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Children's acquisition of science terms: Simple exposure is insufficient

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Abstract

The ability of school children ($N = 233$) to acquire new scientific vocabulary was examined. Children from two age groups ($M = 4.8$ and $M = 6.5$) were introduced to previously unknown words in an educational video. Word knowledge was assessed through accuracy and latency for production and comprehension over a 9-month period. A draw and write task assessed acquisition of domain knowledge. Word learning was poorer than has previously been reported in the literature, and subject to influences of word type (domain specificity) and word class. The results indicate that the acquisition of scientific terms is a complex process moderated by lexical, semantic and pragmatic factors.

Keywords: Vocabulary; Learning; Science; Fast mapping; Domain knowledge

1. Vocabulary acquisition in the early school years

Vocabulary learning has been conceptualised as a "relatively simple affair" (Plunkett & Wood, 2003, p. 165). Studies have documented the fast and efficient ways in which initial mappings between word and the world are achieved. These mappings have been conceived as being governed by a range of constraints (Baldwin, 1995; Markman & Hutchinson, 1984; Waxman & Kosowski, 1990) supported by the child's established vocabulary (Carey, 1978) and phonological memory (Gathercole & Baddeley, 1989). An ability to acquire new vocabulary quickly and efficiently would be a highly useful skill. Vocabulary knowledge is a strong predictor of academic success; it plays a central role in cognitive development especially in relation to literacy and learning (Cunningham & Stanovich, 1997; Stanovich & Cunningham, 1993). Yet much of the work examining children's skills as word learners has focussed on the preschool years, and those studies that have examined acquisition processes in elementary schools have focussed primarily exclusively on story based methods (see Biemiller & Boote, 2006). The lack of experimental investigations of subject related vocabulary that children encounter in schools represents a significant empirical and theoretical gap, especially since the halting and oft times inaccurate progress children make in learning new subject related vocabulary is at odds with claims of early, rapid learning achievements.

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Experimental word learning studies, typically, focus on the acquisition of object words in relatively restricted contexts without attempting to assess the depth or stability of the child's ensuing representations (Dockrell & Messer, 2004). More recently the explanatory power of the constraints paradigm has been challenged (Clark, 2003; Deák, 2000a, 2000b) and detailed analyses of contexts of acquisition have pointed to the importance of the nature of the exposure to new terms and the ways in which this differs across word classes (Childers & Tomasello, 2002; Tomasello, Akhtar, Dodson, & Rekau, 1997). Research has, however, continued to point to the remarkable feats of the early word learner (but see Deák & Wagner, 2003) with few attempts to address lexical acquisition in the school years (but see Biemiller & Boote, 2006; Senechal, 1997). There is indicative evidence that the processes and factors associated with efficient word learning in the preschool years may be less important as children grow older (Anglin, 1993; Swanborn & de Glopper, 1999). Given the reported failure to provide direct vocabulary instruction in school (NRP, 2000) it is important to identify the factors that support later lexical learning. This study aims to address this gap by investigating older children's ability to learn new science vocabulary in the early school years.

1.1. Word learning in the preschool period

When children acquire a new word, they must identify the sound in the speech stream, encode a corresponding phonological representation and then establish a mapping between this word form and the world; ultimately a detailed semantic representation is developed for the new term with an indication of its morphosyntactic features. Inaccurate phonological representations reduce the accuracy of children's lexical productions and may also hamper the initial establishment of semantic representations. During early and middle childhood there is a close link between children's vocabulary knowledge and their ability to retain new phonological information for short periods of time (Gathercole & Adams, 1994; Gathercole & Baddeley, 1989). However, much of the data supporting the link between working memory and vocabulary acquisition are correlational with the result that the nature of their relationship is disputed. Phonological sensitivity can enhance the acquisition of phonologically unfamiliar words (Bowey, 1996, 2001; de Jong, Seveke, & van Veen, 2000), and children's early vocabulary growth may be supported by the existence of similar sounding words; but as children develop they acquire words with less frequent sounds and sound combinations (Coady & Aslin, 2003). Phonological processing on its own is not sufficient to establish a lexical representation and there is evidence to suggest that, in the preschool period, phonological memory predicts the acquisition of explicitly taught lexical items but not those that are introduced in an incidental fashion (Michas & Henry, 1994). However, much of children's early lexical learning appears to occur incidentally. Thus phonological memory may only become a critical dimension once a potential referent has been explicitly identified, that is, after a word-world mapping has been established.

The question of how children establish a word-world mapping has been the subject of considerable research (Bloom, 2000). Many of the studies imply that this is a simple process, where all that is needed is the selection of the referent from an array of stimuli. However, a match between an object or set of objects and a linguistic form is insufficient on its own to develop a semantic representation; children must also integrate the new term with their existing lexicon (Anglin, 1993; Clark, 2003; Dockrell & Campbell, 1986). A child's prior vocabulary knowledge plays a critical role in subsequent semantic representation. As children's vocabulary increases the existence of semantically related words afford potential benefits. This larger pool of lexical items provides an increasing range of taxonomically and thematically related items to support learning. Novel words are hard to interpret from non-verbal or syntactic cues alone but the phrases and words around a novel term — the predicate context — constrains potential meanings (Deák, 2000a, 2000b). Children are able to use semantic context to infer the meanings of a new word (Goodman, McDonough, & Brown, 1998) and children with larger vocabularies acquire new terms more quickly than children with smaller vocabularies (Elley, 1989; Leung & Pikulski, 1990). A larger vocabulary helps children identify gaps in their lexicon and can direct the process of lexical acquisition (Merriman & Bowman, 1989) providing the basis for more differentiated concepts.

1.2. The demands of later vocabulary learning

These child-based factors — phonological memory and prior vocabulary — need to be considered in relation to the lexical items to be acquired. The words children learn in school and the ways in which words are encountered will differ from earlier patterns of exposure (Best, 2003). As children progress through the school years, they encounter words that are abstract, low in frequency, both domain-specific and domain-general, and possibly with non-literal meanings (Nagy, Diakidoy, & Anderson, 1993; Nippold, Cuyler, & Braunbeck-Price, 1988; Smiley & Huttenlocher, 1995). Establishing semantic representations for entities that are not easily seen, heard or touched is achieved much later than representations of concrete words (Nippold, 1998). Much of the work on early vocabulary acquisition focuses on concrete words and, as such, may be less relevant to the processes involved in later word learning. Semantic relations between words play a pivotal role in lexical representation. Labels of clearly contrasting categories are learnt quickly and efficiently by preschool children whereas inclusive and overlapping categories pose greater learning challenges – their acquisition occurring in a fragile or sluggish manner even ''when abundant, explicit input about relations is provided'' (Deák & Wagner, 2003; Nelson, 1996). These features are likely to be critical to later vocabulary acquisition and subject specific knowledge such as science.

