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# Does using sign language in science with hearing Year 8 students reinforce learning of key vocabulary, whilst affecting motivation and enjoyment of science?

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## Abstract

*The abstract and technical language used in science classrooms can produce a barrier to students' understanding. Multimodal communication, particularly visual aids alongside spoken language, has been shown to strengthen vocabulary acquisition, leading to improved conceptual understanding. This study investigates the use of Sign Language to teach scientific vocabulary with a hearing Year 8 class. The acquisition and understanding of this vocabulary are measured, alongside monitoring changes in motivation and enjoyment towards science, using a mixed methods approach. Whilst claims are made cautiously, Sign Language proved to increase vocabulary acquisition and understanding, with students finding Sign Language a useful tool. Sign Language had little effect on motivation towards science and whilst general enjoyment towards science was unaffected, Sign Language was proven to be an enjoyable approach to learning. This study provides a starting point for the investigation of using visual language to support vocabulary acquisition in the secondary science classroom.*

# Does using sign language in science with hearing Year 8 students reinforce learning of key vocabulary, whilst affecting motivation and enjoyment of science?

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## Introduction

This study investigated whether teaching key vocabulary accompanied with sign language supports vocabulary acquisition and understanding in science and whether this affects motivation and enjoyment of lessons. Science vocabulary is considered difficult to grasp and can act as a barrier to students understanding concepts. Multimodal communication, particularly visual aids alongside spoken language, has been shown to strengthen vocabulary acquisition. Thus, the visual language of Sign Language may help students have a better grasp on science vocabulary, which could lead to higher achievements. In turn, this could increase students' motivation and enjoyment of science lessons. This was investigated with a Year 8 class in a Cambridgeshire secondary school.

## Literature Review

This review will discuss research into visual communication and communicating with sign language. The benefits of sign language will be discussed, including the effect on cognition and enjoyment of the language. The current stance on motivation and enjoyment in the science classroom, and how sign language can be used to improve this, will also be reviewed.

### Acquiring Vocabulary with Your Eyes

The language of science is often abstract, frequently representing phenomena that cannot be directly observed or visualised, but also technical due to the need to be concise and precise as possible (Townsend, Brock, & Morrison, 2018). This makes it a difficult language to grasp for students. Whilst knowledge of scientific vocabulary is not the same as being scientific literate and having deep conceptual understanding, the latter cannot occur without it. Thus, the teaching and learning of vocabulary is a particular area of interest in science education. Vygotsky studied language acquisition and created the theory of development, which suggests that word knowledge and conceptual understanding are interlinked (Vygotsky, 1986). This reinforces that gaining new knowledge must be correlated with the acquisition of scientific vocabulary. The complexity of scientific language therefore could act as a barrier to learning.

Lemke, a renowned professor of language in education, recognised this barrier to learning. He discussed how scientific language is a synergistic integration of words with visual-graphical representations, such as pictures, graphs, maps, equations, tables (Lemke, 2008). Often in science, words make little sense without accompanying pictures to set the context, therefore these visual tools must be utilised.

Visual communication for vocabulary acquisition is prominent worldwide. For example, in 2007, Merriam-Webster and QA International developed an online visual dictionary that lists over 20,000 terms with contextual definitions alongside full-colour images. They propose, “when you know what something looks like but not what it’s called, or when you know the word but can’t picture the object, The Visual Dictionary has the answer” (QA International, 2019, para. 2). This further highlights the key role visual tools can play in learning vocabulary.

Kress and van Leeuwen stated the importance of visual communication alongside linguistic approaches for meaning making. They developed the multimodal theory of communication. It explores how people use a variety of semiotic resources to make sense of and interpret vocabulary. Multimodal refers to the different, interrelated modes of communication: oral language, written language, digital media, gesture and so forth. (Kress, Jewitt, Ogborn, & Charalampos, 2001).

Philips (2016) studied the effects of visual strategies, specifically picture-word pairing and semantic mapping, on vocabulary knowledge using a pre- and post-test. They found that all participants improved their score by 15 per cent after the intervention, with over half the participants scoring over 80 per cent on the post-test. This further signifies the importance of visual language for vocabulary acquisition. However, this study had a very small sample size of 14 participants, so its external validity is questionable.

More recently, Townsend et al. (2018) discovered using multimodal instruction in the secondary science classroom led to significant gains in the use of scientific vocabulary in students’ writing. A control group was not used so it is difficult to generalise these results, however, the mixed methods approach strengthens the claims made.

In agreement with Philips (2016) and Townsend et al. (2018), Alamri & Rogers (2018) also found an advantage of teaching technical and academic vocabulary with visual aids. Participants remembered more words that were given visual aids, despite the participants themselves thinking the visual aids were not helpful. This study used random sampling and a control group, however, only used male participants in a university setting so it is difficult to say whether the effect would also be seen in females and therefore should be repeated to include all genders and various age groups at different educational levels.

Overall, it is clear that using visual language can have a beneificial role in the acquisition of vocabulary.

## Communicating with Sign Language

Sign Language is the universal, visual-gestural communication method developed for deaf people, with variations used in different countries, such as British Sign Language (BSL) and American Sign Language (ASL), both of which are officially recognised languages. Sign Language is often distinct from the country's own spoken language, with its own grammar and syntax, but has been derived from the phonological and morphological structures of spoken language (Ogawa, Ito, & Masataka, 2009). Sign Language is often the first language acquired by deaf children in the UK, prior to English (British Deaf Association, 2018).

Sign Language could provide another avenue to assist children, deaf and hearing, in learning and utilising spoken language. In fact, the International Reading Association recommends Sign Language to assist children with learning to read (Melville, 2001).

One form of Sign Language, referred to as Makaton, involves using signs and symbols to support spoken language and is used for interacting with hearing children and adults that suffer from learning or communication difficulties (The Makaton Charity, 2017). Poor language skills are associated with behavioural problems, academic difficulties, lower self-esteem and social immaturity (King, 2017). When visual language is provided, children can express their wants, desires and intentions whilst speech is still maturing allowing them to communicate earlier and decrease the likelihood of behavioural issues. For example, Makaton is used for mute autistic children to help them acquire speech (The Makaton Charity, 2017). This shows that Sign Language should not be reserved for the deaf and has other useful applications.

Signs are considered to have four “aspects”: handshape, location, movement and orientation. Combining them simultaneously gives a substantial range of signs (Battison, 1978). The majority of signs are rational, revealing the semantics of the words. As well as through gestures, meaning is also conveyed through facial expressions and body language, making it an innately expressive form of communication. This expression can provide richer associations for context. Furthermore, Sign Language reveals the logical structure of spoken language, for example, pointing is used to place objects within a conversation, setting the scene for the interlocutors. Individual signs can also be modulated to give further context, such as the sign for grow can be exaggerated for large growth, or signed quickly to show quick growth (Schlenker, 2018). These aspects together make Sign Language a very useful addition to conversations.

**Sign Language and Cognition**

Sign Language has been shown to have many cognitive benefits to children. In tests of spatial construction, spatial organisation, and facial recognition, deaf signing children were markedly ahead of the hearing, non-signing children and far in advance of their chronological norms (Bellugi et al., 1990). To prove that this was due to Sign Language and not deafness itself, Parasnis, Samar, Bettger and Sathe (1996) compared deaf non-signing children on five tests that measured visual spatial skills, against hearing non-signing controls. There was no difference in their performance suggesting Sign Language may be the critical factor that leads to differential development of visual-spatial skills in deaf people (ibid.).

Many studies have shown that Sign Language improves the communicative skills of hearing children and adults with special educational needs (SEN) such as dyslexia, Down’s Syndrome and attention deficit hyperactivity disorder (ADHD), and is widely used for this purpose (Capirci, Cattani, Rossini, & Volterra, 1998; Downing, Earles-Vollrath, Larson, & Chang, 2007). For example, as previously discussed, the benefits of Makaton for these people has been well-documented since the 1970s (The Makaton Charity, 2017).

