education sciences

MDPI

Article

Exploring the Use of Cognitive Science Approaches Alongside SOLO Taxonomy as a Pedagogical Framework to Build Deeper Knowledge in Science and Foundation Subjects at Primary Schools in UK

Olivia Davies [1] and Nasser Mansour [2,*]

[1] Vigo Primary School, Hampshire, Andover SP10 1JZ, UK; oliviamadavies@yahoo.co.uk
[2] College of Education, Qatar University, Doha 9FFR+FC9, Qatar
* Correspondence: n.mansour@qu.edu.qa or n.mansour@hotmail.co.uk

Abstract: Recent discoveries in cognitive science have led to understanding that there may be more effective ways to help pupils retain information, which then supports them to improve their critical thinking, thus leading to deeper learning. This paper explores a combination of two of these cognitive science approaches: retrieval practice and spaced learning. These were then combined with SOLO Taxonomy, a hierarchical system of learning words, to form a system in classrooms which could help pupils achieve deeper knowledge and understanding of a topic. The study seeks to examine whether the system is effective. With increased emphasis put upon the teaching of foundation subjects through Ofsted's 2019 framework, it has become prescient to consider the struggles of primary school teachers who are not subject specialists. Accordingly, the system being studied was also devised to signpost less confident teachers through the knowledge and thus potentially help them, as non-experts, to better teach science and foundation subjects. This study demonstrates that the system has promise for helping non-experts, which in turn leads to improved learning and retention of knowledge.

Keywords: Structure of the Observed Learning Outcomes; SOLO; subject knowledge; cognitive science; retrieval; spaced learning; low-stakes testing

Citation: Davies, O.; Mansour, N. Exploring the Use of Cognitive Science Approaches Alongside SOLO Taxonomy as a Pedagogical Framework to Build Deeper Knowledge in Science and Foundation Subjects at Primary Schools in UK. *Educ. Sci.* **2022**, *12*, 523. https://doi.org/10.3390/educsci12080523

Academic Editor: James Albright

Received: 4 July 2022
Accepted: 29 July 2022
Published: 1 August 2022

1. Introduction

Primary school teachers in the UK are expected to teach at least ten subjects. Duncombe et al. [1], believe that the introduction of the national literacy and numeracy strategies widened the gap between the importance of the core and foundation subjects. This, they contend, has had an impact on the amount of time allocated to the exploration of foundation subjects during teacher training, which has in turn led to a lack of confidence amongst newly qualified teachers. Randall and Griggs [2] point out that after the first national curriculum was published, trainee teachers were undertaking three or four-year degrees alongside a subject specialism. They observe that that has now changed, as from 2002 teachers were no longer required to hold a specialism. As a result, teacher training organisations cut their courses to one post-graduate year and therefore, Randall and Griggs [2] contend, trainee teachers have become even more generalist.

Metzler and Woessmann [3] agree that teacher subject knowledge should be given a higher priority and be recognised for having an impact on student learning. Byrom [4] supports this view through his own observations and research. As a subject advisor in his local authority, he observed that many teachers lacked the requisite subject knowledge and therefore, often gave little consideration to sequencing coherent curriculums which would help students have a clear understanding of the topic or subject they are learning. Therefore, Byrom [4] concluded that too many students were leaving school in possession of a series of disjointed facts that did not sit in any useful schema which could be used

to aid their understanding of the world around them. A recent report by The Ogden Trust and the University of Manchester [5] highlights this observation, citing several cases where students spoke enthusiastically about their lessons but were unable to illustrate any understanding of the concepts covered. In fact, a survey carried out by the Wellcome Trust (2020) showed that only half of those interviewed felt that science lessons in primary schools had prepared them adequately for secondary schools.

The cognitive scientist Daniel T. Willingham [6] observes that although there is not always a consensus on what students should be taught, most people agree that critical thinking skills are vitally important for students to engage meaningfully and successfully with their community. However, although this agreement exists, Willingham [6] points out that teachers are often frustrated by the lack of depth of knowledge that is vital for this level of thinking. The new Ofsted framework [7] is concerned with intent, implementation, and impact of the curriculum on pupils' learning. Rollett [8] observes that this new Ofsted framework therefore requires inspectors to talk to subject leaders about these criteria and to assess the subject knowledge of the current teachers and what is being done to support any lack of knowledge. Consequently, this has become an issue that schools need to address.

2. What Is SOLO Taxonomy?

SOLO Taxonomy was devised by Biggs and Collis [9] and is the Structure of the Observed Learning Outcomes which learners show when building up their knowledge and understanding of a topic. There are five hierarchical levels within the taxonomy and students must articulate their knowledge in response to tasks designed using the vocabulary from each level in turn, to ensure meaningful understanding and learning. Therefore, progression is already built into the system for the teachers. SOLO provides a language for both the learning and assessment of a pupil's depth of knowledge. Moving on to the next part of the topic being taught is not advised until the teacher has ascertained that the pupils have understood and retained their prior learning. This way, the learning is built and is less likely to become fragmented. Hattie [10] concurs that one of the strengths of SOLO is that it is hierarchical and emphasizes the need for good surface knowledge before trying to build deep knowledge. He believes that many systems such as enquiry-based teaching fail to produce deep understanding, because the children do not have the sufficient baseline knowledge to solve the problem and therefore suffer cognitive overload.

Damopolii [11] maintains that SOLO can be used as a coherent framework for guiding deeper learning and understanding across the curriculum. In an interview with Roberts [12], Pam Hook, an educational and learning consultant who promotes the use of SOLO, explained that the taxonomy had been designed to classify the differences between surface and deep knowledge [13]. Within the taxonomy, surface knowledge is defined as reaching a multi-structural level (see Figure 1) and deep knowledge is reaching a relational and extended abstract. Hook [13] further refers to the illustration in Figure 2 which shows the different levels of potential responses to a multi-structural question at each level of the taxonomy.

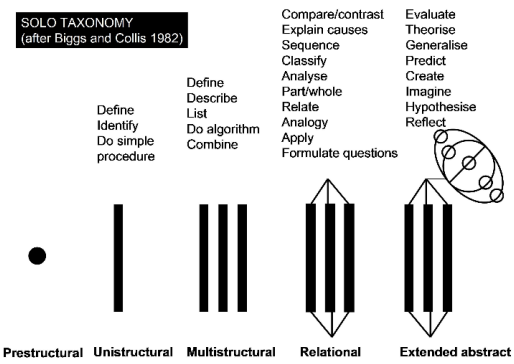

Figure 1. Solo taxonomy symbols and verbs, Produced by Pam Hook (@arti_choke) http://pamhook.com/wiki/The_Learning_Process (accessed on 17 March 2022).

