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Pals, Frits F. B.; Tolboom, Jos L. J.; Suhre, Cor J. M.; van Geert, Paul L. C.

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Memorisation methods in science education: tactics to improve the teaching and learning practice

Frits F. B. Pals^a, Jos L. J. Tolboom^b, Cor J. M. Suhre^a and Paul L. C. van Geert^a

^aFaculty of Behavioural and Social Sciences, University of Groningen, Groningen, Netherlands; ^bSLO, Netherlands Institute for Curriculum Development, Groningen, Netherlands

ABSTRACT

How can science teachers support students in developing an appropriate declarative knowledge base for solving problems? This article focuses on the question whether the development of students' memory of scientific propositions is better served by writing propositions down on paper or by making drawings of propositions either by silent or muttering rehearsal. By means of a memorisation experiment with eighth- and ninth-grade students, we answer this question. In this experiment, students received instruction to memorise nine science propositions and to reproduce them afterwards. To support memorisation students were randomly assigned either to a group that received instruction to write each proposition on paper or to a group that received instruction to make a drawing about the content of the proposition. In addition, half of the students in both groups received instruction to mutter and the other half of them received instruction to write or draw in silence. The main conclusion from the experiment is that after four weeks students who had made a drawing remembered significantly more propositions than those who had memorised the propositions by writing them down. Our research further revealed that it did not matter whether students muttered or memorised silently.

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Introduction

The main task of pre-university teachers is to aid students in developing a sound knowledge base. In science education, where students need to develop a thorough understanding of abstract concepts, the teachers' challenge is to illustrate things that cannot be seen by referring to concrete situations. Establishing links between concrete situations and abstract phenomena seems essential for students to be able to adequately represent relations between abstract concepts in symbols, formulae and graphs (Johnstone, 2000). Establishment of links between concrete situations and abstract concepts and recurrent priming seem also essential in developing students' ability to solve science problems. To give an example from chemistry education: students already know something about the process of burning (for instance, cooking potatoes without water). This prior knowledge could be the starting point for elucidating what happens in the process of heating (without

oxygen): sugar can turn among other things into carbon and tar (please see [Table 1](#), proposition 3). Teachers can connect daily-life experiences of students to school science practice and coach them by logical steps to gain insight into and to solve problems of the origin of oil.

As learning content about science topics is covered over longer periods, it is essential that teachers promote the development of strong linkages between knowledge of concrete situations and abstract concepts. To support students in their learning, science teachers need to be aware of memorisation methods that aid students in reproducing links between relevant core principles and situational knowledge in an effective manner (cf. De Jong & Ferguson-Hessler, 1996). Students' ability to recall such so-called declarative knowledge not only facilitates the understanding of new and related learning material. It may help to enhance students' capacity to analyse the nature of science problems (cf. Pol, Harskamp, Suhre & Goedhart, 2008).

Despite the fact that memorisation has been studied extensively in the past, little is known about the differential effectiveness of memorisation methods to scaffold learning in science and the rate at which subject content is forgotten.

In this article, we report on an investigation into memorisation methods science teachers could encourage students to use to establish firm links between concrete situational knowledge and abstract concepts. Our main interest lies in determining which tactics make such memorisation most effective. We specifically focus on two activities in the learning phase: drawing pictures or writing down propositions to frame what students need to learn and remember. We expect that making personal drawings about concepts and relations between certain concepts, as well as writing propositions that express these relations, help students to become aware about the conceptual relations. However, we expect that the use of drawings results in better memory and recall because of its appeal to mental imagery (Edens & Potter, 2003; Van Meter, 2001; Wammes, Meade & Fernandes 2016).

Besides writing down propositions or making drawings, teachers could also encourage students to mutter during memorisation. Research by MacLeod et al. (2010) shows that when students mutter while studying words, sentences and texts, their recall of textual content is better than when they read in silence. They suggest that when more modalities are involved in encoding information recall may benefit. Icht & Mama (2015) confirmed

Table 1. The nine propositions and the general concepts to which they refer.