The benefits of Sign Language are not restricted to deaf or SEN people. Hearing children of deaf adults (CODAs) are bilingual and bimodal, due to communicating in spoken English and Sign Language. Daniels (2001a) discovered these children achieve higher scores for receptive vocabulary than non-CODAs, suggesting knowledge of Sign Language has a positive effect on the acquisition of English of hearing children. Zweibel (1987) also found hearing CODAs to have an enhanced cognitive development, and suggested they had an increased ability to absorb messages and stimuli (ibid.). However, research into the use of Sign Language to improve cognition of hearing children of normal development is limited. Studies that do exist in the literature are discussed below.

Most recently, Ogawa et al. (2009) carried out an intensive Sign Language course with hearing primary school children and found a significant increase in cognition in those that imitated signs, in measures of short-term non-verbal memory, short-term learning of non-verbal symbols, visual perception and fine-motor coordination. They concluded this could be because learning of Sign Language required generation of mental imagery, not just memorisation of lexicon. Whilst the findings are promising, this study only had eight participants and therefore must be repeated with a larger sample size to increase external validity. Furthermore, whilst a comparison was made between those who imitated and those who did not, there was no true control that did not get shown Sign Language, so it is difficult to decipher if Sign Language is the variable that causes this cognitive enhancement (Ogawa et al., 2009).

During another study of Sign Language with primary children, Brereton (2008) discovered that children used signing to clarify spoken communication with their peers if, for example, they did not remember the spoken word or found the word difficult to say. This further proves sign language complements spoken language.

On the contrary, when studying the effects of ASL on memory enhancement of specific words with preschool children, Downing et al. (2007) did not find any significant differences from their control group. However, the children were not made to imitate the sign, only observe signs. It is possible constructing the physical movement themselves could increase word associations as they would be more engaged and active in the learning process.

Conversely, Capirci et al. (1998) completed a study with hearing primary children that did find a cognitive benefit of Sign Language. Children who took part in a Sign Language course, observing and imitating the signs, improved more rapidly on tests of spatial memory and visual-spatial cognition than their peers who did not attend the course. Furthermore, the course appeared to promote faster development in non-verbal cognition, with the Sign Language-learning children reaching the level achieved by their peers not learning Sign Language almost one year earlier. This study had a large sample size and carried out a wide range of cognitive testing over two years making the conclusion robust, providing support for Ogawa et al.'s (2009) conclusion.

In agreement with the aforementioned study, a 14-month project was completed by Daniels (2001b) with similar findings. Hearing primary children were integrated into a classroom with 6 deaf students with a deaf teacher who taught the national curriculum in BSL once a week. It was found that using BSL in the classroom improved the hearing children's vocabulary, reading, and spelling. Unexpectedly, their mathematical ability also increased. This was attributed to the visual aspect of BSL being more applicable for mathematical thought. Furthermore, the children were more enthusiastic and engaged in their learning, with increased confidence. The children communicated with their deaf peers, as well as their teacher, in BSL and developed positive attitudes towards the deaf society (Daniels, 2001a). The longitudinal nature of the study provides some robustness, however, this report reads as field notes as opposed to a peer-reviewed study and does not provide any rationale or methodology for the measurements used, nor any control groups, making it difficult to draw generalisations from it, but does provide us with food for thought about the cognitive benefits of SL.

Daniels is an advocate for Sign Language training in education for normally developing hearing children and has completed the majority of studies in this area, which are all published in her book (Daniels, 2001a). The studies consistently show that Sign Language programmes provide significant gains in English vocabulary, against control groups. Importantly, she also showed that Sign Language assisted in reducing the achievement gap between underprivileged children and their peers. Daniels suggested this enhancement of vocabulary development was due to presenting the words in visual, kinetic, and auditory manner, as opposed to just auditory with spoken language, which further supports the previously discussed multimodal communication theory (Daniels, 2001a; Kress et al., 2001). However, the majority of these studies are completed with pre-school age children. Further studies should be completed to understand if Sign Language provides an advantage to older children and whether the benefits of Sign Language are long-lasting throughout childhood.

One study focused on the long-term memory retention of signs and found that ability to reproduce and understand taught signed words was retained at 6 and 12 weeks after the Sign Language workshop (Smidt et al., 2019). The retesting at six and twelve weeks could provide a limitation, as the participants knew they were going to be followed up and may have practiced the signs beforehand, so it may not be a true representation of a real-life circumstance. However, this shows that the visual language may help memory retention of vocabulary.

## Other Benefits of Sign Language

As well as academic, cognitive benefits, Sign Language has been shown to have other benefits in the classroom. Using Sign Language has been shown to increase students' focus and motivation at school. Daniels concludes children are more attentive as their hands are engaged and they must watch the teacher carefully for information. Furthermore, the children responded positively to using signing and enjoyed being active (Daniels, 2001a).

As previously mentioned, a lack of ability to communicate is linked to behavioural issues. A study completed in a primary classroom has shown that Sign Language has a significant and positive impact on behaviour management, showcasing another benefit of Sign Language (Mottley, 2012).

Currently, 85 per cent of the 35,000 deaf children in the United Kingdom are integrated into mainstream schools, where they are expected to communicate in English (National Deaf Children's Society, 2018). With hearing children learning sign, it contributes towards the development of positive attitudes towards deaf people in society and can promote the success of full integration of deaf children into mainstream schools.

## Sign Language in Science

Signs for science were originally developed by the Scottish Sensory Centre as deaf students were struggling in science due to a lack of signs for the scientific vocabulary. Like most signs, the signs developed convey meaning, providing a visual prompt for understanding the scientific concept, and thus could have benefits beyond the deaf population.

The use of signing alongside spoken language engages more senses in the learning process, providing a greater opportunity for children to make sense of information (Edwards, 1998). Thus, using Sign Language in the science classroom may assist children with acquiring the difficult scientific vocabulary.

**Motivation in the Science Classroom**

Motivation has long been considered an important factor for conceptual change and thus lessons must be planned to maximise the motivation of students, especially when experimenting with new teaching methods (Palmer, 2005). Thus, for students to be scientifically literate, they must first be motivated to learn in the science classroom. For the purpose of this study, this motivation will be defined as "an internal state that arouses, directs, and sustains science-learning behaviour" to match the principles of the instrument used (Glynn, Brickman, Armstrong, & Taasoobshirazik, 2011, p.1160). This motivation could originate intrinsically, where you do something for your own enjoyment, or extrinsically where you complete tasks to receive a reward or avoid punishment (Ryan & Deci, 2000). An environment must be provided that stimulates motivation to ensure effective learning and enhanced wellbeing of the students. The Science Motivation Questionnaire II (SMQ-II), developed by Glynn et al. (2011), provides an instrument for measurement of five motivation components (as reproduced in Table 1), which all mutually contribute to the arousal, direction and sustainment of students' science-learning behaviour.

| **Motivation Component** | **Definition** |
|---|---|
| Intrinsic motivation | The inherent gratification in learning science for its own sake |
| Self-determination | The control students deem to have over their learning of science |
| Self-efficacy | Students' belief that they are capable of achieving well in science |
| Grade motivation (extrinsic) | Learning science as a means to a tangible end (a good grade) |
| Career motivation (extrinsic) | Learning science as a means to a tangible end (a career) |

**Table 1: SMQ-II components (Glynn et al., 2011)**

Daniels found that primary children were more motivated at school after Sign Language was incorporated, thus motivation will be a factor considered in this study (Daniels, 2001a). When considering factors that could change the performance of students in the classroom, intrinsic motivation is thought to play a higher role than any other (Ryan & Deci, 2000).

### Enjoyment in the Science Classroom

As discussed above, intrinsic motivation is directly linked to enjoyment and has the biggest effect on student performance, therefore should be simultaneously investigated when also studying motivation. Enjoyment is defined as "a particular form or source of pleasure" in dictionaries (Dictionary.com, 2019). The Department for Education established 'enjoyment of education' as a key outcome of children's education and is given the same level of importance as being healthy and safe (Lumby, 2011). Studies have shown that students have increased enjoyment and subsequently learn more when they have been active in the learning process (Al-Shara, 2015). Sign Language is an active teaching method and its effects on enjoyment will be investigated.