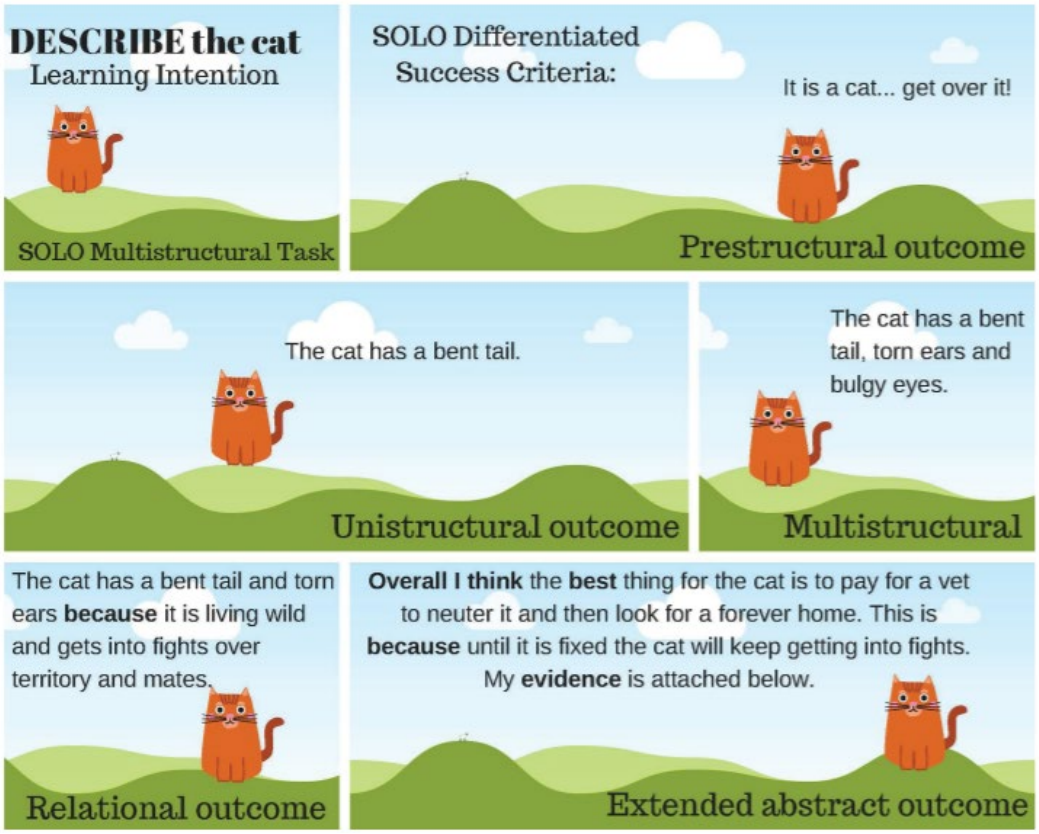

Figure 2. Multi-structural task, Produced by Pam Hook [13].

3. The Use of Cognitive Science Approaches in Primary School

In 2021 the Education Endowment Fund (EEF) carried out a review of the available evidence on cognitive science approaches applied in a classroom context. They highlighted the lack of such studies and therefore feel there should be more research carried out in this field. The review looked at several different strategies which included spaced learning and retrieval practice. Most cognitive scientists define spaced learning as the practice of giving students opportunities to revisit their learning several times over several weeks or months, rather than teaching it once and then never going back to it. This method is based on Ebbinghaus's research into memory loss and the Forgetting Curve [14]. Brown et al. [15] explain the science behind the effectiveness of spaced learning by pointing out that long-term memory plays a vital role in entrenching new information through consolidation. This knowledge, if taught correctly and over a period of days, is added to prior knowledge in long-term memory and therefore creates pathways in the brain. Each time it is revisited it has been forgotten a little bit, but the act of retrieving it strengthens the neural pathways. Information learnt more quickly or crammed relies more on short-term memory and therefore is not retained [15].

Retrieval practice or low stakes testing is a simple and quick way to show understanding, gaps, and misconceptions and is defined as independently recalling learned information from memory [16]. Donaghy [17] supports the notion of using regular low stakes testing to identify pupil misconceptions. He also highlights what he calls the 'testing effect' which strengthens the development of knowledge. There are several other studies which support the theory that practice testing, which is low stakes, helps with knowledge retention and improves learning [18–20]. A study by Tauber et al. [21] concluded that the most effective retrieval practice was 'overt', which is the term they use to describe either physically typing answers to questions or verbalizing the answers rather than mentally answering questions in a self-testing situation. They believe that by having to verbalize the response, the student is having to provide all the relevant details, whereas if they

are mentally recalling information, then they might avoid certain aspects of the answer, believing that those elements are already well enough known. This perception they believe can lead to less retention of the knowledge being learnt.

Roediger and Brown [19] agree that for effective learning of new knowledge to take place, students need to actively engage with their learning through testing, retrieval practice and instant feedback, addressing misconceptions or consolidating the knowledge. Roediger and Brown [19] point out that there is a misconception amongst teachers and learners that embedding new knowledge is about lodging the information in the brain, when in fact it is about skilfully retrieving the knowledge.

This study examines a combination of retrieval practice with spaced learning, something the EEF [22] believes has interesting consequences for the identification of key knowledge and concepts that must be prioritized within the curriculum. The evidence reviewed by the EEF shows that retrieval practice was highly effective in classroom settings, however many of the studies reviewed were carried out by researchers rather than the class teacher, therefore it may offer an unrealistic view of application in the classroom [23–25]. They also highlight concerns around whether retrieval practice can only really be used for surface learning [22]. However, despite the confines of the studies already undertaken, the EEF conclude that the application of retrieval practice in the classroom shows good potential and therefore should be carefully considered by teachers.

4. The Rationale of the Study and Research Questions

With such a broad spectrum of subjects to teach, Ofsted [7] observed that it is difficult for primary school teachers to be experts across the entire curriculum. Much energy and hard work, they have noticed, is put into being experts in English and math. Consequently, science and the foundation subjects in the past have been side-lined, and as a result the teaching and learning of them have suffered. This was one issue that the 2014 UK National curriculum and 2019 Ofsted criteria were designed to address. However, tackling teacher-subject-knowledge gaps across such a broad curriculum is difficult, so a comprehensive system that non-experts can use seems vital for both helping practitioners teach and improving children's learning. Therefore, one of the purposes of this study was to explore if a design to build the understanding of topics for students would also help with the knowledge and confidence in teachers who are non-experts across the foundation subjects.