Propositions to remember	Concept of the propositions
1. You put your hair in a ponytail with an elastic band	Safety instructions in practical chemistry and physics related to the hair
2. With your pencil, you draw a figure	Use of visual aids in making chemical and physical lab setups and an example of carbon layers in graphite when drawing with a pencil
3. You heat sugar in a test tube	A chemical reaction (decomposition) during a practicum
4. Your pen drops. Now it has a scratch	Falling bodies in mechanics and the relation with (potential – and) kinetic energy
5. The Aldel plant produces aluminium	Part of a process line (inorganic) raw material to finished product
6. After one day in the sun, your skin is tanned	Example of a chemical reaction under the influence of light
7. The laundry is hanging to dry	Evaporation process of a liquid (water)
8. You make wine from grape juice	Part of a process line (organic) from a raw material to a finished product
9. You use vinegar to remove the calcium deposits in the coffee maker	Practical application of a chemical (acid-base) reaction

the findings of Macleod, when they tested preschoolers in controlled testing conditions. Although the conditions of the present experiment differs from the research by MacLeod et al. (2010) and Icht & Mama (2015), the similarity is to investigate memorization results by applying several encoding processes in conjunction with silence or while talking.

Practical and theoretical considerations

Practical considerations

In secondary education, learning typically is a shared responsibility of teachers and students. Teachers usually commence their lessons by framing sections and clarifying of subject matter from the students' textbooks. Teachers are accustomed to verbally comment on a topic, sometimes using visual aids to support students' understanding.

Subsequently, they have students make assignments, either as seatwork or as homework (TALIS-report, 2009, pp. 99–100). Such a way of teaching works well if students apply effective memorisation methods and show discipline in using them. Otherwise, the continuous flow of information contained in daily instruction can easily overwhelm students and diminish their motivation to pay attention (Martin, 2015; Mayer, 2014a). To facilitate students' ability to memorise core subject matter content, it is crucial for teachers to indicate how this content relates to students' prior knowledge and induct them in the use of memorisation methods that take into account limitations and affordances of their working memory (Allen, Baddeley, & Hitch, 2006).

In this study, we compare memorisation methods differing on two crucial activities: the mode of encoding information and the mode of rehearsal. In designing and investigating memorisation methods, we restrict ourselves to methods that comply with prevailing instructional practices. Feasible encoding tasks include having students rewrite propositions or making a drawing. By 'drawing', we mean that students form personal associations regarding the content and integrate these in a picture, thus allowing for the creation of a mental image (Van der Veen, 2012).

Theoretical considerations

According to Baddeley (2000), human working memory comprises four components: a central executive control system and three slave systems, consisting of a phonological loop, a visuospatial sketchpad and an episodic buffer. The episodic buffer integrates information from the phonological loop and the visual sketchpad with information already residing in long-term memory (Baddeley, 2000; Rudner & Rönnerberg, 2008). Research by Baddeley (2000) shows that the phonological loop and the visual sketchpad can be used relatively independently, allowing students to simultaneously complete two simple tasks that rely on information received from these two senses. The ability of students to simultaneously process phonological and visual spatial information seems a valid reason to investigate the effectiveness of a method that combines drawing a picture about science propositions and compare its effectiveness to writing in combination with verbal rehearsal. For science teachers to be able to support students' learning, it would be useful to know which memorisation methods they could teach students best, in line

with the theory of Baddeley (2000). Schnotz' integrated model of text and imagination (ITPC) uses this theory to provide a comprehensive view on the way alternative methods of encoding information may affect students' ability to recall information differently. The ITPC model has therefore the potential to guide us in the design of alternative memorisation methods and in explaining why these methods could lead to differences in short-term and long-term memory loss.

Among other things, Schnotz (2014) has contributed to the development on this body of knowledge of a comprehensive view on remembering information from text by constructing a model. His integrated model of text and picture comprehension (ITPC) assumes that the nature of memories differs depending on how information from pictures (or drawings) and written text is processed. The ITPC model is actually based on four components of empirical evidence about human information processing:

- Inclusion of information takes place via two separate sensory systems (Baddeley, 1986, 1999; Paivio, 1986);
- The capacity of the working memory is limited for each separate system (Baddeley, 1986, 1999; Chandler and Sweller, 1991);
- Meaningful learning results from activation of prior knowledge and integration of both propositional and visual information into one coherent mental representation (Mayer, 2001, 2014a, 2014b); Wittrock, 1989; Kosslyn, 1994);
- Pictures or drawings that align with students' knowledge base are beneficial for learning and memorisation.