## Research Questions

Analysis of the literature has revealed a need for investigating the use of Sign Language in the science classroom. The primary question that this action research study aimed to address, and the three sub-questions used to inform the primary question, are provided in Table 2.

| *Primary Question* | *Does using sign language in science with hearing Year 8 students reinforce learning of key vocabulary, whilst affecting motivation and enjoyment of science?* |
|---|---|
| Research Question 1 (RQ1) | Does teaching vocabulary accompanied with sign language support acquisition and understanding of those terms? |
| Research Question 2 (RQ2) | Does using sign language increase motivation in science? |
| Research Question 3 (RQ3) | Does using sign language increase enjoyment of science? |

**Table 2: Research questions considered during this study**

## Methodology

In this section, an outline and supporting rationale of the methodological approaches used throughout this study are described.

### Research Design

Research was carried out during a school-based professional placement during the Postgraduate Certificate in Education (PGCE) programme at the University of Cambridge.

An action research study was completed, which involves identifying a problem (poor vocabulary acquisition in science) and then using a reflective approach in an attempt to resolve the problem. The ultimate aim of action research is to attempt to improve one's practice by trying out something new (using Sign Language to teach vocabulary). It is a cyclical and continuous process, involving planning, action, observing and then reflecting (Wilson, 2013). Due to time constraints of this study, only one cycle was completed.

A mixed-method approach is used when the complexity of the problem cannot be fully understood from a single quantitative or qualitative approach and therefore was adopted for this study (Ponce & Pagán-Maldonado, 2015). Multiple data sources were used to answer the research questions to increase the robustness of the results, despite the small sample. Quantitative methods were used primarily, with qualitative methods used simultaneously to provide additional evidence for the findings of the same research question. This is known as a 'convergent parallel design' (Figure 1).

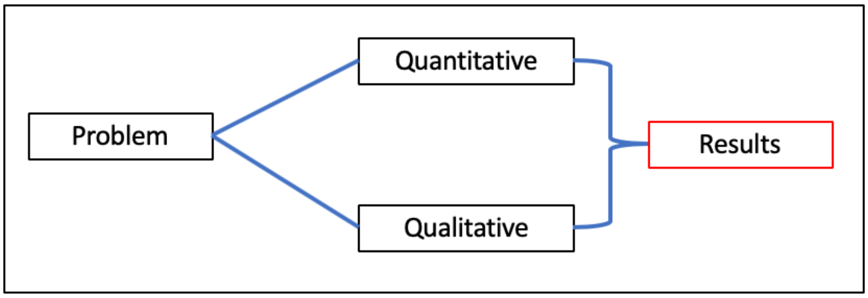



**Figure 1: Convergent parallel design structure**
**(Redrawn from Ponce & Pagán-Maldonado, 2015, p 117)**

*School and Class Context*

This study was conducted at a Cambridgeshire coeducational secondary school for students aged eleven to sixteen. A mixed ability Year 8 class (predicted GCSE Science grades 4-9), who will be referred to as 8A (n=34; 19 girls, 15 boys), was selected to take part in the study and received science lessons twice a week throughout the study, all delivered by the researcher of this study. The class contained seven students on the SEN register, five students considered to have English as an Additional Language (EAL) and nine students considered disadvantaged by the pupil premium conditions.

*Lesson Sequence Outline*

The unit delivered for this project was ‘Structure and Bonding’ which consisted of five 100-minute lessons, delivered over three weeks. The lessons were based on the school’s Scheme of Learning, which also provided a list of 35 novel key terms. For each lesson, half of the key terms were assigned a sign, using a Chemistry BSL Glossary provided by the Scottish Sensory Centre (Scottish Sensory Centre, 2019). If there were two terms listed with opposite meanings, only one was assigned a sign so it would be more apparent that the accompanying sign had an effect, as the terms would be given in the same context. 50%+1 terms were assigned a sign when an uneven number of terms were given. Appendix 1 presents the Vocabulary List and indicates the Assignment of Signs for this unit.

**Data Collection Methods**

A variety of data collection methods were chosen to suit this action research project. Here, the process and justification of each method will be discussed in turn, together with the data analysis procedures.

*Vocabulary Acquisition and Understanding Measurement*

Before starting each lesson, each participant was given a list of all the lesson’s key vocabulary and asked to give a definition. Firstly, this allowed prior knowledge to be assessed to inform the teaching of the topic, and secondly, provided a baseline to measure against. Number of correct definitions recalled at this stage were tallied for each term and converted to a percentage using the following equation:

$$\frac{participants\ recalled\ correctly}{total\ number\ of\ participants} \times 100$$

A vocabulary definitions post-test was created, which included 16 terms from the topic vocabulary list, with eight sign-assigned terms and eight non-signed-assigned terms. Care was taken to select vocabulary from all five lessons and where possible, two terms that were given in the same context, but only one was sign-assigned, were used. For example: oxidation and reduction, from Lesson 2, have opposite meanings and were both included, but only oxidation was sign-assigned. Using the pre-test data, baseline knowledge of the non-sign-assigned and sign-assigned terms were statistically compared using an unpaired, two-tailed, t-test.

The number of correct responses was tallied for each term and converted to a percentage as per the above equation. The percentage was baseline-corrected using the following equation:

$$posttest\ percentage\ recalled\ correctly - pretest\ percentage\ recalled\ correctly$$

A mean percentage for both sign-assigned and non-sign-assigned words was calculated and statistically compared using a using an unpaired, two-tailed t-test.

The number of correct definitions were totalled for each participant. Each participant was categorised into preference for 'sign-assigned', 'non-sign-assigned' or 'equal recall of both'. The percentage of participants in each category were compared.

*Science Motivation Questionnaire*

The SMQ-II, developed by Glynn et al. (2011), was used before and after the study to quantitatively measure if using Sign Language had changed the students' arousal, direction and sustainment of science-learning behaviour. The SMQ-II consists of 25 questions, that measure five different types of motivation, summarised in Table 1 above, with five questions for each (ibid.). This questionnaire was selected for its proven high construct validity and its high citation impact. Questions were marginally altered to be age-appropriate for the participants, without changing the question intent. The questionnaire used a five-point Likert format (examples provided in Figure 2) and was answered individually within lessons. Using Likert scales provide the opportunity to gain degrees of opinions and attitudes, which can be quantified for easier analysis (McLeod, 2008).


The science I learn is relevant to my life *

- Never
- Rarely
- Sometimes
- Often
- Always

It is important that I get a 9 in Science GCSE *

- Strongly disagree
- Slightly disagree
- Neither agree or disagree
- Slightly agree
- Strongly agree

**Figure 2: Examples of questions and possible responses in the Science Motivation Questionnaire**

Participants were informed it was not a test and there was no correct answer. They were asked to work without discussion so peer influence could be kept to a minimum.

After data was collected, the answers were scored from 0-4 using responses from Figure 2 (Never to Always or Strongly Disagree to Strongly Agree, respectively) and totalled for each construct and every participant. Each construct could be awarded a maximum score of 20 for each participant. General motivation for science could be measured by looking at the total score awarded for each participant, out of a possible 100. Responses for before and after the intervention were directly compared for each participant. Overall class change in motivation were also studied by comparing the mean motivation score (out of 100) before and after the intervention and statistically analysed using a paired, two-tailed t-test.

*Lesson Evaluations*

Participants were given the opportunity to give anonymous feedback on two lessons using an online survey platform. Time constraints made it not possible for every lesson. The first question required a score from one (useless and boring) to ten (very useful and enjoyable). Three more questions were answered in 'essay' format. Two were about their favourite and worst parts of the lesson, which were compulsory with a minimum character length of 30 characters (the average size of one sentence) and the final question was an optional comment (see Figure 3).

| | TITLE | QUESTION TYPE |
|---|---|---|
| Q1 | Today, I rate this lesson... * | Scoring |
| Q2 | My favourite part of today's lesson was... | Essay |
| Q3 | The worst part of today's lesson was... * | Essay |
| Q4 | Do you have any other comments about today's lesson? | Essay |

**Figure 3: Lesson Evaluation questions**

For Q2-4, mentioning of the words 'sign', 'signing, 'sign language', or 'BSL' were tallied for each question for each evaluated lesson. Optional comments were categorised into mentions of 'usefulness' and 'enjoyment'.