Recent research by the Education Endowment Foundation (EEF) [22] concluded that giving teachers opportunities to become familiar with cognitive science principles is highly beneficial. Much of the research shows that these principles can have a considerable and positive effect on learning in the classroom. However, the EEF maintain that more teacher-led research needs to be carried out. There are still very few classroom-based studies, particularly in the primary school sector, which add weight to these theories. This study seeks to add to that body of evidence by taking place in a primary school setting and by having the system tested by teachers.

The study took place in a 3-form entry UK primary school. It was derived and designed in response to anecdotal observations of pupils' responses in interviews with subject leaders as well as observations of pupils' books within the studied school. These showed that, overall, the pupils' answers within science and the foundation subjects were answered at a superficial level. Therefore, a system was devised to try to address this problem. This system combined strong cognitive science research with a formative self and teacher assessment tool called SOLO (Structure of Observed Learning Outcome) [9] with the aim of deepening knowledge and understanding across science and the foundation subjects. SOLO is a taxonomy which provides a framework for learning, through its specific vocabulary so that teachers can easily see how knowledge is built and deepened. Consequently, it appeared to be a quick and easy assessment tool for gauging where the children were in their understanding. A further purpose of this study was to assess whether this was a reasonable assumption.

5. Research Questions

1. How can cognitive science approaches alongside SOLO taxonomy help children achieve a deeper knowledge and understanding of the topics in science and foundation subjects?
2. How can cognitive science approaches alongside SOLO taxonomy support pedagogically non-expert teachers teach confidently in foundation subjects in primary schools?

6. The Procedures of the Study and Methods

As it was important to test the approach in a classroom setting and have it be conducted by practitioners rather than researchers, a design-based research study was used. This type of research is often used in education as it is thought to be ideal for testing out solutions to problems that have been highlighted in the classroom. Armstrong, Dopp and Welsh [26] maintain that the reason this kind of research works so well in education is because it is used in collaboration with the practitioners and therefore has a greater impact on future practice. This study was designed to test out the new method devised and was therefore applied to selected classes by the class teachers. These classes were then studied to analyse the effect of the intervention. A combination of quantitative and qualitative data was collected to try and provide a clear picture of how the approach was working and whether it was something that could be easily replicated and expanded across the whole school.

Research Sample

All participants were asked to complete a consent form in accordance with the ethics approval sought and given for the study. The sample for the study was relatively small but was chosen to give a spectrum of ability across three primary upper key stage classes: Years 4, 5 and 6, therefore children between the ages of 8 and 11. Eighteen children took part, six from each class: two higher attainers, two middle attainers and two lower attainers. There was a 50:50 split of male and female participants. All three teachers who volunteered and were chosen to take part were non-experts in the teaching of the subjects chosen and had very little experience of using either SOLO taxonomy or spaced retrieval practice in their classes.

The study was carried out over half a term of seven weeks. Although progress had been made and can be proved, it would have been more beneficial to carry it out over an entire term and for perhaps even longer. This would have provided an opportunity for all the classes to finish their learning in the topic as well as to revisit and see how much knowledge had been retained weeks after the topic had been completed.

For the study, it was decided to explore a history topic on the ancient Greeks in Y4; a science topic on space in year 5 and a second science topic on light in year 6. Therefore, the spread of subjects was not particularly broad, but the intention was that the school would eventually use this approach across science and all the foundation subjects. The three upper key stage 2 class teachers taking part in the study were given extra input to help to design learning outcomes to strengthen understanding of the knowledge and concepts throughout the topic, as well as the low stakes tests which were being studied and were to be carried out at the beginning of every lesson (Table 1).

Table 1. Examples of low-stakes tests for Y5 topic on space.

Name the planets (Uni-structural)
1. Identify/give children a picture of the solar system and ask them to label the planets they know.
2. Describe how the Earth going around the Sun creates the seasons (Multi-structural)
3. Compare conditions on Mars with conditions on Earth (Relational) Compare/contrast

7. Research Methods

7.1. Tests

The tests were constructed using the SOLO taxonomy which, as a hierarchal taxonomy of questioning words, served to build a schema of the topic being learnt. The tests would therefore ask for more complex answers each week as they built on the learning in the previous lessons so that the knowledge was deepened gradually and systematically. The tests were designed to review prior knowledge from previous academic years linked to present learning, as well as what had been covered in the topic so far. The retrieval practice was therefore spaced. Each test consisted of two or three questions which the children had to answer independently. The answers were then shared with the teacher and the rest of the class in a quick discussion to ensure understanding. Thus, another purpose of the study was to investigate how the use of this kind of cognitive science approach alongside SOLO taxonomy as a framework, could build a deeper understanding in foundation subjects.

The wording of the tests devised and used the SOLO taxonomy as a framework to give a clear method of formative assessment throughout the topic and to highlight and deal with any misconceptions. This then provided a scaffold for the planning and building of understanding across the key concepts within each topic. As the teachers were non-experts, it was important to test if the extra scaffolding provided by the design of the low-stakes tests would guide the pupils and the teachers through the learning to achieve the desired learning outcomes more effectively.

The SOLO symbols were put on the learning outcome for each lesson so that the pupils could see the different levels of thinking within the success criteria (Figure 3).

Learning Objective: To construct ideas about why we have seasons.				
Vocabulary orbit:				
Independent	*Group Work*	*Peer Support*	*Guided*	*Adult led*
III	Identify how the earth orbits the Sun and the Moon orbits the Earth and the time it takes to do so.			
	Analyse the movement of the Earth and the other planets, relative to the Sun in the solar system and the movement of the Moon relative to the Earth.			
	Formulate ideas based on the movement of the Sun and Earth about why we have changing seasons.			

Figure 3. Learning objective label from a Y5 book, showing the SOLO taxonomy symbols.

7.2. Interviews

All eighteen participating children were interviewed by the researcher throughout the study. This was to test whether the knowledge being taught in class was being retained. The teachers were also observed carrying out a low-stakes test by the researcher once during the study. This was to ascertain if the approach was being carried out in the way it had been designed. The teachers were then also given a questionnaire at the end of the study which sought to provide an objective view of their observations of the system and their perceived confidence in teaching that subject.