An analogous problem can be identified with differential rates of learning for words representing different word classes: nouns, verbs and adjectives. Verbs typically denote events whereas nouns typically denote entities. Noun learning appears to be privileged; an early bias for nouns has been established for lexical acquisition across a range of languages (Bornstein et al., 2004; though see Tardif, Gelman, & Xu, 1999, for evidence from Mandarin). This differential pattern of learning has been explained in terms of both the constraints underlying lexical acquisition and the underlying semantic representations of the different terms. Lexical constraints, such as the taxonomic bias and the noun category linkage (Waxman, 1994), could support the prevalence of noun mapping over verbs (Markman, 1987) and adjectives (Hall, 1999). However, it has also been argued that the category corresponding to nouns is simpler or more basic than those corresponding to verbs (Gentner, 1982); verbs typically entail more abstract dimensions (Gillette, Gleitman, Gleitman, & Lederer, 1999).

Events can often be described in many different and acceptable ways. This adds a pragmatic dimension to verb production. Children and adults tend to agree in object naming tasks (92%) whereas much greater variability is evident in verb naming (52%) (D'Amico, Bentrovat, Gasparini, Costabile, & Bates, 2002). This difference in performance may be less evident in comprehension tasks, where the dependent measure is the choice of referent from a small, fixed set of alternatives, than in naming, where the child has to identify the correct item from their lexicon. As such, if difficulties with verbs are dominated by pragmatic rather than conceptual processes, then we might expect children's responses to nouns and verbs to differ in production but not comprehension.

As children progress through school, they will encounter terms that are semantically complex and both domain-specific and domain-general. Domain-specific terms are specific to a subject or area and typically their acquisition has not been examined closely (Drum & Konopak, 1987). There are reasons to predict that domain-specific terms could pose a particular challenge for children. Such terms will typically be determined by the domain, and so be relatively narrow in denotation. Successful understanding of these terms will necessitate an awareness of relevant knowledge (or 'theory') underpinning the domain. In such cases, the child's prior beliefs and understandings would be expected to influence their ability to develop extended meanings of the term. If these representations are not well developed, the cursory meaning of a word that can be established after one exposure may be limited. However, if the child's representations are better developed the fact that the novel term is related to a limited conceptual domain may support acquisition (Markman, 1992). For example, knowing that a 'fep' is an animal allows the child to ascribe certain properties to the referent of the term and further develop their beliefs about this semantic domain. In contrast, domain-general terms may be easier to acquire. Domain-general terms potentially provide the child with more exemplars because of their wider usage across domains – a novel word could be encountered in a range of different contexts, and potentially more often overall. However, the similarities between referents across domains may be highly abstract, so hindering the child's ability to develop a semantic representation. Given the importance of prior vocabulary, domain specificity is likely to exert an influence on word learning, though its direction is uncertain and its significance has not been established (Snow, 2002).

Studies of later lexical acquisition allow us to evaluate the extent to which lexical learning is supported by factors that scaffold early vocabulary acquisition and provide the data to identify potential impediments to the mapping process. Given the increasing new subject vocabulary children encounter at school entry, one path of investigation is to study subject specific vocabulary where examples of both domain-general and domain-specific terms can be found.

1.3. Science Vocabulary

Science is an area of the curriculum that plays a central role in the development of children's logical and critical thinking abilities (Harlen, 1985). It is widely viewed as being a difficult subject, both by pupils and primary teachers

(Millar, 1991) and children's understanding of science is a major concern for educators. Surprisingly little is known concerning the child's scientific lexicon as they enter school or of its subsequent development. Children encounter new science vocabulary from teachers, texts and through multi-media exposures. Current data suggest that teachers make relatively few accommodations, in science lessons, to the needs of the novice learner (Best, 2003). Examination of the process of acquisition in typical classroom activities allows an evaluation of the extent to which children 'fast map' the science terms to which they are exposed. An initial rough notion of a word's meaning would provide the basis for the enrichment and reconstruction of concepts entailed in the learning of science (Vosniadou & Ioannides, 1998). Indeed, data from such studies provide the basis for establishing evidence-based strategies for teaching and learning. To assess the patterns of lexical acquisition of novel science terms, an important first step is to ensure that children have already established a semantic domain into which the new word can be embedded.

Two contrasting topics in the early years and elementary school curriculum provide a basis for testing these ideas: animals and space. Both of these domains map closely to elements of the UK National Curriculum at Key Stages 1 and 2, designed for teaching from the age of 5 to 11 years. Animal terms are some of the earliest acquired terms by young children and appear to readily enter well-established domains (Dockrell & Campbell, 1986). Space terms appear to hold a specific interest for young children, and acquisition of specific space terms in certain contexts is associated with extended understandings (Best, Dockrell, & Braisby, 2006).

1.4. Assessment of vocabulary knowledge

Understanding patterns of acquisition is influenced by the measures used to assess learning and the time frame under which learning is examined (Dockrell & Messer, 2004). Experimental word learning tasks mimic single word exposure for young children but they are rarely modelled on the range of different naturalistic contexts in which children encounter new words (Nelson, 1988). Nor do they resemble the more extensive oral language exposures that older children receive when they encounter novel words (Graves, 1986, 1987; Nagy & Herman, 1987; Nelson, 1988). In these extended exposures, the accompanying language may support inferences about different types of meanings (Brabham & Lynch-Brown, 2002).

There have been several attempts to create assessment techniques that tap different aspects of vocabulary knowledge. A synthesis of these various approaches can be seen as elaborating the view that word knowledge falls along a continuum, and it is necessary to consider where knowledge of a particular lexical item lies on that continuum (Ralli & Dockrell, 2005). Comprehension is generally mastered before production but there are methodological confounds in comprehension measures that need to be considered (Braisby, Dockrell, & Best, in preparation; Dockrell & Messer, 2004). Measures of speed of response (reaction time) offer an alternative measure of the activation of lexical knowledge. Such measures are commonly used in studies of adult naming and comprehension and with atypical child populations, and provide the basis for extending our understanding of the factors that underpin lexical process (Dockrell, Messer, & George, 2001; Gaskell & Dumay, 2003). However, they have been less evident in developmental approaches with typical children. As such, measures of latency provide an alternative measure of acquisition when naming or comprehension are successful.