*Learning with Sign Language Survey*

At the end of the lesson sequence, each participant was given another online survey consisting of four questions about their opinions on using Sign Language in science lessons (Figure 4). This provided subjective data to support the measurements of vocabulary acquisition. Questions 1-3 used a five-point Likert format (see Figure 5), for reasons previously discussed. The optional Question 4 used an 'essay' format. This provided qualitative data to back up the quantitative section of the survey.

| | TITLE | QUESTION TYPE |
|---|---|---|
| Q1 | Learning sign language in science has been... | Multiple Choice |
| Q2 | Learning sign language in science has been... * | Multiple Choice |
| Q3 | Learning sign language in science has helped me remember key words | Multiple Choice |
| Q4 | Do you have any other comments about learning sign language in science? | Essay |

**Figure 4: Learning with Sign Language survey questions**

To decipher usefulness of Sign Language in science, Likert responses, 'slightly useful' and 'very useful' were combined and displayed as a percentage. To decipher enjoyment of Sign Language in science, 'slightly enjoyable' and very enjoyable' were also combined and displayed as a percentage. Optional comments were categorised into mentioning of 'usefulness' and 'enjoyment' and also into positive and negative groups.

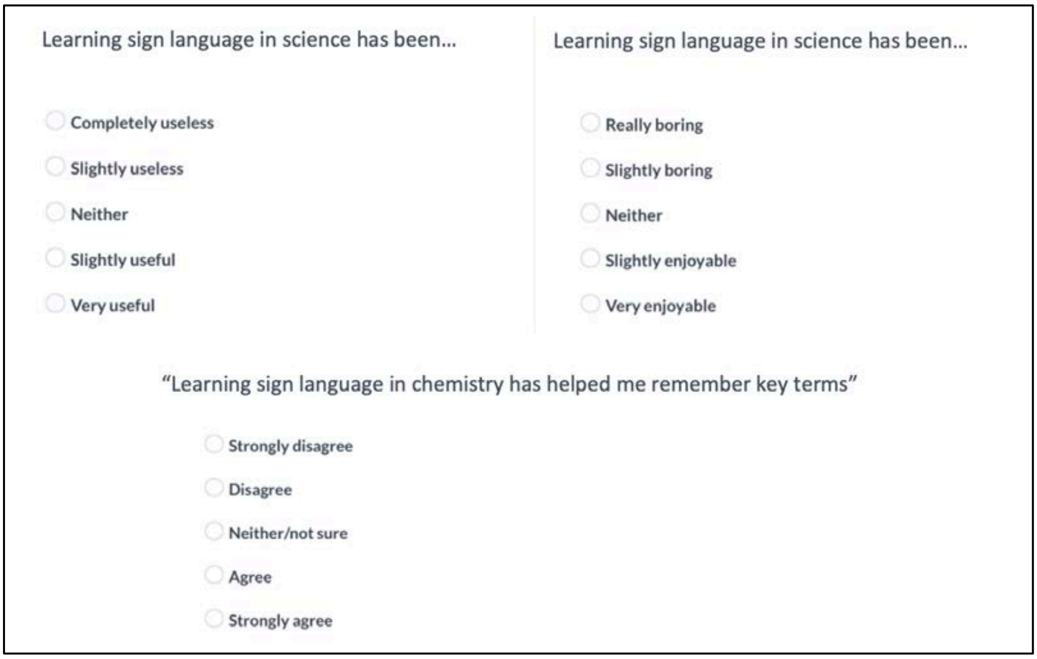



**Figure 5: Likert scales used in the Learning with Sign Language survey**

*Class Data*

After the sequence of lessons, an end of topic test was completed. The average mark was calculated for the test and compared with the average mark of all Year 8 tests for this class. This data was also compared with a comparable Year 8 class (8B) with similar ability, target grades and demographic who were not taught any Sign Language during the Structure and Bonding unit.

Additionally, two questions on the test were compared for the 8A class that both included vocabulary of properties and were worth two marks. One question required giving sign-assigned vocabulary for metal properties as the answer (*"Tick two properties of steel alloy that make it suitable for the use as the ball in a hip joint"*) and the other required vocabulary for plastic properties that was not assigned a sign (*"Suggest two physical properties that make plastic a good material for a socket")*. The number of participants scoring 0, 1 and 2 marks for each question was tallied and compared.

Lastly, high use of sign-assigned terms was noted for one question and the use of these terms were analysed.

All statistical comparisons for this section were completed using unpaired, two-tailed t-tests with significance reported at $p < 0.05$. Participant numbers (n) are reported for each analysis.

**Ethical Considerations**

The ethics of the research were carefully considered before commencing the study and approval was sought from the school. British Educational Research Association (BERA) guidelines for educational research were strictly adhered to throughout the study (BERA, 2018).

The class were briefed about the purpose of the research, as well as their role, during Lesson 1 and were informed that the study was in no way linked to their assessment and would be published anonymously. Letters were provided to parents/guardians informing them and their child of the confidential nature of the research and offering the right to withdraw at any point.

All data was collected anonymously, except in the case of the SMQ-II, where it was necessary to compare each student, where it was anonymised after both surveys were completed. Any pupil names or class names were given different names for this study.

**Limitations**

Whilst the tools used have been shown to be valid for probing the research questions of interest, there are a number of limitations that may affect this study.

Firstly, due to the small scale of this research, it was not possible to include a true control group. Ideally, a comparison using a different class of similar ability and size that did not get taught Sign Language would have been taught the same topic with the same teacher and all data would have been collected for both. When answering RQ1 using test data, the Sign Language class were compared to another Year 8 class (8B) of the same set and demographic, who were not taught Sign Language. Whilst they should be a comparable class according to target grades, the class were taught the Structure and Bonding unit by a different teacher and at a different time point; thus, it cannot be said that the topic was taught in the same way making it a dubious comparison.

Secondly, giving the same survey twice, in the case of the SMQ-II, may have diminished its reliability due to participants becoming bored or subconsciously biasing their data due to retained memory of previous answers.

Another issue with using surveys is that the measurements could be compromised due to social desirability, meaning data could be false due to the participant wanting to please the researcher

(McLeod, 2008). To minimise this risk to internal validity, data should be collected anonymously, however, the repeated measures design did not always make this was not possible.

Demand characteristics could have threatened the internal validity of this study if the participants knew exactly what was being measured. To avoid this, participants were deceived of the exact measurements of the study.

Finally, action research projects are usually cyclical, with methodology being refined with each cycle (Wilson, 2013). However, due to the time constraints of the project, this was not possible.

Despite these limitations, utmost care was taken to avoid experimenter and participant bias. For example, all terms and definitions were emphasized and explicitly taught, not just those assigned a sign.

## Findings

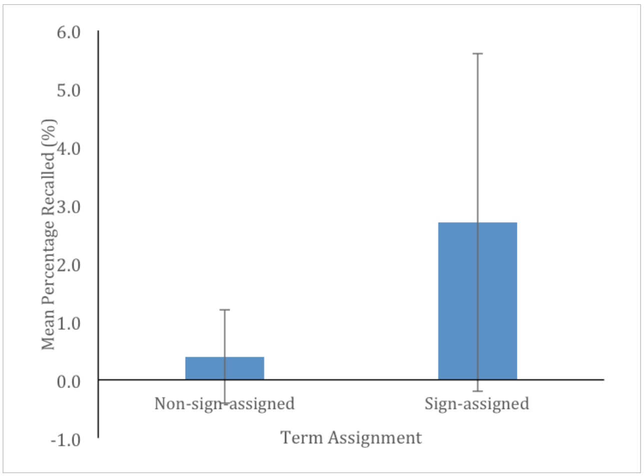
### RQ1: Does teaching vocabulary accompanied with sign language support acquisition and understanding of those terms?

*Determination of baseline knowledge (pre-test)*

Pre-existing knowledge of the novel vocabulary definitions was tested. For the 35 key terms, the percentage of participants that correctly responded for each term ranged from 0-53.1% (data not shown). For the 16 terms selected for the post-test, on average 2.7% of the class correctly responded to the sign-assigned terms and for the non-assigned terms, 0.4% of the terms' definitions were correctly recalled (see Figure 6, next page) An unpaired t-test revealed there was no significant difference ($t(8) = 1.51$, $p = 0.17$).