The pupils were interviewed in ability pairs to put them at ease. Each interview was less than 10 min, therefore a similar length to the low-stakes test in class. The interviews were carried out three times during the study: firstly, right at the beginning of the topic to assess any prior knowledge. Then, twice more throughout the topic to see how their knowledge of the topic was building. Unfortunately, the Y6 pupils missed the last interview due to COVID. The year 5 students were interviewed right at the end of their topic. However, the Y4 and Y6 content was still being taught when the research time concluded and therefore the children did not get to the end of their learning journey. The interview

questions were written using the SOLO taxonomy terms and therefore provided a building of complexity each time (see Table 2). They were therefore like those being used in the classroom by the teachers for the low-stakes tests and were based upon learning that was known to have taken place.

Table 2. Types of interview questions used across the three interviews (the words from SOLO Taxonomy are in bold italics).

Interview 1	What can you tell me about space? Do you know anything about Ancient Greece? What do you know about light?
Interview 2	Can you list some of the important things that the ancient Greeks did that we still do now? Can you describe to me exactly how light helps us to see? Can you explain how shadows are formed?
Interview 3	Predict what might happen to you on a trip to Mars and justify your predictions. Would you want to live in ancient Greece? Why/Why not? (Relating to the lives and experiences of the Ancient Greeks)

In year 5, where the topic was concluded during the period of the research, the first interview consisted of purely uni-structural questions, therefore establishing prior knowledge. The second interview was made up of multi-structural and relational questions and the final interview focused on the extended abstract level of the taxonomy. In year 4 and year 6 the first interview was also unistructural and the subsequent interviews moved up through the taxonomy, but only to the relational level as they were a few lessons from finishing their topic when the research concluded, therefore they had potentially not learned enough knowledge to allow them to have extended abstract answers.

Each of the interviews were recorded but they were anonymised by giving the pupils letters and numbers to distinguish them from each other when the interview was analysed. Any misconceptions that arose in the interviews were addressed after the interview was concluded and then also passed on to the teacher to address in class.

Each of the pairs in each class were asked the same stem questions but then the interviews went in different directions, giving each group a chance to demonstrate any more understanding they might have in that area. Therefore, some groups provided more responses. The data from the interviews with the children was codified according to the stage it applied to on the SOLO taxonomy scale. Each of the stages of the taxonomy was given a colour and the responses were then highlighted in that colour so that they could be counted. The total number of responses were then calculated, and a percentage was created for each type of response in each interview. A comparison could then be made between the three interviews to show how much the pupils' thinking had deepened during the topic. Codifying the interviews, however, was not completely straight forward as the pupils were inclined to speak at a tangent to the question and therefore needed re-focusing. Accordingly, only the clear answers were included. If the pupils had been guided through the thinking to the correct answer at a suitable level on the taxonomy, those responses were not recorded as the knowledge was not deemed consolidated enough to count. All incorrect answers were recorded as pre-structural.

7.3. Observation

As well as interviewing the pupils, the teachers were observed once each at the beginning of one of their topic lessons to ascertain how the framework was being used. The researcher observed whether the children were given scope to articulate their understanding when answering the SOLO scaffolded questions within the low-stakes test; as well as to see if misconceptions were being identified and addressed. Field notes were made and then considered to add more perspectives to the usefulness of the approach.

7.4. Questionnaire

At the end of the study the three class teachers were emailed a questionnaire. The questionnaire consisted of seven multiple choice questions and two open-ended questions asking for their comments. The questions were used to ascertain how easy they felt the approach was to use as well as their opinions on whether they felt it had a beneficial effect on both the learning of their pupils as well as their teaching. They were also asked how much they were using the approach in other areas of the curriculum as well as grading their level of confidence in the subject knowledge needed for the topics taught.

Through the lesson observations, qualitative judgements were made on the effectiveness of the use of the approach in class. These judgements were set against the criteria of the approach which had been set out for all the teachers in the initial training and was re-iterated throughout the research process to ensure effectual practice. The qualitative data from the questionnaires was analysed to assess where perceived strengths and weaknesses lay in the system from the perspective of the teachers and therefore to ascertain if the system was scalable across the school.

8. Findings

8.1. Interviews: Identifying Prior Knowledge and Recognising and Addressing Misconceptions in Years 4, 5 and 6

8.1.1. Identifying Prior Knowledge in Year 4

The pupils interviewed in Y4 had no prior knowledge of the ancient Greeks before they started learning the topic, therefore 100% of the responses recorded in the first interview were at the pre-structural level (see Figure 4). However, after one lesson and one immersion day where they dressed up as ancient Greeks, they were able to reduce the pre-structural responses to less than 7% and provide multi-structural and even a couple of relational answers. These relational answers referred to the fact that the Greeks did not let women take part in the Olympics and therefore the pupils were able to make inferences about how they would have felt to have lived in those times and provide opinions for their thoughts. All three ability groups were able to provide relational answers by interview three. The evidence clearly showed, therefore, a building of knowledge that followed the SOLO language framework.

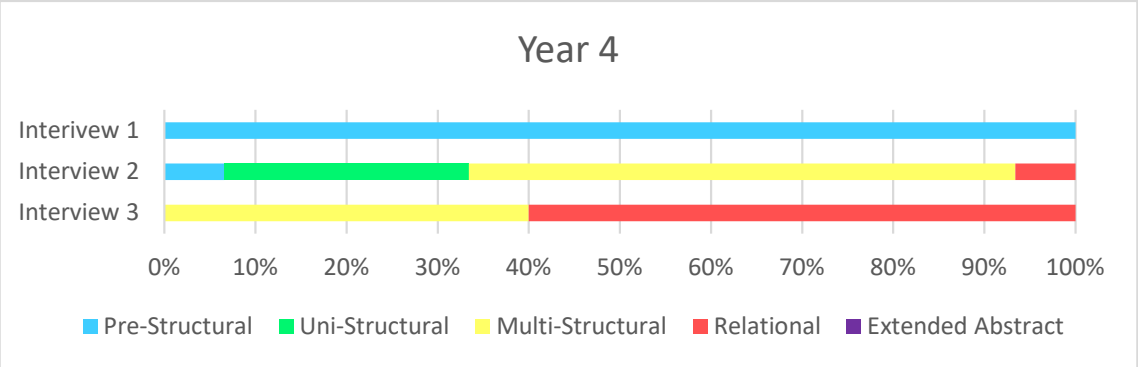

Figure 4. Progression of SOLO taxonomy observed over the 7-week course of interviews (Year 4).