Comprehension and production do not provide information about the richness of the child's semantic representations, or how they link to their wider domain knowledge. Forced choice methods of questioning, such as in comprehension tasks, can inhibit the generation of children's own representations (Vosniadou, Skopeliti, & Ikospentaki, 2004). Semantic representations can be tapped through a range of verbal measures such as antonyms, synonyms, hyponyms and semantic attributes (Carey & Bartlett, 1978; Heibeck & Markman, 1987; Richard & Hanner, 1985). All these measures rely on the child's competence in oral language and may therefore not capture the semantic knowledge of the child, as acquired. In contrast children's drawings can reveal knowledge that is not easily tapped orally (Best et al., 2006; Gross & Teubal, 2001; McGregor & Appel, 2002) and appear to be successful in eliciting "fragile" lexical and domain knowledge (McGregor, Friedman, Reilly, & Newman, 2002). The use of alternative assessment measures has been limited to small-scale tests of their effectiveness in experimental learning studies (e.g., Jenkins, Stein, & Wysocki, 1984; McKeown, Beck, Omanson, & Pople, 1985; Nagy, Herman, & Anderson, 1985). An important step in understanding the development of lexical representations is to consider acquisition patterns across more than one measure. If different dimensions of lexical knowledge are considered, a multifaceted picture of vocabulary development can emerge (Graves, 1986).

1.5. Purpose of the study

The current study investigates children's ability to learn new science vocabulary. Previously unknown science terms were presented to elementary school children in contexts that mimic those that have been successful with the preschool child, albeit with simpler vocabulary items (Rice & Woodsmall, 1988). These contexts were designed to reflect opportunities that typically occur in a primary science lesson and thereby provide an ecologically valid means of monitoring children's acquisition of unfamiliar science terms. Children's success in learning these new vocabulary items is considered in relation to both the skills the child brings to the word learning tasks (phonological memory and expressive and receptive vocabulary) and in terms of the lexical items to be learnt. Very low frequency, unfamiliar nouns, verbs and adjectives that were either restricted to a specific conceptual domain (domain-specific) or applicable across domains (domain-general) were introduced in a series of specially constructed science videos. Four videos were constructed each introducing a different set of novel terms. Lexical acquisition was assessed through measures of comprehension and production and the child's wider understanding of the scientific domain was evaluated through a draw and write task (Best, 2003).

2. Methods

2.1. Participants

Two hundred and eighty four primary school children between the ages of 4.0 and 7.6, drawn from nine London primary schools, were recruited to participate in the first experiment. Of these, 30 were unable to participate fully because of illness or moving home, 10 were unable to complete the first testing session examining their acquisition of the new terms, and data from 11 participants were lost due to a computer fault. Two hundred and thirty-three participants therefore completed the pre- and main-tests of the experiment. Participants were recruited from two age groups: 136 four and five year olds ($n = 136$, $M = 4.8$, range 4.0–5.11) and 97 six and seven year olds ($n = 97$, $M = 6.5$, range 6.0–7.1). Children scored within the average range for measures of receptive and expressive vocabulary and phonological memory as assessed by standardised measures (mean standard scores receptive vocabulary BPVS II $M = 103$, SD = 14; expressive vocabulary BAS II $M = 103$, SD = 14; phonological memory children's test of non-word repetition $M = 103$, SD = 14).

2.2. Materials

2.2.1. Novel words

Our objective was to identify 16 novel science terms of very low frequency which would fill gaps in the children's lexicon. The English National Curriculum for science was used to initially identify appropriate subject areas for consideration. From this we initially identified two taxonomic domains (*animal* and *plant kingdoms*) and two non-taxonomic domains (*electricity* and *astronomy*). Science terms relating to these domains were extracted from children's science texts such as Nuffield Primary Science and more advanced texts such as A-level science texts. Three parts of speech were chosen (nouns, adjectives and verbs). Terms were further categorised according to their use in other domains – general (terms used in other domains, e.g., *satellite* can be used in both of the domains of space and television) and specific (terms used in one domain only, e.g., *migrate* is specific to the animal kingdom). Following a procedure developed by Dockrell et al. (2001), the novelty of the terms was ensured by a systematic process of identification whereby all words were of extremely low frequency in the Burroughs (1957) count of juvenile books, the general Thorndike and Lorge's (1944) word frequency count, and Francis and Kucera's (1982) word frequency count. Ambiguous terms were avoided, as were terms that label sub-ordinate categories, and terms were matched for syllable length (i.e., two or three syllables). Age of acquisition could not be used as a criterion since none of the words appear in current data sets (Francis & Kucera, 1982; Thorndike & Lorge, 1944).

In addition, other criteria relating to apparent conceptual complexity, appropriateness for narrative structure and relation to topics covered in the national curriculum were checked. The best fit for all criteria was achieved with lexical items from the domains of space and the animal kingdom which were therefore chosen for the study. The 16 target terms are shown in Table 1. These terms were piloted in exchanges with nursery age children at a University nursery. This confirmed that the terms were genuinely novel for the children and were appropriate for learning in a classroom context.

2.2.2. Videos

Four videos were constructed, one for each of the four combinations of domain (animal, space) and domain specificity (specific, general). Each video presented four novel words appropriate to that combination. Thus, one video presented four novel domain-general animal words, another presented domain-general space words, another domain-specific animal words, and a fourth domain-specific space words. The videos were constructed so as to retain comparability with similar educational video materials used in primary education and to be of a similar standard to programs the children might watch on television.

The videos were constructed using short segments from educational videos as well as from national broadcasts. The videos and the individual segments they contained were timed, resulting in each video lasting approximately 5 min. Voice-overs were designed to introduce each novel word in the soundtrack at the same time as a video image of its referent was presented (e.g., apogee was presented with a graphic showing the orbiting earth close to the sun). The voice-overs were scripted with particular care being paid to present implicit linguistic and pictorial contrasts to the target term in a format similar to those used in standard demonstrations of fast mapping. The introductions of the novel words immediately followed two identically scripted introductions involving familiar contrast words. The same structure and duration were adopted for all of the novel words. The scripts were recorded and the resulting videos produced in a University television and media services department. The videos were then subject to piloting with primary school children. This work demonstrated that the children found it easy to maintain interest and attention, that they found the videos highly enjoyable and that they could learn something of the novel words from these exposures.