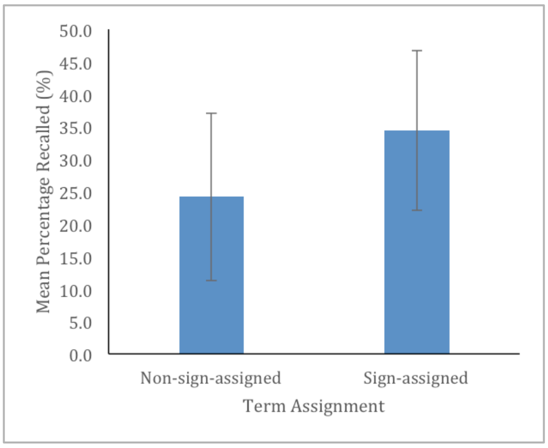
*Vocabulary acquisition and understanding measurement (post-test)*

Generally, recalling of definitions correctly is low on average (30.9%). The term with the highest correct recall was at 68.8% and lowest was 6.3% (data not shown). On average, more sign-assigned term definitions (34.4%) were recalled than non-sign-assigned terms (24.4%), however, this was not significantly different when evaluated with an unpaired t-test ($t(7) = 1.08$, $p = 0.30$) (Figure 7).




*Error bars show ±95% confidence intervals (CI) (n=32)*

**Figure 6: Difference between mean percentage recalled for correctly recalled definitions for non-sign-assigned and sign-assigned terms pre-intervention**




*Error bars show ± 95% CI (n=32)*

**Figure 7: Mean percentage change from baseline of correctly recalled definitions after intervention**

The number of correct non-sign-assigned and sign-assigned terms was totalled for each participant. It was found that 53.1% of participants recalled more definitions for sign-assigned terms, compared to 18.8% remembering more non-sign-assigned terms and 28.1% with equal recall (see Figure 8).

Two definitions were tested that have opposite meanings but were given in the same context in the classroom: reduction and oxidation. Six participants correctly recalled the definition for reduction, whereas 12 participants recalled correctly for oxidation, which was sign-assigned (see Figure 9).

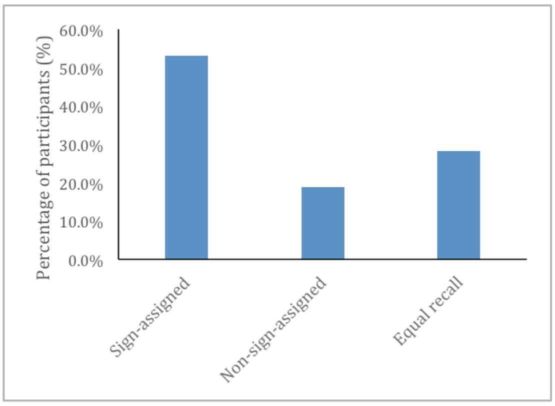



**Figure 8: Difference in participants' successful recall of sign-assigned or non-sign-assigned terms post intervention (n=32)**

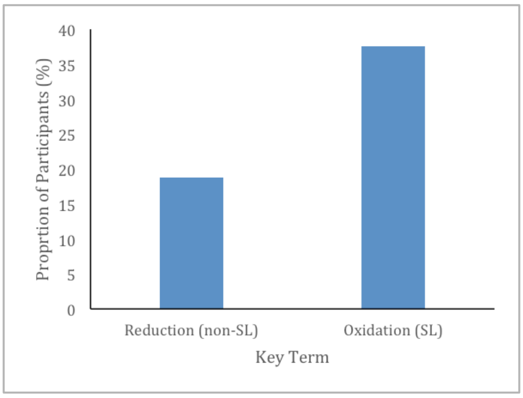



**Figure 9: Comparison of the number of participants correctly answering a sign-assigned and non-sign-assigned terms with opposite meanings in the vocabulary test (n=32)**

*Participant Opinions*

After the intervention, participants completed a survey to express their opinions on using Sign Language in science. Firstly, participants were asked to rate the usefulness of Sign Language in science. The mode answer was 'slightly useful' and overall, 68.8% of participants found it useful (see Figure 10).

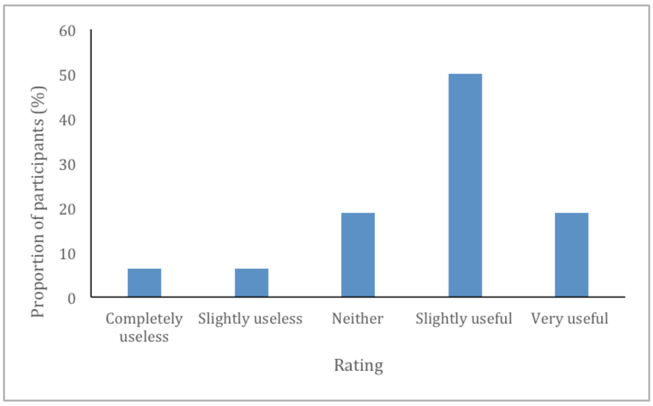



**Figure 10: Participant opinions on the usefulness of Sign Language in science lessons (n=32)**

Additionally, participants were asked about the statement "*learning sign language in science has helped me learn key terms*". The most common answer was 'slightly agree'. Overall, 71.9% of participants agreed with the statement (see Figure 11).

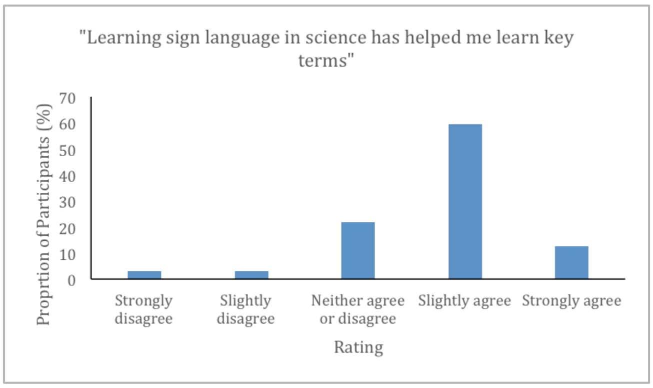


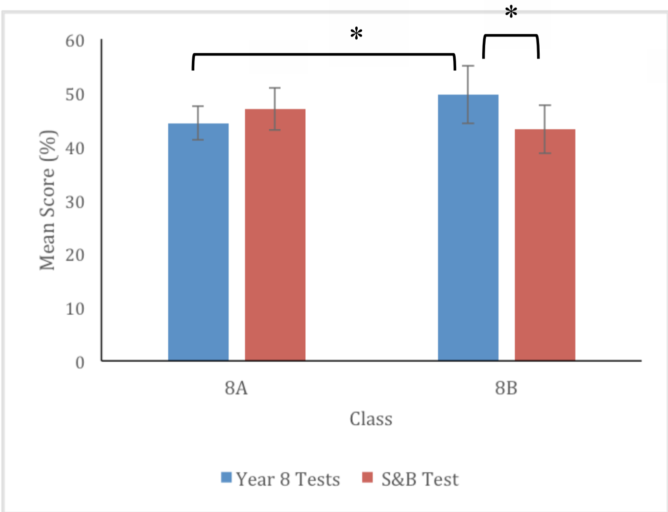

**Figure 11: Participant opinions on whether Sign Language helps learn key terms (n=32)**

16 participants took up the opportunity to give additional comments about Sign Language in the surveys. 11 of these were positive comments, often commenting on memory retention of key terms. For example, "*it also helps us remember the words going with the action if we can't remember the word of the top of our head"* and, *"it helped to remember things in the test"* (Learning with Sign Language survey), tells us that Sign Language can act as a prompt. One participant said, *"It should be used in schools more often because it helps you learn key words"* (Learning with Sign Language survey), showing us the value of its use and that it could be useful for subjects beyond science.

*Class test data*

After the intervention, a topic test was given. The mean score for the class across Year 8 tests was 44.3% (n=33). For the Structure and Bonding test, this class achieved a mean score of 47%. Whilst this increase in marks was not significant ($t(52) = -0.89$, $p = 0.38$), it is thought-provoking that 57.6% of the class scored their highest mark of Year 8 on this test.

Additionally, this dataset was compared to 8B (n=34). This class had a significantly higher average (49.6%) for Year 8 tests ($t(62) = 2.06$, $p = 0.04$). Interestingly, their mean Structure and Bonding score was significantly lower than their Year 8 test mean at 43.1% when compared with an unpaired t-test ($t(63) = 2.11$, $p = 0.04$). This mean score was also lower than 8A's mean score for Structure and Bonding but was not significant ($t(61) = -1.10$, $p = 0.27$) (see Figure 12).