8.1.2. Demonstrating the Building of Knowledge in Year 4

The class clearly had a fun and enjoyable immersion day dressing up and had completed many activities. However, when asked what they had learned on the day, they struggled to articulate any actual learning that had taken place. Nevertheless, as the data illustrates, their knowledge was showing more complexity, therefore some learning must have taken place even if they were not able to articulate it exactly from the day's activities. It appears then as if the building up of knowledge in the low-stakes tests was having more impact on the level of understanding than more exciting activities like those that took place on the immersion day.

The third and final interview in Y4 was conducted after only three lessons and the immersion day, so it is highly probable that having followed the framework of low-stakes tests, the learning outcomes of this topic would have led to more knowledge retained and understood at a deeper level had they been interviewed closer to the end of their topic.

8.1.3. Identifying Prior Knowledge in Year 5

The first Y5 interview was conducted after one lesson exploring their prior knowledge of space. Therefore, no learning had yet taken place in class. There was evidence of prior knowledge amongst two thirds of the interviewees (see Figure 5). This, however, consisted of a series of unconnected facts that they had picked up from books and television programmes which had not been accurately remembered in all cases, and therefore when fed into the new knowledge later in the process, this sometimes made their answers confused. Across all three interviews, 40% of the responses were pre-structural as the pupils were trying to articulate their understanding but failed to provide accurate observations, which illustrates some of this confusion with prior knowledge.

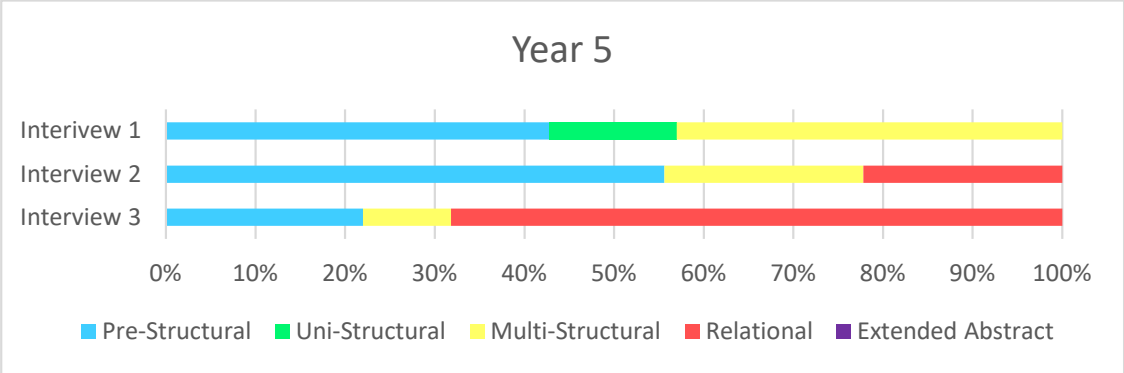

Figure 5. Progression of SOLO taxonomy observed over the 7-week course of interviews (Year 5).

In the second interview, the pupils discussed an activity they had done in the playground to demonstrate the distances between the planets. However, they were unable to remember any of the distances and the only residual learning amongst this group seemed to be that "the planets are quite far away from each other". A third of the interviewees were able to provide relational answers when asked in the second interview "can you explain why shadows get longer and shorter?" whilst the others were confused about whether the Sun or the Earth was doing the moving, therefore these answers showed poor understanding and were pre-structural.

8.1.4. Recognising and Addressing Misconceptions in Year 5

In the last Y5 interview the pupils were asked an extended abstract question about what equipment and supplies they would need for a trip to Mars. Although able to consider these questions, the answers given were only at the relational level as they lacked detail [9]. To give an extended abstract answer in this instance the pupil must understand cause and effect and provide solid predictions and justifications. A possible example of an extended abstract answer in this context can be seen below:

For a trip to Mars, you would need to wear special space boots because there is less gravity there because it is a planet less massive than Earth. Furthermore, because Mars has an atmosphere made up of carbon dioxide, we would be unable to breathe, therefore we would need to take a large amount of oxygen. Also, as Mars is a lifeless planet where there is no water and plants cannot grow, you would need to take plenty of food and water to survive. Overall, I would say it would be very challenging to go to Mars as it is a very different planet to our own planet.

However, all the pupils interviewed across all attainments were able to provide relational answers in this context and therefore as indicated by the taxonomy framework, demonstrated deep knowledge and understanding [9].

8.1.5. Identifying Prior Knowledge in Year 6

The Y6 pupils were at an advantage in their first interview as they had already had two science lessons. This is reflected in the results as in the first interview the pupils were able to give some relational responses to questions about light (see Figure 6).

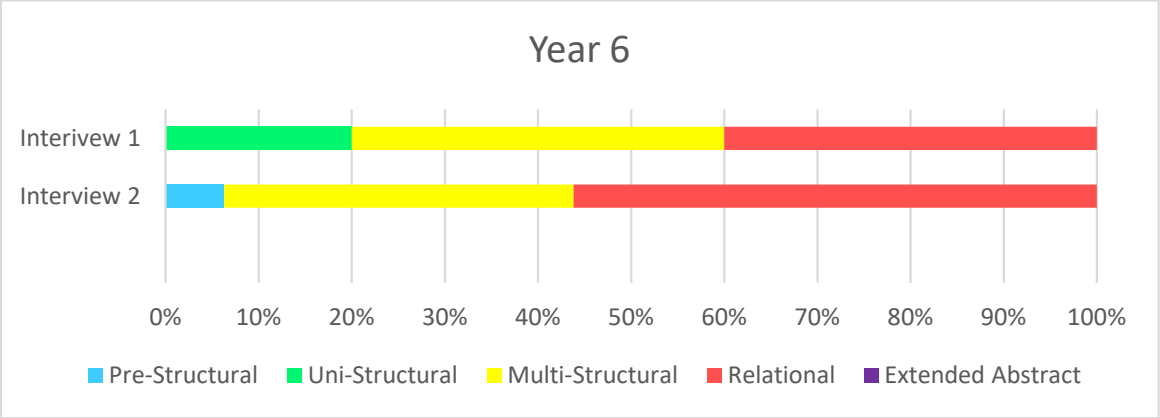

Figure 6. Progression of SOLO taxonomy observed over the 7-week course of interviews (Year 6).