2.3. Test materials

Three standardised measures were used:

(i) British Picture Vocabulary Scale (BPVS II; Dunn, Dunn, Whetton, & Burley, 1997): Children are shown four line drawings and asked to choose the one that best illustrates a word spoken by the assessor.
(ii) British Abilities Scales II (BAS II): Naming subtest (Elliot, Murray, & Pearson, 1997): Children are shown a series of familiar items and asked to name them.
(iii) Children's Test of non-word repetition (CnREP, Gathercole & Baddeley, 1997): Children are asked to repeat a maximum of 40 unfamiliar spoken items.

Comprehension and production tasks were partially computer-administered. Two students from London Guildhall University's Department of Art were paid to draw pictures corresponding to the video images for the novel words and for the familiar contrast words. Scanned versions of these images then formed the basis of the comprehension and production tasks.

Still images from the videos were also captured and printed, and these formed the basis of a further comprehension task.

2.4. Procedure

Children within each age group were randomly assigned to one of four groups: domain-general animal, domain-general space, domain-specific animal and domain-specific space. These groups were balanced for gender.

Table 1
The 16 novel words selected

	Domain			
	Animal		Space	
	General	Specific	General	Specific
Non-observable noun	Phylum	Hominid	Googol	Apogee
Observable noun	Parasite	Mollusc	Satellite	Tektite
Adjective	Camouflaged	Ratite	Galactic	Lunar
Verb	Reproduce	Migrate	Gravitate	Precess

Children were assessed individually over four sessions. Within 4–8 weeks of an initial pretest (Time 0, T_0), children were shown one of the four videos and then immediately tested for their comprehension and production of the novel terms (Time 1, T_1). Subsequent to this main-test, children were tested again after 8–12 weeks (Time 2, T_2) and again after a further 16–24 weeks (Time 3, T_3).

2.4.1. Pretest (T_0)

The initial pretest allowed a baseline assessment of each child's vocabulary and language skills. They were tested using the British Picture Vocabulary Scale II, the British Ability Scales II (naming vocabulary), the CnRep (non-word repetition), a draw and write task, and a picture comprehension task.

In the draw and write task, children are told a story and asked to draw and write answers to questions derived from the story. Children were asked to draw a picture of animals and the things that animals do or a picture of space to determine their knowledge of the domains prior to receiving information from the video presentation. Children were asked to label their drawings or tell the experimenter what they had drawn so she could provide labels. Most children spent 2 or 3 min drawing their pictures – there was no time limit. Pilot data had established that all of the new terms were unfamiliar to the children.

The final task in the pretest was a comprehension task involving pictures of referents of the familiar contrast words – words from the same domain that were used as contrast items in the videos. Children were required to point to the target picture from a choice of four. This task established that the children's exposure to the new term occurred within a context of other known words.

2.4.2. Acquisition of new terms (T_1)

Children were first introduced to the novel scientific words via presentation of one of the four videos. Children's production and comprehension of the new terms were assessed immediately following the video presentation (T_1). For the production task, each child was presented with each of the four artist-drawn images corresponding to the novel words introduced in the video. Children were instructed to tell the experimenter what they thought each picture was or represented. Two practice items preceded these. The comprehension task followed. Each child was presented in turn with the same artist-drawn images, each being accompanied by three distracter images. Distracter images were of the following types: image illustrating the same concept within a different domain, a different concept within the same domain, and an irrelevant image from the video. In the case of hominid, the target was a picture of a hominid and the foils were pictures of an early car (similar concept, different domain), an ostrich (different concept, similar domain), and a cliff (irrelevant image shown in the video). The child was instructed to point to which of the four images was named by the novel word. Each child was also given production and comprehension tasks for the novel words presented in another of the four videos, so that each acted as a control for another video group. The domain-general space group acted as controls for the domain-general animal group (and vice versa), and the domain-specific space group acted as controls for the domain-specific animal group (and vice versa). For the above production and comprehension tasks, responses were recorded by the experimenter entering an appropriate key press on the computer (e.g., correct, incorrect or do not know); 'response latencies' (i.e., onset of image to experimenter's key press) were also recorded. Finally, the comprehension tasks were followed by a draw and write task in which children were asked to produce drawings of what they had seen in the video. They were also prompted to provide labels to each element in their drawing, the experimenter producing written labels from the children's oral descriptions of their own drawings. Thus, the task was intended to tap the children's domain knowledge in ways that might reveal learning.

2.4.3. Post-tests (T_2 and T_3)

Between 8 and 12 weeks after the main test, these tests were repeated (T_2). After a further 16–24 weeks, these tests were repeated once more (T_3).

3. Results

3.1. Domain knowledge

Analysis of the pretest data indicated that at T_0 children demonstrated accurate comprehension for the majority of the familiar contrast terms presented in the videos. Mean correct comprehension for these words was 7 out of 8

(SD = 1.3) for the older children and 6.3 out of 8 (SD = 1.5) for the younger children. Pretest performance on the draw and write task provided further evidence that these were established domains for the children. All children were able to produce and describe at least one appropriate item in the draw and write task with the mean being 2.98 items (SD = 1.6, range 1–10).

We considered whether exposures to the videos had increased the children's knowledge about the relevant domain by examining their drawings at T_0, prior to exposure to the video, and at T_1, subsequent to the video exposure. A 2 time (T_0 vs. T_1) × 2 word type (domain-general vs. -specific) × 2 age group (younger vs. older) analysis of variance for elements in the drawing yielded a main effect of time, $F(1,210) = 27.94$, $p < 0.0005$, $\eta p^2 = 0.12$) and a main effect of age, $F(1,210) = 19.68$, $p = 0.037$, $\eta p^2 = 0.09$) but no effect of word type nor an interaction between age and word type, $F(1,210) = 6.99$, *ns*). Children performed significantly better at T_1, after the video, than at T_0 (T_0 $M = 2.98$; T_1 $M = 3.83$) and older children produced more drawing elements than younger children (Younger $M = 2.92$; Older $M = 3.89$). To confirm that this increase over time was related to the intervention, we contrasted the number of elements drawn at the main test (T_1) with those drawn at the subsequent testing point (T_2) with a repeated measures T-test. No effect of time was evident between T_1 and the subsequent testing point, T_2 ($T = -1.23$, $df = 192$, *ns*). The videos increased children's knowledge about the relevant domains. We next consider whether this intervention supported lexical learning.

