or Grade 6 classes?

11) Would you like to do similar activities again? Why or why not?

12) I noticed that your teacher was present during the activity and he/she helped you when needed... How did you like that?

13) When did you need your teacher's help the most? How would you feel if she wasn't present in the activity?

14) Do you think that the activity you did today helped you understand any better the specific topic? If yes, how? If not, why not?

15) Is there anything else you want to say about the whole process?

Appendix 12: Extract from group interview with team A, Grade 5/E'1 class

Time	Interviewer	Students (Anj, Mar., Hel.)
00:00:11.7	… so how would you describe the activity you did before?	**Anj:** a story **Hel:** yeah **Mar:** It was like a story
00:00:22.8	Like the stories you are used to doing?	Anj: No Mar: No, it was different Hel: Different… yeah
00:00:27.9	What was different? Can you explain?	Mar: It was on an iPad and we had to put it in an order Anj: We had to make the commentaries Hel: It was a story with videos instead of pictures
00:00:37.3	Exactly… it's called digital story because it uses digital devices, like iPads. So how did you find it?	Hel: Interesting Mar: Fun Anj: Cooperative Mar: We liked it and we want to do it in other classes as well
00:00:51.8	In what other classes?	Mar: Geography, maths
	You girls? In what other classes do you want to do it?	Hel: same
	And you Anj?	Anj: Yeah, in maths … and the arts maybe
00:00:55.1	Yes, in the arts too… so what did you like exactly?	Hel: that we cooperated Mar: and we made the commentaries
	Anything else that you liked or didn't like, Anj?	Anj: yeah, I liked that too… I liked that we used the iPads … I can do it on my iPad at home too
00:01:05.7	So, how did you find it that you had to order the story scenes and it wasn't an ordered story?	Mar: Erm… it was a bit difficult, because there was no audio or text and we didn't know how the order went

		Anj: yeah… maybe we could use some help from you or the teacher
00:01:10.0	I see… and you Hel., what do you think?	Hel: like they [Mar. and Anj] … said
00:01:11.0	You too think it was difficult?	Hel: mmm [nodding] …
00:01:11.8	Can you give me an example? I want to hear more …	Hel: … I mean… we [looking at the other two] found it a bit difficult … we got troubled at some point … Anj: yeah… but we found it in the end Hel: yeah … because, you know … we didn't know what they [characters] were saying and we had to imagine … and then we had to relate the scenes together so that they match Mar: yes, that was hard …
00:02:07.7	Hmm… I see… so, if you did this activity with still pictures instead of animations, how would you feel about it?	Mar: oh no, harder, I think … because still pictures do not animate, and we wouldn't know what each character did. I mean it was difficult with no sound [audio] or dialogues [commentaries] but with pictures it's more…
00:02:24.1	Aha… what do you think Anj. and Hel?	Hel: yes, I think the videos are better … they are 'live' … we can see what they [characters] do
00:02:35.2	Why is that?	Hel: it's like the cartoons we watch on tv
00:02:42.5	I get it… Anj, what do you think?	Anj: yes, we like them [animations on tv] … they are fun
00:02:48.3	That's nice … and what if you did this activity on a desktop or a laptop rather than on an iPad?	Anj: No… we prefer the iPad Mar: yeah… because we can touch on it and it's easier

		Hel: yeah, and we could drag the videos down [in the storyline] and then back up [on to the main screen]
		Mar: yeah, and we don't use them much at school… only the computers … so it's nice to do something different
		Anj: yeah, I know… and I practice on it at home, my mom gives it to me after I do my homework
00:03:01.0	Interesting… but here at school we use it differently than at home I guess ….	Anj: yeah, I know we do educational things here…

Interview Protocol

o Explain who I am and what I am doing in School.

o Remind the respondent of their rights (Participant Information Sheet) and collect the Consent form.

o Remind the respondent that the interview will take approximately one hour.

o Remind the respondent that I am asking them for permission to audio record. Remind them that their name will not be attached to the data. If the person does not give permission to have an audio recording, then I will take notes. If this is refused, then the interview cannot go ahead.

o I will ask the respondent if they have any questions before the interview goes ahead.

---

1) How are your students doing in the science class?

2) Are there any topics in which you feel they may face more difficulties? If yes, why do you think this happens?

3) When it comes to the topic of the states of matter, do you feel that there are areas or concepts that students find difficult to understand?

4) Do you think that these problems may have deeper roots?

5) How do you try to make these students, who have difficulties in specific science topics, to cope with these? Are there any specific (teaching) approaches that you use to help them understand better, apart from the science textbook? If yes, why those?

6) How do you feel about the use of digital storytelling on iPads in the science class?

7) How did you feel about the activity that your students did today?

8) What about the fact that they had to order the story scenes themselves? The activity that your students did today, brought to surface some difficulties that students faced in the specific topic. For example, they kept confusing 'steam' with 'smoke'… Why do you think that happened?

9) Given that you have seen the other activity, how did you feel about it compared to SEeDS?

10) Nevertheless, your students did well in the relevant tests. How would you explain this?

11) Would you use such an activity in other classes? Why or why not?

12) What role do you think digital tools, like iPads, play in science learning?

13) Would you use it in your teaching?

14) Would you like to create such an activity yourself?

For the first pilot study, a teaching activity similar to SEeDs about *Division in Fractions* was created. It was a short-in-length digital story including animation but no visual or textual commentaries. The story was 1:36 minutes long, broken down into 12 short scenes, lasting approximately 10-20seconds each. Students edited the digital story and invented their own plot. The table below shows the original ordering of the scenes, followed by the plot.