8.1.6. Recognising and Addressing Misconceptions in Year 6

In the second Y6 interview, one pre-structural answer was given as the pupil was confused, thinking that it was the electricity from an electrical light source that 'bounced' off the object being viewed rather than the light itself. Two of the pupils in the first interview had completely misunderstood what the science topic was as they had been discussing how the eye works and had therefore believed they were learning about the human body. However, in their second interview, those same pupils were able to clearly articulate how light behaves to help us see.

8.1.7. Building Deeper Knowledge

More than half of the descriptions of how light helps us see were detailed enough to show the deep knowledge associated with relational thinking. This learning had clearly been consolidated between the first and the second interview, as although some relational responses were given in the first interview, there was also quite a lot of description of the activity as well as the learning.

8.2. Lesson Observations

In all the lessons observed, the pupils were given numerous opportunities to articulate their learning and understanding. In year 4 the teacher was observed giving the class the low-stakes test examining their knowledge of the history timeline and legacy. This was their second history lesson and came after their immersion day. The pupils had the two questions stuck into their books and were given a few minutes to write the answers to them. The teacher then chose 5 children to come and put a mark on the timeline on the interactive whiteboard to show where the ancient Greeks belong. All the children remembered it was BC and not AD (before starting the topic, they thought it was AD). The children were then quickly taught a rhyme 'after Stone Age and before Romans' to remember where on the history timeline the ancient Greeks belong. In the following interviews, most of the children were able to remember and recite this.

The question on the legacy of the ancient Greeks proved to be more difficult, however most of the children were keen to have a turn at answering. None of the children mentioned democracy, although it had been covered in a previous lesson. The teacher reminded them

about the legacy of democracy. The children, however, were a little bit confused by the concept, so the teacher re-defined it and got them to repeat the definition. The teacher also reinforced the meaning of legacy. Despite some confusion which was adequately addressed for future learning, both questions covered in the low-stakes test later produced multi-structural responses from more than half of the studied group.

8.3. Teacher Questionnaire

When the teachers were asked if using the SOLO and the low-stakes test improved their subject knowledge as they were teaching the topic, all three were affirmative with the Y5 teacher saying, 'it meant I was thinking ahead to the relational level to help not only the pupils' recall but also to make those links explicit for the class'. The Y4 teacher also said that by working out the low-stakes tests before starting the topics and weaving in the SOLO language to build complexity, it highlighted for her the important concepts and where she possibly needed to do more research.

8.3.1. Identifying and Addressing Misconceptions

In the comments section of the questionnaire the Y4 teacher said that "using the low-stakes tests gave us as a class the opportunities to revisit and therefore realise that assumed learning had not taken place". She pointed out that in previous years she might have done a lesson on democracy and then left that topic without revisiting having assumed that the learning had taken place. By having the opportunity to keep revisiting through the low-stakes tests, she was able to identify the confusion and address it. Another observation was that the low-stakes tests were clearly showing progression of learning and were very useful for identifying misconceptions and missed learning across the foundation subjects.

8.3.2. Observed Benefits for Pupils' Learning

When asked how much difference they felt the low-stakes tests had made to the pupils' abilities to articulate knowledge, all three teachers noticed a difference. They all saw value in the tests as they could see the progression in their pupils' thinking. One teacher observed that by focusing on links in learning, the children were starting to make links across other topics and recalling previous years' learning.

9. Discussion and Implications

The findings showed that the system being studied appeared to have had a positive impact on both the pupils' learning and the perceptions of that learning by the teachers, and therefore concurs with previous research [11,13,27]. The system itself also seemed to improve staff confidence and help make the learning links explicit for the teacher and pupils and, therefore, shows some promise for providing a usable system for non-experts. The responses in the interviews with the pupils showed a building of deeper understanding across the topics which therefore addresses one of the research questions put forward for the study [10,11,28]. None of the pupils within the study reached the extended abstract level of understanding within the taxonomy, however, the majority were able to give relational answers, which shows that they were able to articulate deep knowledge as categorised by Biggs and Collis [9].

Interestingly, improvements in the level of understanding, as well as the complexity of knowledge, were not necessarily dependent on ability and in fact some of the less-able children performed better as they were not confused by unconnected prior knowledge. However, it was a small-scale study similar to other SOLO studies [27] and it would be beneficial to see the effect on a larger group of pupils.

9.1. Planning

Conducting the study highlighted the fact that the medium-term planning the school was working from needed to be changed, as it was very difficult for non-experts to find the links and opportunities for building an understanding and deepening knowledge.

For example, in the space topic studied by the Y5 pupils in this study, the children were supposed to learn about the composition of stars and black holes as well as the phases of the moon and gravity. It was therefore hard to lead the pupils to a logical comprehension of a space schema that was appropriate for the age group.

Space is a vast topic, and as Ofsted [7] points out, the temptation can be to plan fun tasks that relate to space without linking them together in a meaningful way to help the children build their understanding. This study has shown that teachers, when planning, should try to avoid making the topic a checklist of lots of different elements of that topic. When the different lessons are related carefully it can lead to an extended abstract and therefore a deeper level of thinking for the children [9]. It could be argued that a possible way of doing this for non-experts would be to hone down the topic with a sub question, e.g., Space—How does our solar system work? Therefore, the focus becomes narrower, and it is easier to work out what the children need to understand by the end of the topic. Key sentences could be included in the planning which show what each level of the taxonomy would look like in that context, e.g., the relational answer could for example be:

> At the centre of our solar system is a star which is our sun. That is the only star in our solar system. Eight planets orbit the sun and are held in that orbit by the gravitational pull of the sun. As they orbit, they also spin, which creates the days and nights; the part of the planet facing the sun experiences the day and the part facing away experiences the night. Each orbit of the sun is a year; those years are all different lengths on each of the planets.

The children would not be expected to be word perfect when giving this response and should certainly not be encouraged to learn that definition by heart. As Hattie [10] points out, the hierarchal nature of the SOLO taxonomy ensures that one does not skip to the end without building up the understanding behind the explanation. All the learning that had taken place in that topic would need to lead to that understanding, therefore that understanding needs to be broken down into its component parts to recognise what needs to be taught to reach that level of comprehension.

The extended abstract question at the end of the topic could then be: 'What would happen to the planets if the sun lost some of its mass'? Being able to answer this question would show that the pupils were able to apply all the knowledge they have learnt to a new scenario that has not hitherto been addressed in class [10,15]. Although the study shows that not all the children will necessarily be able to reach that deep level of understanding, it does however appear that if the knowledge is sequenced correctly and the teacher has that end understanding goal in mind while teaching, that each child will have a much better chance of achieving deep level thinking.