3.2. Patterns of lexical acquisition

Two hundred and thirty-three children provided response data at T_1 on the comprehension and production tasks. Evidence of successful learning at T_1 for the new items varied statistically significantly across the assessment measures, $F(1,231) = 698.89$, $p < 0.001$, $\eta p^2 = 0.75$. On the production task, children produced a mean of 0.12 items (SD = 0.32) while evidence of comprehension was higher with children showing evidence of comprehending a mean of 2.63 items (SD = 1.5). Older children were more successful on the comprehension task and on the production task than the younger children; Comprehension, $F(1,232) = 5.52$, $p = 0.02$, $\eta p^2 = 0.02$: Older $M = 2.9$; Younger $M = 2.4$; Production, $F(1,232) = 20.49$, $p < 0.001$, $\eta p^2 = 0.08$: Older $M = 0.22$; Younger $M = 0.03$.

To examine change over time, the data from the 123 children who completed all assessments across the baseline and three testing points were analysed. These data are presented in Table 2. We completed two separate ANCOVAs, one for comprehension and one for production. In both cases, we controlled for pre-intervention knowledge by entering pretest draw and write as a covariate and for domain-specific vocabulary knowledge by entering familiar contrast terms known as a covariate. Results for comprehension and production are presented in Table 2. A repeated measures ANCOVA examining change in comprehension over time for the two age groups revealed no significant effect of time $F(1,119) = 000$, $p = ns$, but a significant effect of age, $F(1,119) = 12.823$, $p < 0.0005$, $\eta p^2 = 0.01$ with a significant interaction between age and time, $F(1,119) = 4.902$, $p = 0.03$, $\eta p^2 = 0.04$. There were no interactions with either the pretest draw and write $F(1,119) = 016$, $p = ns$ or domain vocabulary knowledge $F(1,119) = 026$, $p = ns$. The interaction between age and comprehension over time revealed that the younger children's performance did not vary statistically significantly across the tests points while the older children's performance improved statistically significantly across test times.

Analyses of the production data revealed a similar pattern. There was no effect of time of testing, $F(1,119) = 0.061$, *ns*, but there was a significant difference between the two age groups, $F(1,119) = 30.01$, $p < 0.0005$, $\eta p^2 = 0.20$ with a significant interaction between age and time, $F(1,119) = 18.015$, $p < 0.0005$, $\eta p = 0.13$. There were no interactions

Table 2
Mean accurate performance for comprehension and production items across the three assessment points (max = 4)

	Time 1		Time 2		Time 3	
	M	SD	*M*	SD	*M*	SD
Production						
Total $N = 123$	0.12	0.32	0.16	0.53	0.32	0.60
Older $N = 50$	0.24	0.43	0.38	0.78	0.66	0.77
Younger $N = 73$	0.04	0.20	0.01	0.12	0.08	0.28
Comprehension						
Total $N = 123$	2.74	1.5	2.63	1.49	2.8	1.68
Older $N = 50$	2.92	1.55	3.14	1.59	3.2	1.72
Younger $N = 73$	2.62	1.49	2.29	1.32	2.37	1.56

with either the pretest draw and write, $F(1,119) = 1.079$, $p = ns$, or domain vocabulary knowledge, $F(1,119) = 0.264$, $p = ns$. The interaction between age and production over time revealed that the younger children's performance did not vary statistically significantly across the tests points while the older children's performance improved statistically significantly across test times.

We considered children's speed of response for both correct naming and correct comprehension. Latencies to respond are presented in Table 3. There were insufficient data points to analyse speed over time for naming, though the trend was for responses to get faster over time. For comprehension there were significant effects of time of testing, $F(1,133) = 58.25$, $p < 0.001$, $\eta p^2 = 0.31$, and age $F(1,133) = 19.50$, $p < 0.001$ but no interaction between them. Children became statistically significantly faster ($p < 0.05$ LSD) over time and older children were slower than younger children.

From the first test point, children reveal some knowledge of the new terms through their success in the comprehension test; production of the new term, on the other hand, is rare. Knowledge is consolidated over time for the older children as evidenced by both the accuracy in production and accuracy in comprehension. Neither pretest domain items known nor pretest draw and write results influenced differences between groups or over time. The subsequent analyses consider the factors that impact on the child's ability to establish an initial representation of the lexical item.

3.3. Relationships between vocabulary, phonological memory, domain-specific knowledge and lexical acquisition at T_1

We examined the relationships between measures of expressive and receptive vocabulary, phonological memory, indicators of prior domain-specific knowledge (pretest familiar contrast words known, and draw and write) and children's lexical acquisition measured by their T_1 acquisition scores on the new items. Zero order correlations showed that production (naming) at T_1 was significantly related to pretest measures of receptive and expressive vocabulary and phonological memory but not to pretest indicators of domain-specific knowledge. It was also related to comprehension at T_1 and domain-specific knowledge at T_1 (as measured by draw and write). Pretest expressive and receptive vocabulary, and domain-specific knowledge of the familiar contrast terms, were also significantly associated with the comprehension measure, but pretest draw and write and phonological memory were not (Table 4).

The production and comprehension data were analysed by hierarchical multiple regression. We predicted that production at T_1 would be influenced by age, expressive vocabulary, phonology and receptive vocabulary sequentially. We entered each as regressors. A significant model emerged including only age and expressive vocabulary as significant, $F(2,232) = 11.114$, $p < 0.0005$, $R^2_{adj} = 0.09$; age $t_{232} = 2.75$, $p = 0.006$, Expressive vocabulary $t_{232} = 1.95$, $p = 0.05$). Entering receptive vocabulary and phonological memory did not improve the fit of the model. A parallel analysis was carried out for comprehension. In this case, we predicted that in addition to age and vocabulary knowledge, semantic domain knowledge evidenced by the draw and write score would contribute to comprehension at T_1. A significant model emerged including only receptive vocabulary as significant, $F(2,232) = 5.877$, $p = 0.003$, $R^2_{adj} = 0.003$; age $t_{232} = 0.05$, $p = ns$, receptive vocabulary $t_{232} = 1.96$ $p = 0.05$). Entering either pretest or Time 1, draw and write did not improve the fit of the model.