The original predefined story about division of fractions

Plot: *"Tom and Sara are siblings, who are going on a family trip to Rome. Before starting to pack, they discuss what clothes they should take with them, given that it's their first time in Rome and they don't know much about the weather there. Tom suggests they should take sunhats with them, because Rome is in Italy and Italy is a Mediterranean island, which implies warm and sunny weather. Sara, on the other hand, thinks they should take wellies (wellington boots) because regardless of Italy being a Mediterranean island, November pre-defines winter and therefore it will be cold and rainy. In order to reach a final decision about what to pack, Sara has the idea to check the weather forecast for Rome in the month of November. The weather forecast shows that 1/3 of the days would be cloudy, 1/5 rainy and 9 days would be sunny. It seems that the weather will be bad most of the days (16 days) and therefore they would need to pack wellies instead of sunhats".*

Appendix 15: **Instructions' Protocol for the SEeDS and the Narration activities**

- **Introduction of myself and my research interest:**

Good morning children, I am miss Popi and I am a researcher at the Open University UK. I am here with you today because I am doing a research for my university, which has nothing to do with you, your teacher or your school. I am interested in finding out how students of your age think about some everyday science phenomena and how you discuss about them among yourselves in teams while working on digital storytelling activities. I would love to see how you help each other to understand unclear point about particular topics and also how creative you can be through your digital stories.

- **General guidelines about the two activities:**

You will be working in small teams of three to four students to create a digital story about the topic of the states of matter.

Your teamwork will be audio-recorded, except for those who have not consented to it in the Consent form.

If, at any time, you feel like you do not want to continue with what you are doing, please feel free to stop and let me know. You can withdraw at any time during the activity.

Instructions about the SEeDS activity:	Instructions about the Narration activity:
- You will create a digital story and determine its plot, by ordering 15 scenes in a way that they relate to each other, and they make sense. Then, you will have to make written commentaries for each scene in the extra worksheet provided (Appendix 16). - Each team will get an iPad and you will work on the application called OurStory app to make your digital story.	- You will create a digital story by determining and narrating the plot of a pre-ordered story. To do so you will make written commentaries for each scene in the extra worksheet provided (Appendix 16). - Each team will get an iPad and you will work on the application called OurStory app to make your digital story. - You can now open the OurStory app and I will guide you through it. This is

- You can now open the OurStory app and I will guide you through it. This is the filmstrip of OurStory, where you can see 15 animated scenes that represent different events and phenomena from the topic of the states of matter.

- By clicking on each scene's *play* button, you can watch the scenes as many times as you like.

- At the bottom of the screen is the storyline, in which you will order the scenes. To start ordering them, you have to drag and drop each scene in the storyline. There you can re-arrange the order of the scenes by dragging one scene over the other scenes. You can delete a scene from the storyline by dragging it back to the filmstrip.

- When you are done ordering the scenes, you can watch the complete story by clicking the *play* button on the left-hand side of the filmstrip.

the storyline of OurStory, where you can see the predefined order of 15 animated scenes that represent different events and phenomena from the topic of the states of matter.

- By clicking on each scene's *play* button, you can watch the scenes as many times as you like.

- To watch all the pre-ordered scenes as a complete story you can click the *play* button on the left-hand side of the filmstrip.

- **Further guidance about the two activities:**

- So, is everything clear? Is there anything you want to ask about the activity or the whole process?

- I need to remind you that I will be here with you the whole time that you will be working on the activity, so if you have any questions about how to use the iPad and/or the OurStory app or how to implement the activity, please ask me at any time.

Appendix 16: Commentary worksheet

Please fill in this table with your commentaries about each scene. Make sure you cover all fifteen scenes.

Scene 1	
Scene 2	
Scene 3	
Scene 4	
Scene 5	
Scene 6	
Scene 7	
Scene 8	
Scene 9	

Scene 10	
Scene 11	
Scene 12	
Scene 13	
Scene 14	
Scene 15	

*If you need extra space, please use the empty sheet overleaf.

Phase 1 of the Hybrid thematic analysis: Development of a *priori* codes

Theme	Students' thinking/prior learning of matter	
Codes	**Main code**	**Code definition**
	Access	How the activity might have supported students in recalling prior learning of relevant science concepts
	Reflection	How the activity might have facilitated thinking about the science concepts
	Application	How the activity might have facilitated learners to use prior knowledge, for example to develop explanations or to make arguments
	Types of talk	How the activity might have helped speakers to engage or not critically and constructively with each other's ideas.

Table 19: The four main codes developed *a priori* according to the research questions

Main Codes: Access-Reflection-Application		
Sub-codes	Code description (based on the original story script)	
Structure of matter	SCENE 1	The **three states of matter** are solids, liquids, and gases.
Properties of solids	SCENE 2	Solids (like this block of ice or this ball) **retain their shape and volume**. You can hold them and cut them into pieces, and **they always take up the same amount of space**.
Categorisation into hard and soft solids Particles' movement in solids	SCENE 3	Solids can be **hard,** like a toaster, a pencil or a cricket bat or they can be **soft** like a rubber toy or a piece of clay. A solid means that the **particles are packed in** really **close together** and **they can't move** which means the **object holds its shape** OR the particles in a solid are **in a regular arrangement,** they **vibrate in a fixed position, and** they **sit very closely together.**
Properties of liquids	SCENE 4	Liquids like water or honey can **flow or be poured**. And they are pretty tricky to hold. They **change shape depending on the container** but **always keep the same volume**.
Properties of liquids Particles' movement in liquids	SCENE 5	A liquid can flow which means it can be poured, so if **you pour water into a fishbowl, it will take the shape of the fish ball**. Liquids are sometimes **thick like honey** OR **thin like water** but no matter what they 'll always flow. **Particles in a liquid can move around but they 'll stay together** or the particles in a liquid **are randomly arranged, move around each other** and **they sit close together.**