According to a classical experiment by Peterson and Peterson (1959), still considered valid in cognitive science (Boyd, 2015; Cyr et al., 2017), content is most likely forgotten within a few seconds if it is not rehearsed. Moreover, it is necessary that the information is processed with attention (Oberauer and Bialkova, 2009). Baddeley and Hitch (1974) proposed the phonological loop is an active rehearsal mechanism as 'being responsible for temporary storage of speech-like information'. Allen, Baddeley and Hitch (2006) promote elaborative rehearsal of information to stimulate transfer of knowledge from working memory into long-term memory. Feasible rehearsal tasks in the classroom include repeating words or propositions silently or while muttering. By repeating words, while muttering, we mean that students talk inaudibly or softly hum while memorising.

There is increasing evidence that the use of drawings can support students' understanding of science and their learning (Wilson & Bradbury, 2016). Pictorial representations could help students in schematising subject matter elements as well as in reproducing them correctly (cf. Akaygun & Jones, 2014). The use of drawings as a memory tactic has been brought forward by other researchers in different ways, for example, through the concept mapping method (Novak & Canas, 2006) or other graphical methods (Katz, 2017; Pals, 2003). Kosslyn (1994) advocates the establishment of mental representations by letting students create drawings. Boers, Eykmans and Stengers (2006) concluded that students can benefit from memorising words when they can form a picture of that word. The present study continues on this track asking: if this is true for (single) words, would this also apply to propositions or text sections? Research by Presley, Cariligia-Bull, Deane, & Schneider (1987) seems to confirm the benefit of using imagination. They found that primary school students could remember propositions better when

they were asked to imagine, rather than when they memorised propositions in their own way. The importance of combining mental imagination with verbal memorisation to improve the retrieval of knowledge was initially proposed by Paivio (1986). This combination of verbal learning and visualisation is one of the basic principles of education. According to Kosslyn, Jolicoeur, & Gluck (1984), mental images of an event are held in the left hemisphere, while the coherence of the images of events is stored in the right hemisphere. In modern neurological research, the focus shifts to more specific places, the front, rear or centre of the brain, dependent on the type of information received. Dekker & Jolles (2016) suggest that ‘vocabulary learning’ activates the anterior lobes of the brain and ‘drawing pictures’ the rear. Yurgelun-Todd (2007) observed that adults more often use the anterior lobes of the brain than children to recognise and interpret words. We can interpret this as a psychological consequence of the fact that the frontal lobes are not yet (fully) developed in children (Dekker & Jolles, 2016; Yurgelun-Todd, 2007). In the current study, we assume that this still counts when children have developed into teenagers (Crone, 2012).

That teenagers focus more than adults, on recognising and interpreting images (Yurgelun-Todd, 2007), may have implications for education. In this study, we investigate the difference in effectiveness between having students write down propositions or having them to make drawings based on personal associations to propositions. The value of visualisation for learning is for instance examined by Bull and Wittrock (1973). They showed that imagination, by making visual representations, can help the memory. In exploring students’ drawings, Neumann and Hopf (2017) show links between students’ understanding of a specific concept and their personal experiences. Leutner and Schmeck (2014) state that if students are asked to depict the contents of a text, they are invited thereby to tap deeper layers in learning and understanding of the material. On the other hand, Dunlosky, Rawson, March, Nathan, and Willingham (2013) state with respect to the use of imagery that (p. 26):

Nevertheless, the benefits of imagery are largely constrained to imagery-friendly materials and to tests of memory, and further demonstrations of the effectiveness of the technique (across different criterion tests and educationally relevant retention intervals) are needed.