9.2. Effectiveness of Low-Stakes Testing of Spaced Knowledge

The findings showed that revisiting the concepts and themes throughout the topic had a clear benefit on the teacher and class which correlates with previous research highlighted above on the merits of spaced learning and retrieval practice [15,17]. Combining the two cognitive approaches proved to be an important part of the system, as giving the children spaced opportunities for articulating their learning appeared to have a beneficial effect on the retention of the knowledge and the building of their understanding [17,29,30].

There was evidence in the study to suggest that the most fun activities did not necessarily yield the most learning. At the beginning of the research the pupils were describing the task more than articulating their learning, but in most cases, as they gathered more knowledge and consolidated more of their thinking, they were able to provide much better descriptions of the learning itself. This then contrasts with the findings by The Ogden Trust and the University of Manchester [5] highlighting several cases where students had been observed speaking enthusiastically about their lessons but were unable to illustrate any understanding of the concepts covered. This further illustrates the view of Willingham [6] that knowledge is key. This theory does not necessarily mean that the curriculum needs to be stripped of its dynamism. Within the learning that took place in the study, lots of fun

and practical activities were still being used but the learning clearly needed to be more explicit, with the children being given several opportunities within the lesson to articulate that learning.

The support given to the participating teachers in the building of the knowledge through the low-stakes tests gave them the ability to recognise the links and therefore help the children to see them and build them. This therefore goes some way to addressing the concern of Ofsted [7] over some science teachers frequently struggling to build skills and knowledge progressively within a curriculum and, therefore, the learning often remaining at a surface level. It seems this system could also provide a way to ease the frustration shown by teachers over the lack of depth of knowledge that is vital for a higher level of thinking observed by Willingham [6].

9.3. How Effective Was the Use of SOLO?

By using the SOLO taxonomy language, it assisted the teachers in making the low-stakes test more than purely factual recall [10,13]. Instead of asking for a small list of facts, each week the tests were asking for more complex answers which addressed the concerns held by the EEF [22] about retrieval practice purely focusing on surface knowledge. The regular use of low-stakes tests within the study certainly seemed to show positive benefits for both students and teachers, which is in accordance with previous studies such as Donaghy [17]. It appears, therefore, that the opportunities that the low-stakes tests provided in the study were invaluable, such as the revisiting of the learning. This correlates with the opinion of Brown et al. [15] on the importance of spaced learning for the effective retention of information. The low-stakes tests also gave the teachers the chance to address misconceptions, all elements which Roediger and Brown [30] agree are important for effective learning. The overt nature of their retrieval within the low-stake tests seemed to order their thinking and understanding and therefore seemed to be the better way for children to learn rather than internalising their thoughts and understanding, therefore concurring with the findings of earlier studies such as that of Tauber et al. [21]. In accordance with the research conducted by Damopolii [11], this study has shown that SOLO can be used as a coherent framework for guiding deeper learning and understanding across the curriculum. The study showed a marked improvement in thinking across all attainment levels within the class and there certainly was no evidence of the system making consolidation more complex or challenging.

10. Conclusions

The study shows that the pupils were able to articulate deep thinking concerning the topics they were studying and display progress along the hierarchical stages of the SOLO taxonomy. Their explanations were more than purely unconnected facts. They were able to relate the facts together to provide 'relational' answers [9]. None of the pupils involved got to the critical thinking stage of the taxonomy in the time observed. This was in part because some of the pupils had not finished their topics and therefore were not at the end of their learning journeys where the 'extended abstract' questions could be legitimately expected to be answered accurately [9]. However, it was observed that they all seemed better placed to achieve that level of thinking by the end of the study. The relational level of thinking was observed by the teachers and researcher, both in the classroom during the low-stakes tests and during the interviews. It was both formally recorded in their books as well as articulated verbally. This seemed to be the important element of the system, as giving the children opportunities to articulate their learning to the class and the teacher allowed them to refine their answers each time they were questioned.

The benefits of the low-stakes tests which tested connected prior learning in a spaced fashion, were evident from the pupils' outcomes and the comments from the teachers. The teachers felt that by thinking about how the knowledge related together when working out the low-stakes tests, using the hierarchical nature of the taxonomy, their own confidence in that knowledge was strengthened. Dunlosky et al. [29] pointed out that with time

constraints on teachers, identifying the best learning strategies can be difficult. The low-stakes tests designed in this study seem quick and easy to administer and appear not to have any adverse effects on the children's confidence. Instead, they gave them the opportunity to articulate their learning and ensure that their misconceptions were identified and addressed. This strategy of combining spaced retrieval practice and SOLO taxonomy, therefore, appears simple to use as well as being beneficial for both pupils and teachers.

Recent observations by Ofsted [7] show that there remains an issue with teacher subject knowledge in the primary school sector when trying to teach such a broad curriculum. Therefore, a system like the one studied in this paper seems beneficial. This benefit was positively commented on by the participating teachers. The system does, however, have implications for the medium-term planning of the topic. The research highlighted that this needs to be more connected from the start. Rather than a series of sub-topics taught in isolation, strong links need to be established that run through the topic so that the complexity of the pupils' knowledge can build up, as is supported by previous research [30]. These links could be achieved by introducing a sub-question to the topic which hones an enormous subject into something more easily connected. The answers to that question at different levels of the taxonomy could then be included in the planning. This potentially means fewer areas are covered within the topic, but the areas that are covered are done so in more depth to give the pupils a real sense of what they are learning and therefore avoid them finishing the learning journey with a series of unconnected facts [10,31]. This study has shown that this is a system that is worth researching further and which shows potential for use across the primary school phase for the deepening of subject knowledge in both pupils and teachers.