Properties of gases	SCENE 6	Gases **don't keep their shape or volume**. They **spread out and can fit any container they are put in**. Often you can't even see them. Gas is put into some **drinks to make them fizzy**, and when we drink them, the **gas can sometimes try escape from our bodies**.
Properties of gases Particles' movement in gases	SCENE 7	Gas, **like a liquid, takes the shape of the container** it's in but it will also **spread out to occupy the container**. When a balloon fills with water, **water fills up the bottom first**, but when you **fill it with a gas, gas occupies the whole balloon**. In gases the **particles** of matter **do not stick to each other** and have **space to move into**. Gases **flow** and they **occupy all space in their container** OR the particles in a gas are **randomly arranged** and **move quickly in all directions**.
Change of conditions by adding or removing heat	SCENE 8	The **state of a substance can be changed by heating or cooling** it, with the **aid** of these temperature-controlled rooms (**temperature**).
Melting and freezing	SCENE 9	When **solids are heated, they can melt into liquids** OR heating a substance in the **solid** state will **cause it to melt**, which changes it to the liquid state. When we **cool a liquid, it becomes a solid** OR **continued cooling** a substance in the **liquid** state it will cause it to **freeze**, which changes it to the solid state.
Reversible processes (depending on the material)	SCENE 10	**Freezing** and **melting** seem to be **reversible processes**.

Evaporation	SCENE 11	When **water is heated up it changes** state **from a liquid to a gas**, called **steam**. And this process is called **evaporation** OR Continued heating will cause the liquid substance to evaporate, which changes it to the gas state.
Condensation	SCENE 12	When a **gas cools down** it can **change state back into a liquid**. So when the **warm steam hits the surface of a cold mirror it turns back into water (droplets/vapour) again.** This change is called **condensation**. The **process can be reversed again if we warm up the liquid** OR A substance in the **gas** state **condenses** when it is **cooled**, which **changes** it **to the liquid** state.
Use of thermometer	SCENE 13	A **thermometer measures the temperature** of a state. Temperature **measures the energy** a matter contains, that is **how hot or cold** it is. With the thermometer you **measure how quickly or slowly particles in matter move.**

Table 20: The sub-codes of the three main codes developed *a priori* according to the original story script

Main code: Types of talk (Adapted from Mercer and Littleton, 2007; Mercer *et al*., 1999)	
Sub-codes	Definition
Exploratory talk	Speakers engage critically but constructively with each other's ideas. Statements and suggestions are sought and offered for joint consideration. These may be challenged and counter-challenged, but challenges are justified, and alternative hypotheses are offered. In 'exploratory' talk, knowledge is made publicly accountable, and reasoning is visible in the talk (p. 97)
Disputational talk	Speakers engage in a competitive interaction, disagreement, and individualised decision-making, including cycles of assertion and counter-assertion
Cumulative talk	Speakers share and build information in a positive but uncritical way, accumulating 'common knowledge'

Table 21: The fourth main code and its sub-codes, developed *a priori* based on the theoretical framework of Mercer and his colleagues (Mercer and Littleton, 2007; Mercer *et al*., 1999)

(Highlighted are the parts used in section 6.2.1)

Start time	End time	Transcript
00:00:02.2	00:00:26.1	Βάλε να τα δούμε αυτά πρώτα.
00:00:26.1	00:00:46.0	Νομίζω αυτό πρέπει να βάλουμε. Που παίζει μπάλα.
00:00:46.0	00:00:53.4	Άρα στο πρώτο σ' αυτά που έχουμε βάλει τι να γράψουμε;
00:00:53.4	00:01:02.3	Είπαμε παίζει μπάλα και φτιάχνει το άγαλμα που του μοιάζει.
00:01:02.3	00:02:02.6	Πως θα τον πούμε αυτόν; Κι αυτόν;
00:03:51.9	00:05:28.5	Μπορούμε να τον πούμε Μπομπ.
00:05:28.5	00:05:37.2	Μπο.. Ωραία.. Γεία σας είμαι ο Μπο και παίζω μπάλα
00:05:37.2	00:05:54.5	Τον άλλο πως θα τον ονομάσουμε;
00:05:54.5	00:06:32.3	Τετράγωνο;
00:06:51.2	00:07:01.7	Κοίτα να δεις τι θα κάνουμε. Αυτός είναι ο Μπο, ο δίπλα είναι ο;
00:07:01.7	00:07:09.5	Ο τριγωνάκης με τη μικρή μπάλα
00:07:09.5	00:07:17.6	Το βρήκα. Ο Γλυκομελένιος
00:07:17.6	00:08:22.4	Ναι!
00:08:22.4	00:08:28.2	Πως τον λέει ο Παναγιώτης αυτόν εκεί με το ζάχαρο;
00:08:28.2	00:08:42.4	Ζαχαρένιος;
00:08:42.4	00:09:05.8	Ναι. Γεία σας είμαι ο Ζαχαρένιος
00:09:05.8	00:10:53.4	Λοιπόν, γεία σας είμαι ο Ζαχαρένιος και είμαι επιστήμονας.. Φαίνεται ότι είναι επιστήμονας.
00:11:32.7	00:11:46.1	Ωραία βρήκαμε και ονόματα.
00:11:46.1	00:11:54.2	Ο Μπο, ο Ζαχαρένιος και ο Γλυκομελένιος.
00:11:54.2	00:12:04.6	Πάμε στο επόμενο. Ποιο να βάλουμε;
00:12:04.6	00:12:16.7	Μπερδεύτηκα τώρα πολύ, ποιο είναι το δεύτερο;
00:12:16.7	00:12:23.4	Μήπως να διαλέξουμε έναν απ' τους τρεις να ξεκινήσουμε;
00:12:23.4	00:12:54.9	Τον στερεό;
00:12:54.9	00:13:06.8	Ναι.
00:13:06.8	00:13:21.7	Ωραία πάμε. Βρίσκουμε όλα τα βιντεάκια που έχουν να κάνουν με τον στερεό. Αυτό είναι με τον στερεό;
00:13:21.7	00:13:35.2	Ναι
00:13:35.2	00:13:40.4	Ωραία. Αυτό το δίπλα είναι με στερεό;
00:13:40.4	00:13:50.8	Όχι.
00:13:50.8	00:14:00.7	Αυτό είναι στερεό, αυτό είναι υγρό.