In sum, in line with our predictions acquisition of naming was supported by the child's established expressive vocabulary, and comprehension was supported by the child's established receptive vocabulary. In contrast to predictions, phonological memory did not significantly contribute to naming, and knowledge assessed by the draw and write task did not significantly contribute to comprehension. In the subsequent sections, we consider the role of lexical factors in the children's construction of initial mappings.

Table 3
Mean reaction times (s) for successful comprehension and production items across the three assessment points

	Time 1	Time 2	Time 3
Production			
Mean	3.6	3.5	3.3
SD	1.6	1.3	1.3
N	24	19	30
Comprehension			
Mean	4.5	3.9	3.4
SD	1.8	1.6	1.2
N	220	172	153

Table 4
Zero order correlations between experimental measures and standardised tests of expressive and receptive vocabulary and phonological memory

	Age in months	Time 1 production	Time 1 comprehension	Time 1 draw and write	Pretest domain vocabulary	Pretest draw and write	Expressive vocabulary	Receptive vocabulary
Time 1 production	0.28**							
Time 1 comprehension	0.18**	0.25**						
Time 1 draw and write	0.37**	0.17*	0.10					
Pretest domain vocabulary	0.25**	−0.01	0.17*	0.08				
Pretest draw and write	0.20**	0.02	−0.01	0.36**	0.002			
Expressive vocabulary	0.54**	0.27**	0.14*	0.42**	0.23 **	0.30**		
Receptive vocabulary	0.72**	0.29**	0.22**	0.41**	0.40**	0.28**	0.72**	
Phonological memory	0.40**	0.15*	0.08	0.23**	0.18*	0.21**	0.44**	0.46**

**0.01, *0.05.

3.4. Word class effects

Table 5 presents children's differential success rates for the nouns, adjectives and verbs in comprehension and production. As the data were skewed, non-parametric analyses were computed. A Friedman test revealed that production differed significantly across word classes ($X^2 = 29.29$, $df = 2$, $p < 0.0005$). Children produced significantly more correct naming responses to nouns than verbs ($Z = -4.83$, $p < 0.0001$) and adjectives ($Z = -2.179$, $p = 0.03$). Adjectives were also produced correctly more often than verbs ($Z = -2.000$, $p = 0.046$). Comprehension data provided a different pattern of results. A Friedman test revealed that comprehension differed significantly across word classes ($X^2 = 14.771$, $df = 2$, $p = 0.001$). Children gave significantly more correct comprehension responses to nouns than verbs ($Z = -3.36$, $p = 0.001$) but not adjectives ($Z = -0.153$, $p = ns$). Responses to adjectives were also significantly more accurate that those to verbs ($Z = -2.56$, $p = 0.01$).

3.5. General versus specific (word type)

Children's naming and comprehension responses to the domain-general and domain-specific items were considered. These data are presented in Table 6. A 2 word type (domain-general vs. -specific) × 2 age group (younger vs. older) analysis of variance for comprehension yielded a main effect of word type, $F(1,232) = 4.41$, $p = 0.037$ $\eta p^2 = 0.019$, and a main effect of age group, $F(1,232) = 4.98$, $p = 0.037$ $\eta p^2 = 0.027$, but no interaction between age group and word type, $F(1,232) = 2.48$, ns). Children were more successful with domain-general terms (General $M = 2.86$; Specific $M = 2.45$) and older children were more successful than younger children (Older $M = 2.87$; Younger $M = 2.43$). No child produced a domain-specific term and younger children produced significantly fewer domain-general terms than older children (Older $M = 0.059$; Younger $M = 0.40$). An analysis of latency for correct comprehension indicated that children were significantly slower at correctly responding to domain-specific items than to domain-general items, $F(1,219) = 15.30$, $p < 0.001$, $\eta p^2 = 0.066$: General $M = 4.2$ s; Specific $M = 5.1$ s).

4. Discussion

We evaluated the word learning skills of a large group of elementary school children in the context of their developing representations of two science domains − animals and space. The children had strong phonological memory skills complemented by good vocabulary skills. They came to the task with existing lexical and conceptual knowledge of these domains, as evidenced by their knowledge of the familiar, contrast terms and by their performance in the draw

Table 5
Production and comprehension by word class

$N = 233$	Production		Comprehension	
	Mean	SD	Mean	SD
Noun	0.045	0.14	0.74	0.48
Adjective	0.017	0.13	0.74	0.68
Verb	−	−	0.58	0.66

Table 6
Correct responses for production and comprehension for general and specific terms

		Time 1		Time 2		Time 3	
		Production	Comprehension	Production	Comprehension	Production	Comprehension
General	*M*	0.21	2.8	0.28	2.7	0.46	3
	SD	0.43	1.4	0.66	1.5	0.69	1.7
Specific	*M*	0	2.6	0	2.4	0.013	2.6
	SD		1.5		1.8	0.11	1.6

and write task at pretest. The exposures to the videos that the children then experienced resulted in increased conceptual knowledge about the domain (again, assessed by a draw and write task) indicating that short engaging exposures support acquisition of domain knowledge. However, the impact on lexical learning was less clear. In contrast to the quick and efficient word learning reported for preschool children, the children in this study provided equivocal evidence of acquiring the new terms. When successful production was used as a criterion of acquisition there was little evidence of learning for the younger children, with few correct productions of the new words. For the older children, performance improved over time but levels of successful naming were still low. In contrast, success on the comprehension task was higher with the older children providing evidence of consolidation of lexical knowledge over time with decreases in latency to respond and improved success rates. However, again younger children were less successful and showed no changes overtime. When children acquired some information about the new term this knowledge was retained over the approximately 9 months of the study, and this supported quicker comprehension at subsequent test points. Performance also varied across word type. Performance with verbs was significantly poorer than adjectives for both comprehension and production and domain-specific terms were learnt less well and responded to more slowly.

Although a number of measures correlate with successful production and comprehension, regression analyses show that only age and pretest expressive vocabulary help to explain the production data, and just receptive vocabulary the comprehension data.

These findings raise a number of issues concerning word learning.