In this study, we address the call of Dunlosky et al. (2013) by also testing over a longer period of time, i.e. four weeks after memorisation. We are further interested in assessing whether there is an additional memory advantage when students mutter during memorisation. This is an interesting question as MacLeod et al. (2010) have reported that talking aloud may increase recall of words to be learned.

Research questions and hypotheses

1. Does drawing pictures about science propositions result in better memory recall of propositions than writing them down?

The second question pertains to the way students pay attention to the content of the propositions during the drawing or writing activities:

2. Does muttering during drawing or writing science propositions result in better memory recall than using inner silent speech?

On the basis of the above literature review, we formulated the following hypotheses:

Hypothesis 1. We expect drawing during memorisation to result in a better reproduction than when writing during memorisation.

Hypothesis 2. We expect muttering while memorisation to result in a better reproduction than when learning in silence.

Method

Materials

In this study, we examine students' ability to reproduce nine scientific propositions (Table 1) around certain phenomena in the fields of physics and chemistry. The propositions include safety prescriptions, cause-effect propositions and statements usable during (theory) classes or practicums. All propositions are briefly formulated and stated in active form and formulated in the Dutch language. The number of words ranges from 4–10 ($M = 6.78$; $SD = 2.04$). The average number of letters per word ranges from 2–18 ($M = 10.11$; $SD = 3.70$). There are two propositions consisting of 4 words (the shortest propositions), and there is one proposition consisting of 10 words (the longest proposition). The number of monosyllabic words is 40. The number of monosyllabic words per proposition ranges from one to nine ($M = 4.44$; $SD = 2.50$). The number of nouns per proposition ranges from two to three ($M = 2.22$; $SD = 0.42$).

Participants

We conducted the experiment in eight classes of the same school: four 9th-grade and four 10th-grade pre-university education classes. One hundred and fifty-seven students participated in this study, 92 girls and 65 boys. All students were between 13 and 15 years old (average 13.77 years, standard deviation 0.72). The school is located in a rural region in the Northern part of the Netherlands. The propositions are stated in Dutch, so where mentioned in the article, they are translations of the Dutch propositions.

Students from each of the eight classes were assigned to either a writing condition or a drawing condition, using a 'heads' or 'tails' throw. The resulting 16 groups were systematically assigned to either a 'muttering' condition or a silent condition. In total, there were 74 students in the 'writing' condition and 83 students in the 'drawing' condition. In total, 76 students learned in silence and 81 were instructed to mutter (without disturbing others). Students were informed that their performance on the reproduction test would be graded, but students' term score could only positively influence their term score.

Table 2. The two memorisation components distributed over four conditions.

Mode of rehearsing the propositions	Mode of encoding the propositions	
	Drawing	Writing
Silent	D1	D4
Talking	D2	D3

Design

The design is based on two essential components of memorisation methods. The first component is the mode of encoding and the second component refers to the mode of rehearsal. In this experiment, each component can take two values. In Table 2, we portray the four resulting conditions (2×2 design). Concerning *encoding*, we make a distinction between *drawing* and *writing*. Concerning *rehearsal*, we make a distinction between *silent rehearsal* and *rehearsal by talking or muttering*.

In this study, students in condition D4, writing and silent, constitute the control group. Students usually apply this method when memorising in class or in a library. The other conditions constitute experimental methods. Students in condition D2, the drawing and talking condition, were instructed to use a method that deviates strongly from their usual practice.

Measuring the memorisation effects

Three reproduction tests were conducted one immediately after the instruction and memorisation episode, a second one week later and a third four weeks after the initial instruction and memorisation episode.

Procedure

One week before the start of the experiment, students were informed that they were to participate in a memory test. At the start of the experiment, the researcher informed the students that their task was to study and memorise a list of nine propositions. The students were asked to reproduce as many propositions as they could on three occasions (five minutes, one week and four weeks after memorisation).