*Error bars show ± 95% CI. * shows significance at p <0.05. (8A n=33; 8B n=34)*

**Figure 12: Comparison of two Year 8 classes mean test data and Structure and Bonding mean scores**

Furthermore, answers for two questions about properties of materials, both worth two marks, were compared (see Table 3 below). Intriguingly, for the question requiring vocabulary that was not sign-assigned (*"Suggest two physical properties that make plastic a good material for a socket")*, 75.9% of the class scored no marks, and no participants scored full marks. For the question requiring sign-assigned vocabulary (*"Tick two properties of steel alloy that make it suitable for the use as the ball in a hip joint")*, 85.2% of the class scored full marks, and no participants scored no marks.

| | Marks gained by participants (%) | | |
|---|---|---|---|
| | 0 | 1 | 2 |
| Non-sign-assigned question | 75.9 | 24.1 | 0.0 |
| Sign-assigned question | 0.0 | 13.8 | 86.2 |

**Table 3: Comparison of sign-assigned and non-sign-assigned questions in Structure and Bonding test (n=33)**

Finally, the use of sign-assigned terminology was noted throughout the test. Interestingly, for a two-mark question about the ionisation of sodium ("*Explain how a sodium atom, Na, becomes a sodium ion, $Na^{+}$*"), 37.9% of participants gave detailed answers that used the sign-assigned terms 'cation' and 'oxidation'. This was correct terminology, but beyond what was required by the mark scheme, which only asked for "*loss of an outer shell electron*". This suggests these sign-assigned terms were acquired and understood by the participants, allowing them to apply them in the correct context.

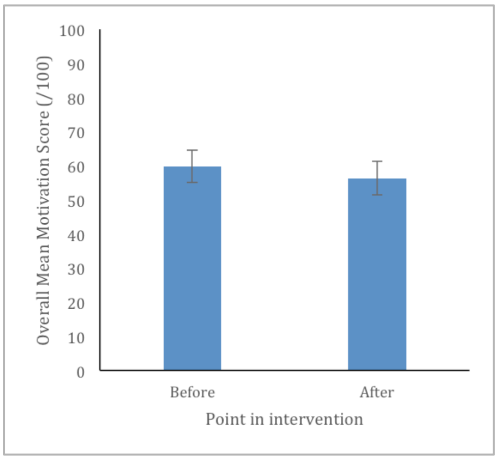
*RQ1 Conclusion*

Although more Sign Language-assigned terms were recalled correctly, the vocabulary test did not produce a significant effect in using Sign Language. Despite this, the triangulation of various mixed methods data here largely shows that using Sign Language appears to increase vocabulary acquisition and understanding, which is supported by the participants agreeing that Sign Language was useful for this purpose.

**RQ2: Does using sign language increase motivation in science?**

The SMQ-II (Glynn et al., 2011) was used before and after the intervention. Scores for each construct and for each individual were calculated.

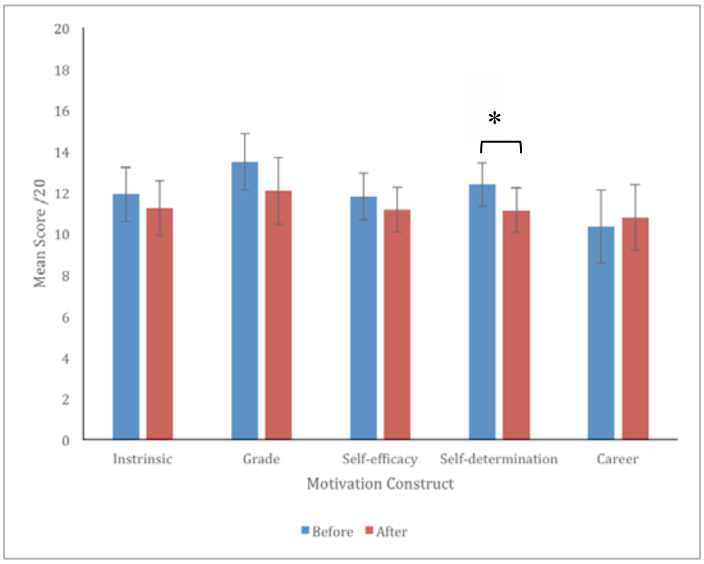
Before the intervention, the class had an overall mean motivation score of 59.9/100. After the intervention, the mean score marginally decreased to 56.4/100 (n=30). When statistically analysed using a paired t-test, this was not shown to be significantly different ($t(29) = 1.47$, $p = 0.14$) (see Figure 13, next page).




*Error bars show ± 95% CI (n=30)*

**Figure 13: Change in mean overall motivation score between before and after Sign Language intervention**

When considering the individual constructs pre-intervention, the class are mostly motivated by achieving their grades and least motivated by their career. After the intervention, this trend is unchanged. Intrinsic, grade and self-efficacy motivations all decreased after the intervention, however these were all found to be non-significant (INTRINSIC: $t(29) = 1.06$, $p = 0.30$, GRADE: $t(29) = 2.01$, $p = 0.05$, SELF-EFFICACY: $t(29) = 1.02$, $p = 0.32$). Self-determination was found to be significantly decreased ($t(29) = 2.12$, $p = 0.04$). Career motivation increased, but this was not significant $t(29) = -0.85$, $p = 0.40$) (see Figure 14).




*Error bars show ± 95% CI (n=30). * shows significance at p <0.05.*

**Figure 14: Change in motivation construct means after Sign Language intervention**

**RQ3: Does using sign language increase enjoyment of science?**

Lastly, using the SMQ-II, Learning with Sign Language Survey and Lesson Evaluations, the enjoyment of the lessons was investigated.

*SMQ-II Question*

One question in the SMQ-II asked for agreement with the statement "I enjoy learning science". The total class score and individual responses were analysed (n=30). If every participant gave the maximum possible score of 4 ("Always"), the total maximum class score would be 120. In the pre-intervention SMQ-II, the total score was 82. Post-intervention, the total score was 80. Overall, there was no change in the class opinion towards their enjoyment of science lessons (see Figure 15).

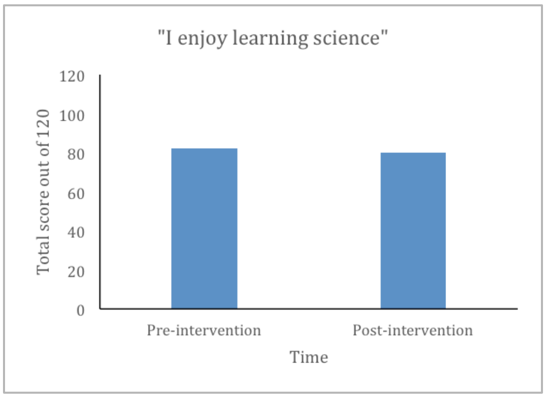



**Figure 15: Overall change in class score for statement "I enjoy learning science" out of a possible score of 120 (n=30)**

Secondly, the individual responses for participants were recorded. The largest change post-intervention was for "often", where the proportion increased by 17%. The responses for "sometimes" and "always" both decreased by 10% (see Figure 16, next page). Pre-intervention, the mode answer was "sometimes", after the study the mode answer became "often".

*Learning with Sign Language Survey*

The participants were asked to rate their enjoyment of the Sign Language intervention. The mode answer was 'slightly enjoyable', with 81.3% of participants finding it enjoyable (see Figure 17, next page).