4.1. The development of lexical representations

The experimental literature on the early word learning of young children suggests that when children encounter novel words in highly restricted contexts, words are learnt rapidly, with little effort and after very limited exposure. Typically, learning is measured by forced choice comprehension tasks at a single point in time. This study employed an ecologically valid word learning context, one more appropriate to an educational setting and as we have shown comprehension measures provided some evidence of learning but there is little change over time in the children's performance. However, when we also consider the production data and the other measures we employed there is evidence that word learning in general is best conceived as being more elaborate, extended and incremental (see Nelson, 1996).

In the production task, older children's performance improved over time, suggesting that exposure to the novel words was sufficient to create an initial semantic representation that could support further learning. The strength of these representations, or access to them, improved over time, as evidenced by the decrease in children's production and comprehension response times between T_1 and T_3. The response times imply changes at a representational level not signalled by success in the task.

These results corroborate research that emphasises the importance of both the integration over time with existing knowledge and the refinement of phonological representations. Moreover, the additional exposures to the term in the comprehension contexts and in subsequent testing provided an opportunity for an extended period of refinement of the term's phonological features and meaning. Indeed, Mervis (1987) has pointed out that the ways in which children's knowledge evolves depends crucially on the way information is subsequently provided. Information that is consistent with initial inferences will serve to support mapping whereas apparently inconsistent information may serve to alter mappings (Dockrell & Campbell, 1986; Jaswal & Markman, 2003). Further work should consider the ways in which mappings change as a result of different forms of exposure (see also Best et al., 2006). Such data would have important implications for teaching and learning.

Discrepancies between comprehension and production also suggest further dimensions to word learning. Where there is potential disagreement over naming, as in the case of verbs (D'Amico et al., 2002), children may be able to solve a comprehension task – picking out the appropriate action from a set of four pictures, for example – but fail when given a single picture in a production task because of uncertainty over which is the most appropriate name. In this study, nouns were named better than adjectives, though success on the comprehension measure did not differ. This implies that adjective production may suffer because of uncertainty over the appropriate dimension referred to and by corollary the target lexical item. No similar argument can be extended to explain the poor performance for verbs since both production and comprehension were compromised. Thus, while word learning for nouns may rely on establishing an appropriate semantic representation, word learning for adjectives may have additional pragmatic dimensions as well as requiring children to learn which of a number of possible names is the most appropriate to use in particular situations.

4.2. Influences on developing lexical representations

We examined the extent to which previous knowledge, word class and domain specificity impacted on children's patterns of acquisition. As evidenced by the production task, age and prior expressive vocabulary predicted word learning, though these variables contributed relatively little explanatory power. In contrast word learning as evidenced by the comprehension task was predicted only by prior receptive vocabulary, though again this explained relatively little of the variance. Nevertheless, these data confirm the importance of prior vocabulary knowledge, and imply that learning words requires integration of new words into an existing lexical and conceptual framework. An exploration of the extent of the integration required, and hence the size of the influence of the child's existing lexical and conceptual capabilities, would be an important avenue for future research. That age helps explain production and not comprehension reinforces the view that these measures may tap different aspects of the word learning process.

Phonological memory played no significant role in these results, despite appearing influential in experimental studies of early word learning. Two possible complementary interpretations need to be addressed. The current cohort as a group demonstrated high levels of phonological competence as evidenced by their mean scores on the non-word repetition measure. Thus there may be a ceiling effect for the role of phonological competence. Alternatively, the demands of the other lexical factors in educational contexts (e.g., pragmatic, conceptual, semantic and syntactic) may reduce the influence of phonological memory. Indeed, this appears consistent with Michas and Henry's (1994) observation that phonological memory appears to play no role in incidental word learning.

The syntactic properties of the words had a substantial effect on learning. As we have shown our prediction that children would be more efficient at identifying the intended mapping for object names, than for actions and attributes was supported. Semantic properties of the words also appear to have had a marked effect on word learning. Children were more successful in learning domain-general rather than domain-specific words. These results appear to contrast with studies of younger children where labels can facilitate classification (Balaban & Waxman, 1997) and the child's theories can serve to guide the child's focus of attention. Even when theories are limited and naïve (Carey, 1995), they provide guidance in establishing reference. Much of this knowledge appears to be at a basic level and often impoverished in detail as a result of lack of experience (Medin, Ross, Atran, Burnett, & Blok, 2002; Ross, Medin, Coley, & Atran, 2003). However, it may be that domain-general terms can be easier to learn precisely because they are less theory-embedded. To make sense of a domain-specific term, it must be integrated into a moderately rich existing conceptual structure (Diesendruck, 2003). For example, if a child is not aware that there is a specific category of flightless birds, of which a penguin is one, in learning the word 'ratite' the child has no conceptual framework to constrain the denotation of the term. Our results suggest that without reasonably rich theories, even partial word meanings for domain-specific terms are hard to establish. In contrast, because domain-general words are less theory-embedded they are less reliant on previous knowledge and pre-established conceptual structures. This interpretation is further supported by the reduction in successful comprehension response times from T_1 to T_3 for domain-general terms. Children appear to have established an initial, partial word meaning which then forms the base for subsequent learning.

4.3. Word learning in educational contexts

In contrast to the difficulties with word learning as measured by the formal word learning tasks, our observations of the draw and write task indicated that children's attention was engaged and they were developing their knowledge about the relevant domains. Moreover, during some of these drawing activities the children sometimes used the novel words to refer to elements of their pictures, e.g., a 'tektite' or 'precessing'. Thus children were clearly acquiring information from the video but typically knowledge was not sufficient to be revealed by the naming or comprehension task. These results contrast markedly with the high levels of learning reported in experimental contexts, evaluating both direct and indirect word learning in preschool children (Jaswal & Markman, 2003).

The limited lexical learning in the current study is similar to patterns of acquisition found when children are reading texts. Nagy, Herman and Anderson (cited in Beck & McKeown, 1991) calculated that the probability of learning a word from a single contextual encounter was between 0.05 and 0.11 depending on the criterion used. The children in this study performed in an analogous fashion; they demonstrate small amounts of learning and this effect is related to the learning criterion used (comprehension, production or latency). In studies examining vocabulary acquisition from books new vocabulary is interspersed among many words that are known and, typically, the gist of the text can be gained without focussing directly on the 'novel' term. Similarly in the video presentations children encountered the new terms as part of a voice over for the video and the focus of the task, unlike fast mapping studies, was not predetermined by the words used. In addition, the cognitive demands of processing the video and the language may challenge the developing cognitive system. The fact that older children with better language skills acquired relatively more words would support this view (see also Stahl & Erickson, 1986). Thus part of the difficulties in acquisition in the current task may reflect the information processing demands of the tasks and the lack of salience of the new term within the video (see Best et al., 2006, for a discussion of the importance of the nature of the exposure in acquiring science vocabulary).

