RESEARCH ARTICLE

Sighted and visually impaired students’ perspectives of illustrations, diagrams and drawings in school science

[version 1; peer review: 4 approved]

Celia McDonald, Susan Rodrigues

Liverpool Hope University, Liverpool, UK

Abstract

Background: In this paper we report on the views of students with and without visual impairments on the use of illustrations, diagrams and drawings (IDD) in science lessons.

Method: Our findings are based on data gathered through a brief questionnaire completed by a convenience sample of students prior to trialling new resource material. The questionnaire sought to understand the students’ views about using IDD in science lessons. The classes involved in the study included one class from a primary school, five classes from a secondary school and one class from a school for visually impaired students.

Results: Approximately 20% of the participants thought that the diagrams were boring and just under half (48%) of the total sample (regardless of whether they were sighted or visually impaired) did not think diagrams were easy to use. Only 14% of the participants felt that repeated encounters with the same diagrams made the diagrams easy to understand. Unlike sighted students who can ‘flit’ across diagrams, a visually impaired student may only see or touch a small part of the diagram at a time so for them ‘fliting’ could result in loss of orientation with the diagram.

Conclusions: Treating sighted and visually impaired pupils equally is different to treating them identically. Sighted students incidentally learn how to interpret visual information from a young age. Students who acquire sight loss need to learn the different rules associated with reading tactile diagrams, or large print and those who are congenitally blind do not have visual memories to rely upon.

Keywords
Diagrams, Illustrations, School science, Visually impaired, School students
Introduction
A project funded by the Wellcome Trust to develop educational resources for visually impaired students has enabled us to collect data that explore how visually impaired students and sighted students currently use and make sense of science diagrams in school classrooms. Most of the topics in school science education include illustrations, diagrams and drawings (IDD) which accompany text and are intended to help learners make better sense of key science concepts. However, Bergey et al. (2015) reported that pupils in general have difficulty understanding science diagrams. Similarly, Treagust & Tsui (2013) suggested that coordinating multiple representations (by switching between representations) is a key skill requirement in understanding diagram comprehension in science. Some studies have explored whether diagram comprehension can be improved through training. For example, Bartholomé & Bromme (2009) identified other studies reporting on the impact of instructing school students about the conventional and common features found in IDD.

Agarwal et al. (2014) suggested that the issues identified as challenging for sighted pupils are exacerbated for students with visual impairments. Students with visual impairments may find concepts in science, technology, engineering and mathematics (STEM) subjects even more difficult to grasp because STEM subjects include concepts that rely heavily on visual representation in the form of diagrams, graphs and charts. Yet, as Bergey et al. (2015) reported, common tasks in many school science text books require students to coordinate texts and IDD. Unfortunately, research shows that students often do not pay attention to IDD while reading science texts in schools (Cromley et al., 2010). The Ainsworth (2006) model of learning with representations identified the role of tasks. A task refers to what the student has to do with the IDD, bearing in mind familiarity with the IDD style, topic, spatial skill, working memory capacity and the challenge set (Khooshabeh & Hegarty, 2010).

Several researchers have reported on the skills required to understand diagrams:

1) Kress & Van Leeuwen (1996) reported on the grammar of visual design, which recognizes that images have rules like languages.

2) Gilbert et al. (2008) discussed “metavisual capability” with regard to diagrams in science education and they highlighted the importance of visual literacy and interpretive codes when relating a diagram to a phenomenon.

3) Unsworth (2001) discussed how representational structures visually construct the nature of an event, the circumstances in which they occur and the relationship between participants and objects. Unsworth (2001) explained how visual resources help construct a relationship between the viewer and what is viewed.

Kumar et al. (2001) suggested that visually impaired students may not have a lower cognitive ability than their sighted peers, but because schools rely heavily on vision, visually impaired students experience academic problems. Kumar et al. found that “overcoming barriers to experiencing activities that are unfamiliar is critical in stimulating the intellectual growth of students with visual disabilities”.

Research reporting on improving diagram comprehension tactics through, for example, the use of hyperlinks (Bartholomé & Bromme, 2009) or learner constructed diagrams (Leopold & Leutner, 2012), or the teaching of conventional features of diagrams (Cromley et al., 2013), uses approaches with sighted pupils to evaluate the impact of these tactics. But these strategies might not be appropriate in exploring how the visually impaired student makes sense of science diagrams. For example, Cromley et al. (2013) report on a 25-item measure of diagrams comprehension in biology in which the use of multiple-choice items includes a colour key and invites the students to identify what this colour key indicates about an animal’s features. For some visually impaired students the question focus on colour renders the multiple-choice items inappropriate.