00:14:05.0	00:14:14.0	Λοιπόν, αυτό δεν είναι στερεό. Κοιτάχτε λίγο παιδιά, εδώ είναι ένα θερμόμετρο.
00:14:14.0	00:14:14.1	Στερεά πράγματα ψάχνουμε.
00:14:24.6	00:14:36.9	Αυτό είναι αέριο.
00:14:36.9	00:14:39.9	Εγώ λέω να βγάλουμε το στερεό και να βρούμε το υγρό που είναι πιο εύκολο.
00:14:39.9	00:14:44.1	Ωραία, πάμε στο υγρό.
00:14:44.1	00:14:54.3	Πρώτα πάμε στο υγρό.
00:14:54.3	00:15:04.7	Ωραία υγρό. Τι άλλο;
00:15:04.7	00:15:55.9	Αυτό είναι υγρό.
00:15:55.9	00:16:06.9	Το στερεό πάει εδώ. Πιο είδαμε τώρα;
00:16:06.9	00:16:07.2	Αυτό είναι στερεό, αφού δεν γλίστραγε, δεν έβγαινε… Δεν ήταν υγρό…
00:16:07.2	00:16:21.0	Αυτό είναι στερέο.
00:16:21.0	00:16:35.7	Δεν είναι στερεό.
00:16:35.7	00:16:38.1	Εδώ βάλαμε αυτό, αυτό κι αυτό.
00:16:38.1	00:16:57.2	Αυτό δεν πρέπει να είναι στερεό, αφού λιώνει.
00:16:57.2	00:17:10.6	Εδώ είναι μετατροπή, ποια μετατροπή όμως;
00:17:10.6	00:18:32.5	Πάγωσε!
00:18:58.6	00:19:20.3	Πως λέγεται αυτή η μετατροπή;
00:19:20.3	00:19:35.7	Πήξη
00:19:35.7	00:19:48.1	Ωραία, ψάχνουμε λοιπόν απ' αυτά εδώ που να δείχνει πήξη.
00:19:48.1	00:20:12.5	Αυτό θα μπορούσε να ήταν πήξη. Άρα κι αυτό.
00:20:12.5	00:20:17.3	Λοιπόν υπάρχει κάτι άλλο με πήξη.
00:20:17.3	00:20:22.4	Αυτό ξέρετε που θα μπορούσε να μπει; Στην εικόνα που δείχνει το βουνό που λιώνει, με τη θάλασσα.
00:20:22.4	00:20:29.6	Λοιπόν πρέπει να 'ναι πρώτα αυτό .
00:20:29.6	00:20:58.2	Αυτό με το θερμόμετρο που σας λέω κοιτάξτε λίγο.. Αυτό πάει σε μια άλλη ενέργεια. Ας βρούμε πρώτα κάτι για το υγρό.
00:21:07.2	00:21:16.8	Οπότε πάμε και σε αυτό που είναι υγρό.
00:21:16.8	00:21:34.2	Ο ήλιος λάμπει…