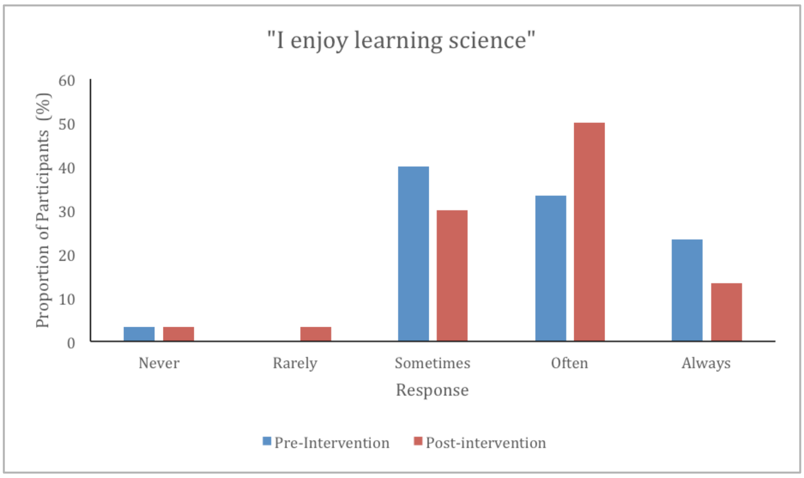



**Figure 16: Proportion of responses to statement "I enjoy learning science" for 8A before and after the intervention**

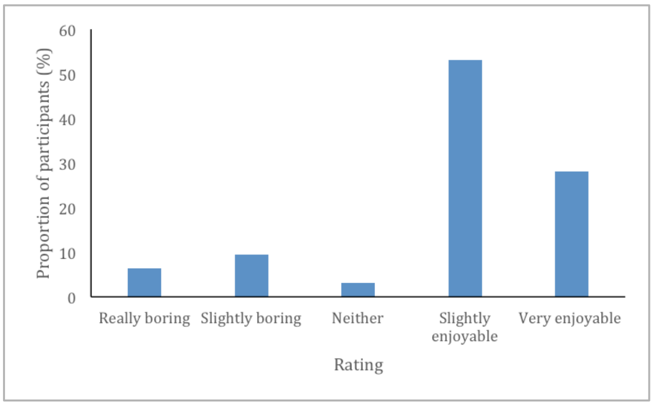



**Figure 17: Participant opinions on enjoyment of Sign Language in science lessons (n=32)**

For optional additional comments on this survey, 68.6% of them were positive (n=16). Many comments mentioned that Sign Language was fun and novel, for example *"It was really fun because it was a new way of learning things"*, *"I think it is a great way to learn something new in science and to learn it in a different language as well"* and *"It was very fun to learn and helped remember key words, it was also a nice change to an average lesson"*.

*Lesson Evaluations*

The participants were asked to evaluate two lessons in the sequence. Mentions of Sign Language were recorded and for the majority of the class, Sign Language was their favourite part of the lesson, alongside comments of *"fun"*, *"interactive"* and *"different"*. Across both lessons, Sign

Language was not directly given as the worst part of the lesson, however, *"visual learning"* was mentioned (see Table 4).

| Lesson | Sign Language Favourite Part (%) | Example | Sign Language Worst Part (%) | Example |
|---|---|---|---|---|
| Metals (n=29) | 65.6 | *"Learning sign language was very fun because it was different to what we usually do"* | 0 | - |
| Ionic bonding (n=31) | 45.2 | *"My favourite part of the lesson is learning the signs"* | 3.3 | *"The visual learning because I enjoy writing things"* |

**Table 4: Mentions of Sign Language during student Lesson Evaluations with example comments**

Additional comments in this survey were given by a minority. This particular quote, from Lesson 1, highlights the significance of Sign Language: *"I really enjoyed learning the sign language because it is something different and has helped me to remember some of the words we learnt today. I enjoyed today's lesson a lot."*

*RQ3 Conclusion*

By analysing the quantitative and qualitative data together, it can be deciphered that the participants did enjoy using Sign Language in science, but their opinion about their general enjoyment towards science has not been affected by using Sign Language.

## Conclusion of Findings

Overall, Sign Language has been shown here to provide a small improvement in vocabulary acquisition and understanding and was greatly accepted by the participants. The Sign Language intervention appeared to have little effect on motivation. Furthermore, whilst general enjoyment in science did not change, there was overwhelmingly positive feedback about the Sign Language specifically, with the majority of the class enjoying it and finding it useful for remembering key vocabulary in science.

## Discussion

This action research project set out to answer the question 'does using sign language in science with hearing Year 8 students reinforce learning of key vocabulary, whilst increasing motivation and enjoyment of science?*'* using three research questions set out earlier in Table 2.

**RQ1: Does teaching vocabulary accompanied with sign language support acquisition and understanding of those terms?**

The technical and abstract language of science continues to be problematic in the classroom. In this study, the level of recall of scientific vocabulary is low, which agrees with Townsend et al. (2018) that scientific language is difficult to grasp for students.

Lemke (2008) discusses how science has an important visual aspect. With this in mind, key terms were taught with Sign Language, a visual language. Despite the low levels of recall, it was found that key terms that had been accompanied with a sign during teaching were recalled more and there was an increased level of understanding for these words, supporting Lemke's notions.

In the vocabulary definitions test, more participants recalled definitions for the sign-assigned terms than the non-sign-assigned terms. As it can be seen from Figure 7, the variance in the data was large, which may have led to the non-significant finding. This could be explained by the huge variation in participant attainment, leading to very different scores for this vocabulary test, ranging 0-12 out of a possible 16. Additionally, the criteria for a correct definition was stringent. Some words have complex definitions, for example, the answer for metallic bonding must have included both "positive atoms/cations" and "delocalised electrons", thus the proportion who answered this correctly was low (12.5%). Some students included one of these phrases, which shows their understanding of the vocabulary was developing. Two terms with opposite meanings: 'reduction' and 'oxidation', were tested. Only oxidation was sign-assigned and had double the proportion of participants than 'reduction' that recalled the definition correctly. The sign for this term was composed of two movements: the first signifying 'negative' and the second signifying 'away'. This gives rise to the definition of the word, loss of electrons, and may be why it had a higher level of recall.

Overall, participant opinions proved that Sign Language is a useful tool, which is a contrasting finding to Alamri and Rogers (2018). However, a small percentage of participants found it completely useless. When teaching the signs, the class were responsive to copying the teacher, however, there was a minority who felt embarrassed and would not copy the signs. This may explain these negative responses.

The quote given as an example earlier (see page 163 above) "*it also helps us remember the words going with the action if we can't remember the word of the top of our head*" supports Brereton's (2008) findings that sign complements spoken language. As previously mentioned, signs are logical and often explain the semantics of the words and as demonstrated by the reduction-oxidation question, can help you acquire an understanding of vocabulary.

8A achieved a higher mean class score on Structure and Bonding test than their previous mean score, with the majority of participants gaining their highest mark of Year 8 here, despite the topic being a GCSE level topic that had not been previously met. Additionally, when paralleled with a comparable Year 8 class who did not learn Sign Language with their vocabulary, they achieved a higher mean score. Intriguingly, this other Year 8 class previously had a significantly higher average Year 8 score before the Structure and Bonding so therefore would be expected to also get a higher mark in this difficult topic. It is impossible to decipher if this was due to the Sign Language being implemented, as many other factors may have influenced this. For example, they were not taught by the same teacher and the topic was taught in different terms.

Within this test, two questions about properties of materials were asked, both worth two marks each. On the question requiring an answer containing sign-assigned vocabulary, 86.2% of participants scored full marks. The other question's answer did not require sign-assigned vocabulary. On this question, 0% of participants achieved full marks and 75.9% of participants scored no marks. However, this was a dubious comparison, particularly as the questions' format was different. The sign-assigned question was multiple choice question, with the properties already listed. The question without sign-assigned vocabulary required a written answer. It could be argued that it is easier to gain marks for multiple choice questions, as you can gain marks from guessing.

During one question of Structure and Bonding test, 37.9% of participants gave an answer in more detail than what was required, incorporating sign-assigned terms. This may suggest the Sign Language supports vocabulary acquisition and also understanding, as the participants remembered the terms and also used them in the correct context. Unfortunately, it was not possible to access 8B's test papers to compare their usage of key vocabulary.

Overall, whilst it is impossible to pin the findings on the use of Sign Language, this provides interesting initial data of its potential benefit in the secondary science classroom, which agrees with Townsend et al. (2018) that multimodal instruction leads to gains in scientific vocabulary.

To discover if this effect is real, longer studies, with larger sample sizes should be completed of a similar nature to confirm if this effect is indeed due to the use of Sign Language.