Depending on the condition, students received instruction to either draw a picture to summarise the content of each of the nine propositions or to write the propositions down on paper. All students were shown the same nine propositions. These propositions (included in PowerPoint) were projected on a classroom wall by means of a data projector. The proposition was read aloud twice by the researcher (or by a colleague when the researcher could not be present), and then the proposition was displayed for 45 seconds. We choose 45 seconds to facilitate ample opportunity to rehearse the propositions several times (Boyd, 2015). During the 45 seconds that each proposition was displayed, students either made a drawing or wrote the proposition down on a sheet provided by the experimenter. The time on task was the same in all conditions. The instruction to the drawing groups read:

The intention is you draw the most important parts of the sentence so that you can remember the sentence. You only have to draw and / or use strip symbols, you are not allowed to write words. The notes of a sentence you make have to support your memorization of the sentences. While drawing, do not speak with the teachers or pupils.

The instruction to the writing groups read: ‘The intention is you write the complete sentence so that you can remember the sentence. You only have to write and you are not allowed to make a drawing. While writing, do not speak with the teachers or pupils.’ The students were instructed to take full advantage of the available time for memorisation by repeating the content of the propositions silently or by muttering. Students were told that they would not be assessed on correct spelling or grammar. Students in the drawing condition were told that their drawing would not be part of any assessment. After the presentation, which lasted nine minutes, students returned their sheets to the researcher/supervisor. Then after five minutes, the researcher/supervisor asked the students to write down as many of the nine propositions as they could recall. Students had five minutes to write the propositions down on a new blank sheet of paper. All students were once again told that they would be asked to reproduce as many propositions as they could after one week and again three weeks after that. The reproduction tests were all conducted in the same manner. Students had to write down as many propositions as they could recall. The testing procedure (writing down) corresponds to the usual way students reproduce what they have learned in class. Of course, during the second and third assessment occasions, the PowerPoint presentation episode was not repeated.

Scoring procedure and outcome measures

After each test occasion, the numbers of correctly reproduced propositions were counted. The order of the reproduced propositions was allowed to deviate from the order during the initial presentation. Propositions were counted correct if all three components (subject, verb and a correct relation) were correctly reproduced. Only a ‘correctly reproduced proposition’ was awarded one point. Partially correctly reproduced propositions were awarded no point. As a result, students could receive a minimum score of no point and a maximum score of 9 points on each reproduction test.

To illustrate the scoring procedure we provide two examples:

- One of the propositions read: ‘You put your hair in a ponytail with an elastic band.’ One student replied: ‘With a rubber band you do your hair in a ponytail.’ That response contained tail, hair, and to do. Therefore, it was scored as correct recall (score 1 point).
- Another proposition was: ‘You heat sugar in a test tube.’ One of the students responded with: ‘note in a test tube starch’. Since this answer only contains the word ‘test tube’, the response was scored as incorrect recall.

Data analysis

We conducted a repeated measurement analysis of variance to examine the differences in reproduction scores between the four memorisation conditions on the three occasions. The four conditions were specified as a between-subjects factor and the three

measurements as a within-subjects factor. The writing group that received instruction to rehearse the propositions in silence was designated as control condition, since the learning method of this condition corresponds with the learning practice that is advocated by most teachers. The other three groups were designated as experimental conditions. Contrast analysis was used to assess the significance of the differences between the four conditions in reproduction scores and the decrease between the first and later test occasions.

Results

Table 3 summarises the descriptive statistics about student performance in the four conditions. Table 3 shows that there are clear differences between conditions in the reproduction scores.

A statistical tests of the differences between the conditions reveals that the four conditions differ significantly in mean reproduction scores on the three measurement occasions: $F(3,153) = 19.85$; $p < .01$, $\eta^2 = 0.16$. Notice in Table 3 that there is a large difference in the reproduction scores of the drawing groups and the writing groups during the three measurements. Students in the drawing groups have average reproduction scores near or above seven on all three measurements. Students in the writing groups have average reproduction scores near or above seven on the first measurement, but on the succeeding measurements, the average scores drop to average reproduction scores of less than six. Notice also that there is a large difference in the reproduction scores of the drawing groups and the writing groups, especially on the second and third measurement occasion. Students in the drawing groups reproduced on average about three propositions more than the students in the writing groups. On average these students have significantly higher reproduction scores than students in the writing groups ($T = 4.71$; $p < .01$).