00:21:34.2	00:21:50.4	Άρα ξεκινάμε απ' το στερεό, πάμε στο υγρό... Αυτό δεν είναι υγρό, είναι εξάτμιση.
00:21:50.4	00:22:06.2	Εσύ το 'βαλες.
00:22:06.2	00:22:06.3	Αυτό τι είναι;
00:22:16.4	00:22:33.0	Υγρό.
00:22:33.0	00:22:34.2	Παιδιά, εδώ γίνεται εξάτμιση.. Άρα αλλάζει ο καιρός
00:22:34.2	00:22:36.2	Αυτό το βγάζουμε, γιατί δεν έχει σχέση αυτό.
00:22:36.2	00:22:36.3	Αυτό δεν είναι αέριο, είναι εξάτμιση.
00:22:39.2	00:22:39.3	Αφού τον καιρό σου δείχνει, σου δείχνει πως πάει κι αν εξατμίζεται.
00:23:01.3	00:23:22.7	Άρα τώρα πάμε στο αέριο.
00:23:22.7	00:23:36.5	Κι αυτό είναι εξάτμιση.
00:23:36.5	00:23:52.3	Αυτό είναι εξάτμιση, άρα το βάζουμε εδώ.
00:23:52.3	00:23:59.1	Για να δούμε λίγο αν τα έχουμε βάλει σωστά...
00:23:59.1	00:24:09.1	Εδώ δείχνει το στερεό.. Εδώ δείχνει πως αλλάζει η θερμοκρασία
00:24:50.5	00:25:02.2	Αυτό εκεί κάτω δεν είναι στερεό;
00:25:02.2	00:25:15.4	Ωραία, εδώ τι δείχνει;
00:25:15.4	00:25:18.1	Εδώ είδαμε το νερό και το βάλαμε.
00:25:18.1	00:25:18.2	Τι δείχνει εδώ; Ο πάγος; Λιώνει και γίνεται νερό. Πώς λέγεται αυτή η μετατροπή;
00:25:21.1	00:25:28.0	Τήξη
00:25:28.0	00:25:28.7	Και μετά γίνεται εξάτμιση
00:25:28.7	00:25:32.3	Αχ κουράστηκα.
00:25:32.3	00:25:38.0	Κι εγώ.
00:25:38.0	00:25:42.6	Λοιπόν Ραφ., τώρα πάτα τα όλα για να δούμε πιο έχουμε βάλει
00:25:45.0	00:25:45.1	Για να δούμε.
00:26:29.5	00:26:29.6	Αυτό είναι που βγαίνουνε, πρέπει να βρούμε το άλλο...
00:26:29.5	00:26:29.6	Εδώ είναι τα στερεά. Και μετά τι παθαίνει αυτό;
00:26:31.3	00:26:31.9	Στερεό.
00:26:35.2	00:26:35.6	Τι εννοείς; Το στερεό παθαίνει στερεό;
00:26:35.6	00:26:35.7	Παθαίνει τήξη.

00:26:36.9	00:26:39.1	Για να πάρουμε την ιστορία από την αρχή για να δούμε τι θα γράψουμε. Να δούμε πρώτα τους χαρακτήρες;
00:26:39.1	00:26:43.1	Ο Μπο ο ποδοσφαιριστής. Είναι στερεό.
00:26:43.1	00:26:43.2	Κι εδώ τι μου δείχνει;
00:26:44.2	00:27:06.2	Είναι στερεά πράγματα.
00:27:46.8	00:29:46.4	Κι εδώ τι είναι;
00:29:46.4	00:31:11.4	Στερεό.
00:31:11.4	00:31:28.1	Και τι παθαίνει;
00:31:28.1	00:31:36.5	Γίνεται υγρό.
00:31:36.5	00:31:44.1	Κι αυτός;
00:33:04.9	00:33:05.7	Ο Ζαχαρένιος
00:33:05.7	00:33:08.1	Ναι αλλά μετά τον Μπο πήγαμε στον Ζαχαρένιο. Τον βάλαμε πριν τον Ζαχαρένιο;
00:33:08.1	00:33:32.8	Όχι
00:33:48.8	00:33:51.1	Άρα πρέπει πρώτα να τον παρουσιάσουμε;
00:33:51.1	00:33:56.0	Ναι νομίζω.
00:33:56.0	00:35:00.2	Εδώ να το βάλουμε αυτό, γιατί είναι πάγος, δηλαδή κάνει τήξη είναι στερεό.
00:35:00.2	00:35:29.5	Ναι.
00:36:04.9	00:36:06.7	Ναι αυτό λέμε.
00:36:06.7	00:36:22.6	Άρα αυτό εδώ πρέπει να βγει, βγάλτε το.
00:36:35.0	00:36:37.5	Μετά το στερεό.
00:36:37.5	00:36:45.9	Νομίζω δεν μπορούμε να συνεννοηθούμε.
00:36:45.9	00:36:51.7	Γιατί; Πρέπει να βρούμε ένα βιντεάκι που να μετατρέπει αυτόν σε υγρό ή σε αέριο.
00:36:51.7	00:37:58.5	Υγρό.
00:37:58.5	00:38:09.9	Αυτό δείχνει τα υγρά, μας παρουσιάζει τα υγρά. Λέει ότι τα υγρά είναι μια κατάσταση.
00:38:09.9	00:38:18.7	Άρα ο Ζαχαρένιος είναι υγρό.
00:38:18.7	00:40:09.3	Υγρό είναι ναι.. Να βρούμε κάτι που να περιγράφει λοιπόν μια μετατροπή.
00:40:09.3	00:40:27.8	Αυτό είναι αέριο.