**RQ2: Does using sign language increase motivation in science?**

Before and after the intervention a survey, the SMQ-II developed by Glynn et al. (2011), was administered to investigate the class's levels of motivation in 5 different areas: instrinsic motivation, self-determination, self-efficacy and two types of extrinsic motivation (grade and career). Initially participants had the highest motivation score in grade motivation. This means their science-learning behaviour was likely driven by obtaining their test results. Their smallest motivation score was for career, considering their ages (12-13) this makes sense as they are unlikely to be thinking about their career yet.

After the Sign Language intervention, there was no significant change in class overall motivation and thus Sign Language does not seem to effect their motivation for science, which disagrees with the findings of Daniels (2001a). This could be due to the age difference in the participants of these two studies.

When the individual constructs are considered, grade and career motivation remained highest and lowest scores, respectively. There was a decreasing trend in the constructs (with the exception of career) but only self-determination significantly decreased. Self-determination was defined in this study as the control students deem to have over their learning of science (Glynn et al*.,* 2011). Before the Structure and Bonding topic, the teacher had only taught two lessons with this group. A change in teaching style could have led them to feel less in control.

As previously mentioned, one of the limitations of repeating surveys is that the participants may not give answers that truly represent their feelings. The participants often complained about the length of surveys. This may have caused the scores to go down upon re-administration. This confounding factor was further established when the SMQ-II was repeated at a later date (data not included) where trends did not change, but scores further decreased.

Another possible explanation is that the Structure and Bonding unit was a GCSE level topic, containing some very challenging concepts. If the participants struggled with the content, this may have decreased their motivation and lowered their confidence.

Ryan and Deci (2000) considered intrinsic motivation to play the highest role for pupil performance in the classroom, where in this context, students have inherent satisfaction in learning science for their own sake. In this study, there was no significant change in instrinsic motivation.

### RQ3: Does using sign language increase enjoyment of science?

With science being a compulsory subject at GCSE, it is desirable for students enjoy it. Daniels (2001a) found that pre-school children enjoy Sign Language, which led to this question to find out whether the effect would be present in older children. When asked to respond to the statement "I enjoy learning science" in the pre-intervention SMQ-II, participants largely responded positively. The change in mode answer from "sometimes" to "often" suggests a shift in enjoyment when Sign Language was incorporated. However, the overall question score did not change, which suggests Sign Language did not change their opinion about their general enjoyment of science.

Nonetheless, when the participants were questioned about their opinions towards Sign Language specifically, a large majority of participants expressed enjoyment, giving many positive comments, including finding it "fun". During lesson evaluations, the majority of participants considered Sign Language as their favourite part of each lesson and no participants considered Sign Language the worst part. The findings of this study are in agreement with Daniels (2001a) and together with her work, this suggests children of different ages enjoy learning Sign Language. More studies will have to be completed across the other age groups to further confirm this.

### Suggestions for Future Research

The findings of this study can only be valid for this particular cohort, in this particular school being taught by this particular teacher. It is impossible to say whether these findings could be replicated in different settings. To determine whether these findings are replicable, it could be repeated across schools with different demographics, different year groups and with different teachers delivering the content, opening up the possibility of further cycles of action research.

Due to time constraints of this study, only one cycle of action research was complete. it was not possible to test recall of the sign-assigned vocabulary at different time points. It would be interesting to re-test the vocabulary acquisition and understanding of the class at different points throughout the academic year to see whether Sign Language has an effect on long-term vocabulary retention, as reported by Smidt et al., 2019.

As previously mentioned, to truly understand if the effects found were due to Sign Language, a control group should be included that is taught by the same teacher, delivering the same topic but without the Sign Language.

Additionally, the effects of Sign Language on motivation need to be further investigated. As the topic only lasted three weeks, it is possible that it takes longer than this to change students' motivation and also opinion towards science. Either, the surveys could be repeated after a longer timepoint, or to prevent subconscious bias, the variables could be measured with different tools.

Generally, the completion of this study made the researcher scrutinise their lesson plans and make a conscious effort to emphasize the importance of vocabulary, which hopefully led to improved teaching and learning overall.

## Conclusion

Overall, this study provides an intriguing starting point for the investigation of using the visual language of Sign Language to increase the acquisition and understanding of the technical and abstract vocabulary in the science classroom, through the previous proven benefits of multimodal instruction. Whilst the claims have been made cautiously in light of the limitations of the study, Sign Language can be considered here as a useful and fun approach to learning. Whilst there are many techniques for multimodal instruction, Sign Language already exists so provides an easy way to trial multimodal instruction in classrooms. If the effect of Sign Language on vocabulary acquisition does not appear to be valid in the future, it was undoubtedly an enjoyable experience for all involved, with no negative effects on vocabulary acquisition and thus could be used as a pedagogical tool to increase engagement and make dry, scientific content more enjoyable.

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# Appendix 1

### Structure and Bonding topic: Vocabulary List and Assignment of Signs

| Lesson 1: Metals | | |
|---|---|---|
| Word | Definition Provided | Sign Assigned |
| Metal | Shiny element that is a good conductor of electricity and heat and is malleable and ductile | ✓ |
| Property | The characteristics of something | |
| Malleable | Can be bent or moulded into shape | ✓ |
| Electrical conductor | Allows charge to pass through it | ✓ |
| Thermal conductor | Allows heat energy to pass through it | |
| Lustrous | Shiny, silvery | ✓ |
| Ductile | Can be drawn into thin wires | |
| Melting point | The temperature at which a solid changes into a liquid as it is heated | ✓ |
| Density | Number of particles in a fixed volume | |
| Metallic bond | Bonding in metal elements consisting of a giant structure of positive metal atoms and their delocalised electrons moving between them | |
| Lattice | Regular arrangement of atoms in a giant structure | ✓ |
| Delocalised electron | Electrons that are not associated with a particular atom | ✓ |
| Ion | Electrically charged particle, formed when an atom or molecule gains or loses electrons | |
| Lesson 2: Ionic Bonding | | |
| Word | Definition Provided | Sign Assigned |
| Ionic bond | Forms between two atoms when an electron is transferred from one atom to the other, forming a positive-negative ion pair | ✓ |
| Anion | A negatively charged ion | |
| Cation | A positively charged ion | ✓ |
| Attraction | Between different ions of opposite charges | ✓ |
| Repulsion | Between different ions of the same charge | |
| Oxidation | Loss of electrons | ✓ |
| Reduction | Gain of electrons | |
| Lesson 3: Covalent Bonding | | |
| Word | Definition Provided | Sign Assigned |
| Covalent bond | A bond between atoms formed when atoms share electrons to achieve a full outer shell of electron | |
| Electron pair | Two subatomic particles, with a negative charge and a negligible mass relative to protons and neutrons, in the same atom | ✓ |
| Nucleus | Consists of protons and neutrons, in the middle of an atom | ✓ |
| Electrostatic attraction | Force between oppositely charged particles | |
| Intermolecular forces | Weak attractive forces between molecules. When a simple molecular substance melts or boils, it is the intermolecular forces that are broken (not the covalent bonds in each molecule) | ✓ |

| Lesson 4: Polymers | | |
| --- | --- | --- |
| Word | Definition Provided | Sign Assigned |
| Polymer | A large molecule formed from many identical smaller molecules known as monomers | ✓ |
| Monomer | Small molecule, usually containing a C=C bond, that can join end to end with other monomers to form a polymer molecule | ✓ |
| Polymerisation | Chemical reaction in which monomers (small molecules) join together to produce a polymer | |
| Molecule | A collection of two or more atoms held together by chemical bonds | |
| **Lesson 5: Allotropes of Carbon** | | |
| Word | Definition Provided | Sign Assigned |
| Allotrope | A different physical form of something | |
| Buckminster fullerene | A form of carbon consisting of molecules made up of 60 carbons arranged to form a hollow sphere | ✓ |
| Graphite | A form of pure carbon in which all the atoms are bonded to three others in giant sheets which can slide over each other | ✓ |
| Graphene | A form of carbon consisting of a single layer of carbon atoms joined together in hexagonal rings | |
| Nanotube | Long cylindrical molecules made from carbon atoms joined together by covalent bonds | |
| Diamond | A form (allotrope) of pure carbon in which all the atoms are bonded to four others in a giant tetrahedral network structure which is very strong. Diamond is the hardest known natural substance, has a very high melting point and does not conduct electricity | ✓ |