One interpretation of these results is that later lexical acquisition, in school age children, may involve subtly different processes to those revealed by the word learning of preschool children. The speed and efficiency of early acquisition appears to be governed by the detailed perceptual representations available for words, typically object names. Morrison, Chappell, and Ellis (1997) observed that young children learn most about objects that they experience directly in their environment. Here perceptual knowledge supports naming. However, for terms acquired later children's lexical representations appear to be more conceptually based (Funnell, Hughes, & Woodcock, 2006; Hughes, Woodcock, & Funnell, 2005). In such contexts the fast mapping strategies that have been so effective earlier on may not be sufficient to support learning.

An alternative interpretation, however, might emphasise the difference in context between these early word learning episodes and those encountered in school. In early word learning, novel words are typically explicitly matched to their intended referents – so long as the context is explicit enough, the child can rely on simple constraints to identify the intended mapping and the only variables that might impede this would be inherent to the child (such as phonological memory) or the word (such as word class). In school age educational contexts, however, the match between novel words and their referents cannot always be explicitly provided, especially so where the terms are more conceptually complex. In these cases, the child cannot rely on simple constraints to identify the intended mapping – instead they are reliant on partial cues to meaning, derived from pragmatic, semantic, syntactic and conceptual factors which, even in combination, may not point to a unique solution. It is not so much that word learning processes have changed, but the child is in a position where the approach that led to early word learning successes no longer provides a solution.

5. Conclusions

The current study extends our understanding of vocabulary acquisition by considering science terms across different measures of knowledge and performance. There is evidence that for such terms vocabulary acquisition is both hesitant and often limited. Acquisition is limited when schemas (Nagy, Anderson, & Herman, 1987) are not present and words are not concrete. In such situations even the establishment of 'fast mappings' is problematic. The results attest to the complexity of the vocabulary acquisition process (Aitchison, 1994, p. 170) and indicate that our understanding of the process of later vocabulary acquisition requires further attention. The research focus will need to consider the ways in which conceptual structures can work as scaffolds to support or inhibit lexical learning. Given the strong relationships between vocabulary and attainment, such studies will have important pedagogical implications.

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Appendix

Videotaped script 1

There are lots of exciting things in the world.
There are animals, plants, rivers, stars and people.
Today you are going to learn some things about animals.

There are many different types of animal.
Animals belong to different kinds of group.
These are insects.
These are birds.
This is a phylym.
As you can see, there are different ways of sorting animals into groups.

Animals eat many different things.
Some animals eat plants and some eat other animals.
This animal eats grass.
This animal eats other animals.
This is a parasite.
So, animals get their food in different ways.

Many smaller animals get eaten by larger animals.
Smaller animals try to avoid being eaten.
This animal lives under-ground.
This animal comes out at night.
This is a camouflaged animal.
As you can see animals have different ways of looking after themselves.

Animals do lots of different things.
In many of the things animals do, they are like people.
They eat.
They breathe.
They reproduce.
So, animals do a number of things as part of their everyday life.

That's all we have time for today.
We hope you liked the video.
Goodbye for now.

Videotaped script 2

There are lots of exciting things in the world.
There are animals, plants, rivers, stars and people.
Today you are going to learn some things about animals.

Very slowly, over millions of years animals change in size and shape.
Here is how animals looked a very long time ago.
This is an elephant.
This is a horse.
These are hominids.
As you can see some animals looked very different in the past.

There are also many different types of animal.
They belong to different groups.
These are insects.
These are birds.
These are molluscs.
So, animals can be put into different sort of groups.

All living things move.
Some animals walk, some swim and some fly.
This is a swimming animal.
This is a flying animal.

This is a ratite animal.
As you can see animals move around in different ways.

Animals move for different reasons.
Sometimes they travel for short distances and sometimes they travel for very long distances.
They find food.
They play.
They migrate.
So, animals move around in different ways as part of their everyday life.

That's all we have time for today.
We hope you liked the video.
Goodbye for now.

Videotaped script 3

There are lots of exciting things in the world.
There are animals, plants, rivers, stars and people.
Today you are going to learn some things about space.

If you look at the sky on a clear night you will see lots of stars.
People have tried to count the number of stars but there are too many.
Some say there are a thousand.
Some say there are a million.
Some say there are a googol.
As you can see there are many stars in the sky.

There are lots of things in space we know very little about.
Many things have been sent up into space to help us find out more.
This is a rocket.
This is a spaceship.
This is a satellite.
So, there are a number of things that have gone into space.

A few people have visited space and have gone to the moon.
One day if might be possible for people to travel much further away.
This is hundreds of miles.
This is distance between planets.
This is a galactic distance.
As you can see space is a very big place.

If you look at the stars you will see that some are close together and others are not.
Some stars seem to move.
These stars look still.
These stars move away from each other.
These stars gravitate.
So, stars move in different ways.

That's all we have time for today.
We hope you liked the video.
Goodbye for now.

Videotaped script 4

There are lots of exciting things in the world.
There are animals, plants, rivers, stars and people.
Today you are going to learn some things about space.

The moon travels around the earth.
At all times it is a long way from the earth, but sometimes it is closer to the earth and sometimes it is further away.
This is the moon at its closest point.
This is the moon further away.
This is the moon at its apogee.
As you can see the moon isn't always at the same distance from the earth.

Sometimes things from space land on the earth.
They are often similar to things found on the earth.
This is a rock.
This is a pebble.
This is a tektite.
So, things from space land on the earth and often look like things from earth.

Sometimes the earth and moon are covered by a shadow.
They are similar to shadows made by trees on a sunny day.
This is a shadow made by the sun.
This is a shadow on the earth.
This is a lunar shadow.
So, shadows cover many things.

The earth travels round the sun.
As it travels it moves in different ways.
This is the earth spinning.
This is the earth leaning over to one side.
This is the earth precessing.
As you can see the earth moves in different ways as it travels round the sun.

That's all we have time for today.
We hope you liked the video.
Goodbye for now.

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