00:40:35.6	00:43:12.2	Εδώ τι έχουμε;
00:43:12.2	00:43:13.9	Εξάτμιση.
00:43:13.9	00:43:19.9	Εξάτμιση. Αυτό δεν έχει σχέση με τον Ζαχαρένιο;
00:43:19.9	00:43:23.0	Ναι.
00:43:23.0	00:43:30.8	Ωραία, το βάζουμε.
00:43:30.8	00:43:30.9	Τώρα βγάζει νόημα έτσι όπως το βάλαμε;
00:43:42.3	00:43:54.8	Εδώ δείχνει το υγρό, ναι και μετά τι μου δείχνει;
00:43:54.8	00:44:10.1	Την εξάτμιση.
00:44:10.1	00:44:11.5	Ωραία, εδώ μου δείχνει εξάτμιση.
00:44:11.5	00:44:31.6	Λοιπόν εδώ είναι ο Ζαχαρένιος. Τι παθαίνει;
00:44:31.6	00:44:34.3	Λοιπόν αυτός εδώ είναι υγρό, άρα από δω πρέπει να κάνουμε ένα υγρό.
00:44:34.3	00:44:37.2	Άρα αυτό εδώ δεν κολλάει.
00:44:37.2	00:44:44.3	Ο Μπο είναι στερεό άρα εδώ που είναι αυτό πρέπει να βάλουμε ένα υγρό.
00:44:42.2	00:44:43.9	Εδώ τώρα πρέπει να βάλουμε το αέριο.
00:44:44.3	00:44:44.4	Εδώ είναι ο Μπο.. Ο Μπο είναι στερεό.. Αυτός είναι ο Ζαχαρένιος, είναι υγρό.
00:44:44.3	00:44:44.4	Ναι
00:44:45.4	00:44:50.3	Άρα κάναμε στερεό, υγρό... Που είναι το αέριο;
00:44:50.3	00:44:57.3	Αέριο δεν είδαμε.
00:44:57.3	00:45:01.3	Αυτό δεν είναι αέριο.
00:45:01.3	00:45:05.7	Αυτό είναι αέριο.
00:45:05.7	00:45:09.2	Αυτό δεν είναι αέριο, είναι εξάτμιση.
00:45:09.2	00:45:09.7	Ξεκινήσαμε με τον Μπο που είναι στερεό, μετά πήγαμε με το υγρό που είναι...
00:45:09.7	00:45:09.8	Ναι αλλά που είναι ο Ζαχαρένιος;
00:45:10.2	00:45:17.3	Εδώ, υγρό είναι ο Ζαχαρένιος.. Αέριο είναι ...
00:45:17.3	00:45:20.0	Λοιπόν ο Μπο είναι στερεό, υγρό είναι ο Ζαχαρένιος.. Αέριο ο Γλυκομελένιος
00:45:20.0	00:45:21.6	Ωραία, συμφωνούμε.
00:45:21.6	00:45:28.3	Ναι

00:45:28.3	00:45:32.4	Ναι αλλά εδώ γιατί ξεκινήσαμε με τον Μπο πρώτα;
00:45:32.4	00:45:51.6	Αφού ο Μπο είναι στερεό, ο Ζαχαρένιος είναι υγρό και μετά δείχνουμε τα υγρά.
00:45:51.6	00:45:58.6	Ο Μπο είναι στερεό, ο Ζαχαρένιος είναι υγρό, ο Γλυκομελένιος είναι αέριο.
00:45:58.6	00:46:04.6	Ρε ωραία το έχουμε κάνει.
00:46:04.6	00:46:07.7	Κι εδώ πέρα έχουμε βάλει την ιστορία τους, που είναι αυτός, μπαίνουν μέσα αυτοί οι δυο, κάτι γίνεται εδώ μέσα και μετά βγαίνουνε από δω μέσα αλλά δεν το βρήκαμε.
00:46:04.9	00:46:29.6	Είναι μετατροπές!
00:46:29.6	00:46:29.7	Άρα αυτό.
00:46:29.7	00:46:36.1	Γράφεις λοιπόν ότι γίνονται μετατροπές.. Που είναι αυτό που πήγαιναν να μπουν στο μπάνιο; Εδώ είναι;
00:46:36.1	00:46:58.8	Ξέρουμε λοιπόν ότι όταν ανεβαίνει η θερμοκρασία μετακινούνται.. Και τώρα πάμε λοιπόν να δούμε τις μετατροπές...
00:46:58.8	00:47:00.0	Μέσα λοιπόν κι αυτοί.. Το στερεό, το αέριο και το υγρό όταν αλλάξει η θερμοκρασία αλλάζουνε κι αυτοί .. Και για να δούμε τώρα τι γίνεται μέσα στο μπάνιο..
00:47:00.0	00:47:04.4	Παιδιά κουράστηκα εγώ.. Αυτό που το βάζουμε;
00:47:04.4	00:47:05.5	Αυτό είναι κοντά στο αέριο. Πιο βίντεο είχαμε που περιγράφει το αέριο;
00:47:07.5	00:47:21.6	Ωραία, αέριο σωστό.. Γιατί περιγράφει το αέριο.. Μετά, ανεβαίνει η θερμοκρασία, γίνονται οι μετατροπές, μετά πρέπει να μπουν μέσα στο μπάνιο, να μας δείξει τι γίνεται εκεί και μετά να βγουν από το μπάνιο.
00:47:21.6	00:47:28.8	Άρα εδώ ανάμεσα πρέπει να δείξουμε τι γίνεται μέσα.
00:47:28.8	00:47:35.6	Αυτό εδώ πέρα που το βάζουμε; Αυτό είναι εξάτμιση.
00:47:35.6	00:47:44.0	Αυτό που έχει σχέση με τον Μπο που το βάζουμε, μετά τον Μπο;
00:47:44.0	00:47:50.9	Πρώτος είναι ο Μπο, με τα στερεά.
00:47:47.2	00:47:48.4	Ο δεύτερος είναι ο τετράγωνος και εδώ είναι που μπαίνουνε μέσα.
00:47:48.4	00:47:51.7	Μπαίνει μες το μπάνιο.
00:47:51.7	00:47:51.8	Και εκεί τι γίνεται;