This result allows us to *accept* hypothesis 1, which read: ‘We expect drawing during memorisation to result in a better reproduction than writing.’ We thus conclude that on average students in the drawing group achieve higher reproduction scores than students in the writing groups. Hypothesis 1 is thus confirmed. In the section ‘Drawing versus writing’ we will elaborate on this result.

Table 3. The results of the four different conditions in the three measurement points with the mean, the standard deviation and the number of each group.

Condition/Measurement	Mean	Std. deviation	<i>n</i>	
D1 drawing silently	Measurement 1	7.79	0.96	38
	Measurement 2	6.97	1.52	38
	Measurement 3	7.29	1.37	38
D2 drawing and talking	Measurement 1	7.47	1.27	45
	Measurement 2	7.18	1.75	45
	Measurement 3	7.20	1.80	45
D3 writing and talking	Measurement 1	6.89	1.62	36
	Measurement 2	5.17	1.84	36
	Measurement 3	5.33	1.96	36
D4 writing silently	Measurement 1	7.71	1.29	38
	Measurement 2	6.26	2.00	38
	Measurement 3	5.87	2.20	38
Total	Measurement 1	7.47	1.33	157
	Measurement 2	6.45	1.93	157
	Measurement 3	6.47	2.02	157

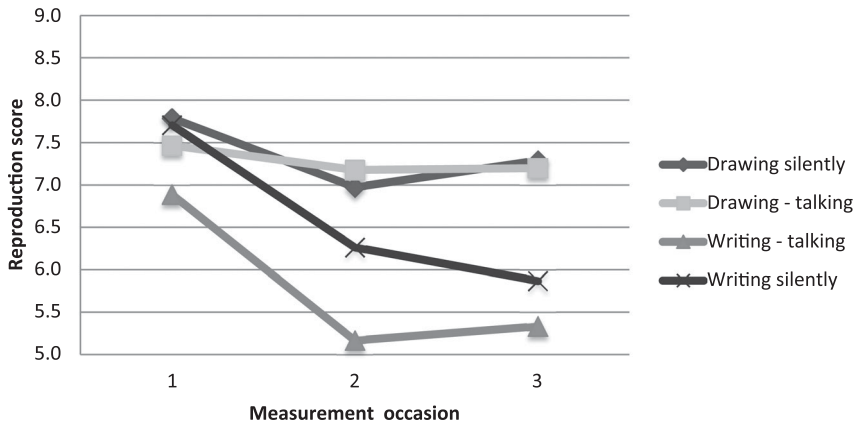


Figure 1. Average reproduction scores on three occasions in the four conditions.

The overall difference in reproduction scores between the three measurement occasions proves to be significant: $F(2, 152) = 36.11, p < .01, \eta_p^2 = 0.32$. **Figure 1** shows that the average number of reproduced propositions is fairly high in all four groups immediately after memorisation but rapidly decreases afterwards. The amount of the decrease differs between the four conditions: $F(6, 304) = 5.81; p < .01, \eta_p^2 = 0.10$. The presence of this interaction effect and the nature of the decrease was the reason for further investigation of the differences between conditions in memory performances on the measurement occasions.