Author Contributions: Conceptualization, O.D. and N.M.; methodology, O.D. and N.M.; validation, O.D. and N.M.; formal analysis, O.D. and N.M.; investigation, O.D.; resources, O.D.; data curation, O.D. and N.M.; writing—original draft preparation, O.D.; writing—review and editing, O.D. and N.M.; visualization, O.D. and N.M.; supervision, N.M.; project administration, O.D. and N.M.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of University of Exeter (protocol code M2021-285 and date of approval: 23 June 2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Duncombe, R.; Cale, L.; Harris, J. Strengthening 'the foundations' of the primary school curriculum. *Education 3–13* **2018**, *46*, 76–88. [CrossRef]
2. Randall, V.; Griggs, G. Physical education from the sidelines: Pre-service teachers' opportunities to teach in English primary schools. *Education 3–13* **2020**, *49*, 495–508. [CrossRef]
3. Metzler, J.; Woessmann, L. The impact of teacher subject knowledge on student achievement: Evidence from within-teacher within-student variation. *J. Dev. Econ.* **2012**, *99*, 486–496. [CrossRef]
4. Byrom, J. Alive . . . and kicking? Some Personal Reflections on the Revised National Curriculum (2014) and What We Might Do with It. *Teach. Hist.* **2014**, *153*, 6–14.
5. Bianchi, L.; Whittaker, C.; Poole, A. *The 10 Key Issues with Children's Learning in Primary Science in England*; The University of Manchester: Manchester, UK; The Ogden Trust: London, UK, 2021.
6. Willingham, D.T. Ask the cognitive scientist: How can educators teach critical thinking? *Am. Educ.* **2020**, *43*, 41–45.
7. Ofsted. Education Inspection Framework—Overview of Research. 2018. Available online: https://www.gov.uk/government/speeches/hmci-commentary-curriculum-and-the-new-education-inspection-framework (accessed on 3 November 2021).
8. Rollett, S. Putting Ofsted's new framework into practice. *SecEd* **2019**, *10*, 10–11. [CrossRef]
9. Biggs, J.B.; Collis, O.F. *Evaluation the Quality of Learning: The SOLO Taxonomy (Structure of the Observed Learning Outcome)*; Academic Press: New York, NY, USA, 1982; ISBN 9781483273310.
10. Hattie, J. Understanding Learning: Lessons for Learning, Teaching and Research. ACER Research Repository. 2013. Available online: https://research.acer.edu.au/research_conference/RC2013/6august/10/ (accessed on 15 January 2022).

11. Damopolii, I.; Nunaki, J.H.; Nusantari, E.; Kandowangko, N.Y. The effectiveness of Inquiry-based learning to train students' thinking skill based on SOLO taxonomy. *J. Phys. Conf. Ser.* **2020**, *1567*, 25. [CrossRef]
12. Roberts, J. The Who, What, When, Where and Why of SOLO Taxonomy, Q & A. 2018. Available online: https://www.nzcer.org.nz/system/files/journals/set/downloads/Set%202018_2_048_0.pdf (accessed on 20 October 2021).
13. Hook, P. SOLO Taxonomy in Derrimut Primary School and Brunswick Secondary College. Learning Strategies. 2018. Available online: https://pamhook.com/2018/08/30/solo-taxonomy-in-derrimut-primary-school-and-brunswick-senior-college/ (accessed on 12 November 2021).
14. Ebbinghaus, H. *Memory: A Contribution to Experimental Psychology*; Ruger, H., Bussenius, C., Translators; Teachers College, Columbia University: New York, NY, USA, 1913.
15. Brown, P.; Roediger, H.; McDaniel, M. *Make It Stick*; Harvard University Press: Cambridge, MA, USA, 2014; ISBN 9780674729018.
16. Mercer, T.; Jones, G.A. Time-dependent forgetting and retrieval practice effects in detailed visual long-term memory. *Q. J. Exp. Psychol.* **2019**, *72*, 1561–1577. [CrossRef]
17. Donaghy, L. Using regular, low-stakes tests to secure pupils contextual knowledge in Year 10. *Teach. Hist.* **2014**, *16*, 157.
18. Rawson, K.A.; Dunlosky, J. Optimizing schedules of retrieval practice for durable and efficient learning: How much is enough? *J. Exp. Psychol.* **2011**, *140*, 283–302. [CrossRef]
19. Roediger, H.L., III; Butler, A.C. The critical role of retrieval practice in long-term retention. *Trends Cogn. Sci.* **2011**, *15*, 20–27. [CrossRef] [PubMed]
20. Roediger, H.L., III; Putnam, A.L.; Smith, M.A. Ten benefits of testing and their applications to educational practice. *Psychol. Learn. Motiv.* **2011**, *44*, 1–36.
21. Tauber, S.K.; Witherby, A.E.; Dunlosky, J.; Rawson, K.A.; Putnam, A.L.; Roediger, I.H.L. Does Covert Retrieval Benefit Learning of Key-Term Definitions? *J. Appl. Res. Mem. Cogn.* **2018**, *7*, 106–115. [CrossRef]
22. Perry, T.; Lea, R.; Jørgensen, C.R.; Cordingley, P.; Shapiro, K.; Youdell, D. *Cognitive Science in the Classroom*; Education Endowment Foundation (EEF): London, UK, 2021. Available online: https://educationendowmentfoundation.org.uk/evidence-summaries/evidencereviews/cognitive-science-approaches-in-the-classroom (accessed on 14 May 2021).
23. Agarwal, P.K. Retrieval practice & Bloom's taxonomy: Do students need fact knowledge before higher order learning? *J. Educ. Psychol.* **2019**, *111*, 189.
24. Damhuis, C.M.; Segers, E.; Verhoeven, L. Stimulating breadth and depth of vocabulary via repeated storybook readings or tests. *Sch. Eff. Sch. Improv.* **2015**, *26*, 382–396. [CrossRef]
25. McDaniel, M.A.; Agarwal, P.K.; Huelser, B.J.; McDermott, K.B.; Roediger, H.L., III. Test-enhanced learning in a middle school science classroom: The effects of quiz frequency and placement. *J. Educ. Psychol.* **2011**, *103*, 399–414. [CrossRef]
26. Armstrong, M.; Dopp, C.; Welsh, J. Design-Based Research, The Students' Guide to Learning Design and Research. EdTech Books. Available online: https://edtechbooks.org/studentguide/design-based_research (accessed on 21 July 2022).
27. Wall, S.; Manger, R. Going SOLO to enhance learning and teaching. *Teach. Geogr.* **2015**, *40*, 112–114. Available online: http://www.jstor.org/stable/26383210 (accessed on 5 November 2021).
28. Murre, J.M.J.; Dros, J. Replication and Analysis of Ebbinghaus' Forgetting Curve. *PLoS ONE* **2015**, *10*, e0120644. [CrossRef]
29. Dunlosky, J.; Rawson, K.A.; Marsh, E.J.; Nathan, M.J. Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychol. Sci. Public Interest* **2013**, *14*, 4–58. [CrossRef]
30. Roediger, H.L.; Brown, P.C. The importance of testing as a learning strategy. *Educ. Dig.* **2020**, *85*, 11–16.
31. Chambers, P. Improving the teaching of science and technology in primary schools—A cluster approach. *Prim. Sci.* **2017**, *148*, 17–19.