00:47:52.1	00:47:52.2	Εξάτμιση
00:47:55.0	00:47:55.1	Τι εξατμίζεται;
00:47:55.0	00:48:01.5	Πείτε ρε παιδιά.
00:48:01.5	00:48:08.1	Αυτό από που βγαίνει; Ο ατμός;
00:48:08.1	00:48:15.1	Από το νερό.
00:48:15.1	00:48:22.3	Απ΄ τη ζέστη.
00:48:22.3	00:48:25.3	Που το κατάλαβες;
00:48:25.3	00:48:25.8	Έχει ένα μικρό κυκλάκι …
00:48:25.8	00:48:27.0	Και μετά εδώ τι μου δείχνει;
00:48:27.0	00:48:34.0	Πόσο ψηλή είναι η θερμοκρασία και πόσο ανεβαίνει το θερμόμετρο.
00:48:34.0	00:48:34.8	Κι αυτά εδώ;
00:48:34.8	00:48:39.2	Είναι τα μόρια.
00:48:38.4	00:48:38.5	Και τι παθαίνουν;
00:48:39.2	00:48:39.8	Ζεσταίνονται.
00:48:39.8	00:48:39.9	Κινούνται πιο γρήγορα.
00:48:41.9	00:48:46.1	Εγώ όμως βλέπω δυο εδώ θερμόμετρα.
00:48:46.1	00:48:48.7	Αυτό εδώ έχει ζεσταθεί πιο πολύ κι αυτό είναι πιο παγωμένο.
00:48:48.7	00:48:50.3	Εδώ που είμαστε;
00:49:03.1	00:49:04.7	Που μπαίνουν μέσα σε δυο δωμάτια. Αυτός είναι ο παγωμένος και αυτός ο ζεστός.
00:49:04.7	00:49:28.3	Εδώ είναι που μπαίνουν μέσα στα δωμάτια.
00:49:28.3	00:49:29.5	Αυτός ποιος είναι;
00:49:29.5	00:49:38.0	Το στερεό και το υγρό.
00:49:38.0	00:49:40.6	Το στερεό τι έχει πάθει απ΄ την πολλή ζέστη;
00:49:38.2	00:50:05.4	Έχει λιώσει … Ενώ αυτό έχει παγώσει.
00:50:05.4	00:50:08.0	Εδώ βγαίνουν απ΄ τα δωμάτια.
00:50:08.0	00:50:28.0	Κι αυτός τους ελέγχει να δει τι κάνουν. Και τι έχει γίνει δηλαδή;
00:50:08.1	00:50:17.3	Αυτός έχει λιώσει και ο άλλος έχει παγώσει.
00:50:17.3	00:50:25.6	Αυτό εδώ τι δείχνει;
00:50:40.0	00:50:51.6	Την εξάτμιση.
00:50:51.6	00:51:00.2	Με ποιο ταιριάζει η εξάτμιση;

00:51:00.2	00:51:45.6	Με το υγρό.
00:51:45.6	00:51:57.4	Στις μετατροπές.
00:52:01.6	00:52:01.7	Ναι.
00:52:41.9	00:53:08.6	Κι εδώ είναι;
00:53:08.6	00:54:42.9	Υγρό.
00:54:52.9	00:55:06.7	Το οποίο τι κάνει;
00:55:06.7	00:55:23.5	Λιώνει από πάγο και γίνεται υγρό.
00:55:23.5	00:55:31.7	Να τα πάρουμε από την αρχή; Αυτοί εδώ λένε γεια σας. Μετά είναι το στερεό που είναι ο Μπο.
00:55:43.1	00:55:52.1	Μαζί με ένα κάδρο από γυαλί.
00:55:52.1	00:56:07.8	Τι να γράψουμε δηλαδή για τον Μπο;
00:56:07.8	00:56:51.0	Ότι μπορεί να είναι και πάγος. Είμαι ο Μπο και μπορώ να φτιάξω στερεά πράγματα από πάγο.
00:56:51.0	00:57:09.3	Αντικείμενα από πάγο
00:57:09.3	00:58:00.9	Πως το πε; Μπορώ να φτιάξω στερεά αντικείμενα από πάγο;
00:58:00.9	00:58:26.0	Λοιπόν στα στερεά σώματα, τα μόρια που έχουν μέσα τα στερεά σώματα δεν κινούνται.
00:58:26.0	00:58:32.4	Λοιπόν, γράψαμε... Τα μόρια που έχουν μέσα τα στερεά σώματα δεν κινούνται.
00:58:26.9	00:58:31.6	Στα στερεά σώματα τα μόρια δεν κινούνται
00:58:32.4	00:58:32.5	Δες τι κάνουν τα μόρια
00:58:45.7	00:58:50.3	Δεν κινούνται
00:58:50.3	00:59:25.6	Κινούνται... Κινούνται ελάχιστα λοιπόν
00:59:25.6	00:59:43.3	Τα μόρια στα στερεά σώματα κινούνται ελάχιστα και σε κοντινές αποστάσεις.. Λοιπόν, στο τρίτο βίντεο ποιος είναι; Ρε παιδιά ασχοληθείτε λίγο, δεν μπορώ μόνη μου
00:59:43.3	00:59:50.2	Εδώ τι γίνεται;
00:59:50.2	00:59:56.1	Είναι ο Μπο που κάνει εξάτμιση.
00:59:56.1	00:59:59.5	Τι εννοείς;
00:59:59.5	00:59:59.8	Ότι το τζάμι απ΄ το ζεστό νερό έχει βρεχτεί
00:59:59.8	01:00:02.4	Τι εννοείς έχει βρεχτεί;;;;
01:00:02.4	01:00:05.5	Όχι, λόγω καιρού, λόγω καιρού..