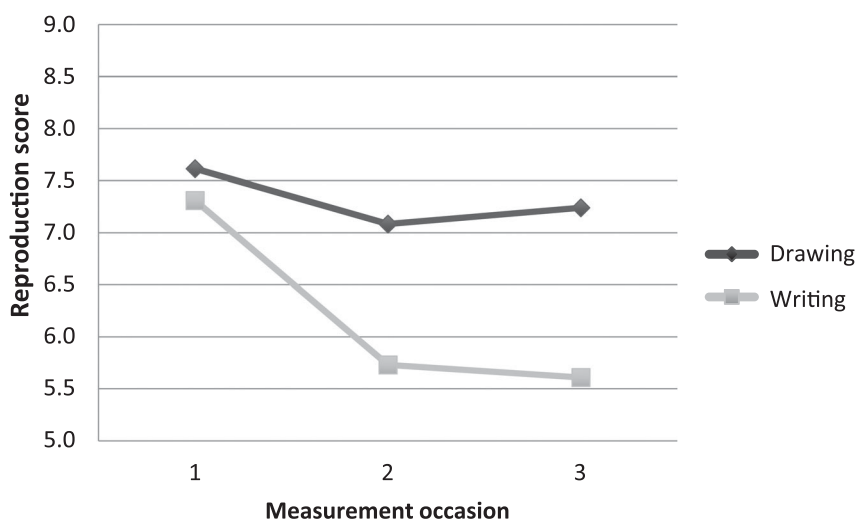
Looking in more detail at **Figure 1**, it becomes apparent that students in the writing group who received instruction to memorise while muttering (D3) achieved the lowest reproduction scores on all three occasions. **Figure 1** further shows that the students in the other writing group, the students who received instruction to memorise silently (D4), unexpectedly achieved somewhat higher reproductions scores. Both writing groups performed less well after the first measurement than students in both drawing conditions. **Figure 1** shows that the difference in the reproduction scores on the second and third occasion of measurement between the writing and drawing groups increased. In other words, in the long-term (between the first and the last measurement there are four weeks) students in the drawing group retain a higher reproduction level than the students in the writing group. **Figure 1** further shows that the differences between students in the drawing group who received instruction to memorise silently and those who receive instruction to talk during drawing are small.

Talking during memorisation versus silent memorisation

Figure 1 shows that in both writing groups the average reproduction score dropped sharply after the first measurement. Strikingly, the scores of students who received instruction to talk or mutter while writing (D3) are significantly lower on the first and second measurement than those of students who received instruction to write in silence ($T = -2.42; p = .018$ on the first measurement, $T = -2.45; p = .017$ on second measurement and $T = -1.11; p = .27$ on the third measurement). This allows us to *reject* hypothesis 2, which read: ‘We expect muttering while learning to result in a better reproduction than when learning in silence.’

Table 4. Group results of three measurements. The average, the standard deviation and the number of each group are noted in drawing – and writing condition.

Memorisation group	Measurement	Mean	Std. deviation	<i>n</i>
Drawing	Measurement 1	7.61	1.15	83
	Measurement 2	7.08	1.64	83
	Measurement 3	7.24	1.61	83
Writing	Measurement 1	7.31	1.51	74
	Measurement 2	5.73	1.99	74
	Measurement 3	5.61	2.09	74
Total	Measurement 1	7.47	1.33	157
	Measurement 2	6.45	1.93	157
	Measurement 3	6.47	2.02	157

**Figure 2.** The reproduction scores of nine propositions on three measurement occasions of the drawing and writing groups.

Drawing versus writing

Analysis of the measurement data reveals that there is a significant overall difference between the drawing and writing groups in the reproduction scores on the three measurement occasions: $F(1,156) = 3400.809$, $p < .01$, $\eta^2 = 0.120$. See Table 4 and Figure 2.

The drawing and writing groups differ sharply in the decrease regarding the reproduction scores after measurement occasion 1. This is shown in Figure 2. In the drawing groups, the observed decrease between the first and last measurement is only 0.37. The decrease in the writing groups is significantly larger: 1.70. This signifies that students in the drawing groups maintain a much higher reproduction level in the long term than the writing groups. The control group in this experimental study (writing propositions in combination with silent rehearsal) mirrors the usual learning practice. Students in this group did not achieve the lowest reproduction scores, but this group had significantly lower reproduction scores than both drawing groups on the second test occasion ($T = 2.22$, $p = .03$, Cohen's $d = 0.43$) and on the third test occasion ($T = 3.45$, $p = .001$, $d = 0.71$).

Discussion

In order to master science content, it is essential to develop a sound knowledge base to ground students' problem-solving. The major goal of this study was to investigate and evaluate the differential effectiveness of drawing and writing as memorisation tactics to improve students' memory of propositions relevant in the field of science. In addition, we aimed to assess the additional value of talking or muttering while performing both tactics.

The results of this study allow us to answer the following two hypotheses. Hypothesis 1 reads: we expect drawing during memorisation to result in a better reproduction than when writing during memorisation. This study provides evidence that confirms this hypothesis.