01:00:05.5	01:00:18.1	*Λόγω θερμοκρασίας!*
01:00:18.1	01:00:19.8	Τελικά τι έχει πάθει δηλαδή το τζάμι;
01:00:19.8	01:00:25.3	Υγρασία;
01:00:25.3	01:00:35.0	Ναι, έχει πάθει υγρασία. Έχει θολώσει.
01:00:35.0	01:00:37.1	Από τον κρύο αέρα.
01:00:37.1	01:00:37.2	Από την ζέστη.
01:00:44.6	01:00:55.3	Ρε παιδιά και πάλι δεν καταλαβαίνω τι μου λέτε.. Για κάντε τα μια πρόταση.
01:01:01.7	01:01:07.1	Το τζάμι είναι βρεγμένο γιατί.
01:01:07.1	01:01:07.2	Όταν λέμε βρεγμένο δηλαδή;
01:01:13.3	01:01:13.9	Έχει πιάσει υγρασία.
01:01:24.3	01:01:26.2	Βρεγμένο.
01:01:26.2	01:01:26.3	Υγρό;
01:01:42.6	01:01:46.9	Αέριο;
01:01:59.0	01:02:08.1	Τι λέτε; Αφού δεν μπορείς να δεις απ' έξω
01:02:08.1	01:02:21.2	Αυτό λέω, θολώνει.
01:02:21.2	01:02:21.8	Ναι, θολώνει.. από τη θερμοκρασία
01:02:31.5	01:02:40.3	Ποια θερμοκρασία;
01:02:40.3	01:02:40.8	Μπερδεύτηκα τώρα.
01:02:42.9	01:02:43.0	Εδώ στο τζάμι έχει κολλήσει αέρας.
01:02:50.2	01:02:55.6	Ωραία, είναι ζεστός αέρας.. Από που έρχεται ρε παιδιά ο ζεστός αέρας;
01:02:55.6	01:03:08.1	Μάλλον απ' το μπάνιο που έκανε.
01:03:08.1	01:03:18.5	Ναι αλλά δεν βάλαμε το βίντεο που δείχνει το μπάνιο που έκανε. Μήπως να αλλάξουμε λίγο τη σειρά γιατί έτσι δεν βγάζει νόημα...
01:03:18.5	01:03:44.8	Ωραία πάμε ξανά να δούμε την αρχή, αφού τις μετατροπές τις βάλαμε. Εδώ, είναι οι τρεις που χαιρετιούνται και μετά είναι ο Μπο.. Και είναι στερεό.
01:03:44.8	01:04:04.2	Μετά είναι τα μόρια που έχουν τα στερεά σώματα και κινούνται ελάχιστα σε κοντινές αποστάσεις.
01:04:04.2	01:04:28.0	Ωραία.
01:04:28.0	01:04:33.1	Και είναι και τα πράγματα που είναι στερεά

01:04:33.1	01:04:36.5	Ωραία γιατί δεν τα γράφουμε. Πείτε μου να γράφω ποια είναι στερεά.
01:04:36.5	01:04:55.7	Το μολύβι, μια πάπια …
01:04:55.7	01:05:07.8	Η τοστιέρα.
01:05:07.8	01:05:16.0	Και μετά πάμε σε αυτόν.
01:05:16.0	01:05:19.4	Ο Ζαχαρένιος.
01:05:19.4	01:05:32.6	Το υγρό.
01:05:35.7	01:05:44.9	Ο Ζαχαρένιος το υγρό
01:05:44.9	01:05:54.5	Ναι τι κάνει το υγρό;
01:05:54.5	01:05:55.0	Μου δείχνει αυτόν που πάει να πιεί από ένα ποτήρι και χύνεται πάνω του.
01:05:55.0	01:05:58.7	Άρα τα υγρά χύνονται.
01:05:58.7	01:05:59.3	Ωραία. Γράψτε το.
01:05:59.3	01:06:06.3	Ωραία… το γράφω κι αυτό… και τελειώσαμε, πες το στην κυρία.

Transcript 1: Team's C, Greek students, SEeDS activity

4 Teams X 4 students = 16 students total (1 left because he was ill, so 15 in total completed the activity)

1) Team A's parents did not consent for their children to participate in the research, but today when I went to the school children got excited and wanted to participate. Their parents were called up to give their consent, but still they did not wish for their children to be recorded/videotaped. So, from Team A I have only their story.

2) From Team B one of the boys, Yiannis, started feeling ill as soon as the activity began, so he decided to withdraw from it.

3) Students asked many questions about the order and the plot of the story because they couldn't mostly decide with which clip to begin their story. Their teacher and I avoided to provide them with any content-related guidance. Students later claimed that they found it relatively easy to relate the clips between them so that they made sense and they could verbally justify why they would order them that specific way.

4) Although all of the groups said that they felt excited from this activity and they found it "mind-challenging" and interesting enough, Group D wasn't very keen on writing the dialogues. Even though it was the group with the best ideas and 'right' answers about the plot of the story, when it came to writing it out, they appeared lazy and bored. After some pressure from me and the teacher they finished on time.

5) Students at the beginning of the activity seemed a bit lazy and bored, and they wouldn't easily work together. Both the teacher and I had to be around their tables all the time to keep them moving through the activity.

6) At the end of the activity, before students went out on a break, their teacher had a quick chat with the whole classroom about the activity and Group C said: "it was a bit difficult that we had to order the clips but that was mind-challenging, and we liked it"; "it helped us understand physics better"; "it was a great activity, I wish we could do more like that"; "we wouldn't have preferred the activity any other way (like with the ordered clips)".