Hypothesis 2 reads: we expect muttering while memorisation to result in a better reproduction than when learning in silence. This study points out to reject this hypothesis. There is no significant difference between the memorisation tactics learning while muttering or silently.

Our study shows that students remember significantly more propositions after receiving instruction to make associated drawings, than after receiving instruction to write propositions on paper. Our study further reveals that, while drawing is more effective than writing down propositions, it does not matter whether students perform both activities in silence or muttering. This result seems to contradict the results of MacLeod et al. (2010), at least in the context of memorising propositions. The results of this study seems to conflict with previous findings of MacLeod et al. (2010). This conflict might be the result of differences in the tasks used (recognition and recall tasks). Our research casts doubt on the usefulness of muttering in addition to either drawing or writing propositions as information encoding tactics to support the recall of scientific propositions. Further research is necessary to clarify this contradiction.

The results about the effectiveness of drawing pictures to summarise propositions as a memory tactic match with earlier studies about the usefulness of drawing as a memory tactic. Wammes et al. (2016) established the effectiveness of drawing as a means to remember words. These authors assume that drawing prepares for a seamless integration of semantic, visual and motor aspects into a memory trace. In this integrated context, students learn to remember a proposition in connection with prior knowledge. Van Meter (2001) observed that drawing as a learning strategy improved students' recall of a two-page science text. Van Meter and Garner (2005, p. 317) speculate that the graphical representation helps constructing the internal nonverbal representation and persistent nonverbal memory traces. This may improve memory retrieval later. In contrast to the former two studies, our study investigated the effects of drawing on memory over a longer period. It provides evidence that drawing pictures to summarise propositions helps in creating a long lasting effect on students' memory.

Besides theoretical implications, the results of our study also have implications for teaching and learning in science education. In contrast to traditional investigations about memory retrieval, which focused on memorisation of lists of unconnected words or (parts of) texts, our investigation, focused on memory retrieval of common used meaningful propositions in daily-life classroom practice. Our study supports claims of earlier studies that making drawings can contribute to further and thorough understanding of abstract concepts (Katz, 2017; Pals, 2003). An interesting question regarding the

development of a sound knowledge base concerns the reproduction effect of drawing if more abstract propositions are used.

Another interesting question to investigate concerns the way students focus their attention while learning the propositions and finally how do they spend their time during memorisation. In other words, is there is a 'time on task' effect (Slavin, 2013) that has an impact in memorisation when students construct their drawing.

A limitation of the design we used in the present study is that it did not allow us to control for a possible confounding effect due to subsequent test periods, which may help students to retain information (Roediger & Karpicke, 2006). It is not impossible that testing after drawing promotes the retrieval of a visual image, which in itself offers a more powerful opportunity for re-encoding propositional information than testing after writing sentences on paper. Further research is necessary to resolve this issue.

In the broader context of education, it deserves further investigation whether the results of this study will also apply to other subjects, at other ages, and on different levels of education. Drawing as a memorisation method to develop a sound knowledge base, as applied in this study, is not a common practice in secondary education, but strategies like these can contribute to learning that is more meaningful.

Conclusion

This study contributes to the knowledge base of teaching strategies in science education. In science education, it is considered essential to prime students' prior knowledge of concrete situations to link it to abstract concepts. We assume that these links are helpful in developing students' skilfulness for solving problems. In this article, the focus is on comparing the effectiveness of different memory strategies in the domain of science. By analysing whether the development is better served by writing down on paper for further study or by making drawings, this study reveals that students remember significantly more propositions after receiving instruction to make associated drawings than after receiving instruction to write propositions on paper.

This research was conducted in science education, but the findings could also apply to other subjects, because every subject domain uses words, sentences, rules relations and concepts. Another relevant outcome of this study is the long-term effect of on memory of making drawings (four weeks). The beneficial effect of this memory strategy can enable students to ground a solid prior knowledge, to construct relations between fields of knowledge to improve students' capacity in applying higher cognitive processes and deep learning.

Disclosure statement

No potential conflict of interest was reported by the authors.

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