While researchers signal the importance of IDD in science they also signal the need to be able to understand the rules associated with IDD or codes implicit within IDD in order to be able to reach the best interpretation of an IDD. These are visual rules and visual experiences. In order for visually impaired students to have a better understanding of diagrammatic rules or codes when using IDD in science lessons, they need to be encouraged at an early age, not only to learn haptically with explanation, but some advocate that they also need to learn to draw. As Maneki (2013) explained, to be tactile fluent the person needs to be proficient in Braille reading and writing and proficient in drawing and interpreting diagrams. Maneki (2013) suggests that visually impaired children, like sighted children, should be encouraged to read and draw before kindergarten. This needs to be supported throughout their education, just as sighted students are supported in their learning through experience (including observation and making drawings).

This would tie in with Constructivist views on learning, which suggest that a learner responds to sensory experiences by building personal cognitive structures, which constitute the meaning and understanding of their world (Saunders, 1992). As Harlen (2010) noted, babies move their heads and eyes looking particularly at straight lines and contrasts and soon learn to predict movement. For example, when a ball rolls behind a screen they look at the point where it should reappear. In the same way children learn at a very early age about how something is visibly obscured when something is in front of it. These are aspects of understanding science and drawings/diagrams at an early age. However, if a student is congenitally blind or has (some form of) congenitally partial sight then many of the aspects listed earlier are not incidentally learned. This lack of incidental learning means that students with a visual impairment are at a disadvantage when it comes to understanding science diagrams. Similarly, the ability to understand IDD can also be influenced by the student’s life experiences.

Project synopsis
In this article we report on the views of sighted and visually impaired students when they encounter various IDD in science lessons. We use the Ponchillia & Ponchillia (1996) view of visual impairment, i.e. any degree of vision loss, including total blindness
that affects an individual’s ability to perform the tasks of daily life. This may include some of the following: low vision, blindness, congenital birth, adventitiously blind and light perception. We are interested in how visually impaired learners construct meaning and understanding of science concepts when responding to experiences that involve the use of science IDD. The first step for us in addressing this interest was to ascertain the views of sighted and visually impaired students with regard to the current use of IDD in their classes.

Methodology
We identified and contacted schools with students with visual impairments (VIP) through formal routes (through the University’s Special Educational Needs (SEN) contact, the University’s partner schools and through rehabilitation officers at three local authorities). Our research sample was therefore one of convenience. Ethics approval for the research project was given by the Faculty of Education at Liverpool Hope University.

The sample included six mainstream school classes (one primary and five secondary) and a secondary class in a school for visually impaired students. As this was a convenience volunteer sample, the nature of the lesson and the topic being taught were not within our control. (In England, year 5 refers to 9–10 year old students, year 8 refers to 12–13 year old students, year 9 refers to 13–14 year old students, year 10 refers to 14–15 year old students, year 11 refers to 15–16 year old students (Gov.UK, 2016)).

- Mainstream primary class A involved 26 year 5 students, (including 1 VIP student) learning about the phases of the moon.
- School for the visually impaired class B involved 4 (all VIP) year 8 students recapping acids and alkalis, digestive system, electrolysis and distillation.
- Mainstream secondary school class C involved 14 lower ability year 8 students (including 1 VIP student).
- Mainstream secondary school class D involved 24 year 9 students (including 1 VIP student) completing a GCSE physics topic and starting on GCSE biology topic.
- Mainstream secondary school class E involved 20 year 9 (including 1 VIP student) learning about cells.
- Mainstream secondary school class F involved 24 year 10 students (including 1 VIP student) learning about how the universe was formed.
- Mainstream secondary school class G involved 9 year 11 students (including 1 VIP student) learning about kinetic and gravitational energy.

Consent: The schools taking part in the study acted ‘in loco parentis’, thereby meeting the University’s Ethics policy. Prior to issuing the student questionnaire students were asked to complete an informed consent form (versions of the questionnaire and consent form were adapted where necessary to address student access). The form indicated the purpose of our project (trying to improve IDD that are used in school science lessons). The informed consent form indicated that we were in the process of developing materials and we wanted the students’ views of the diagrams that they currently use in science lessons. The informed consent form also indicated that completion of the questionnaire was voluntary and that the completed questionnaires would not identify students by name. In order to maintain anonymity, the students placed their questionnaire in a project box in their classroom.

The questionnaire content (see Supplementary material) included 3 questions. Two questions included tick box options and the third question was an open question. The wording used in the first two questions was arrived at after a discussion with two teachers (one with experience in primary school education and one with experience in secondary school education). Hence, for example, the word ‘messy’ rather than ‘cluttered’ was used in question two.

Results
The tables below present the findings in terms of the number of students (including VIP) who ticked the appropriate box (as a fraction of the total number of students in that class). The table also shows the number of visually impaired (VIP) students in that class who ticked that box (as a fraction of the total number of VIP students in that class). * Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.

Our findings show that over 50% of the students in the mainstream secondary classes, years 8 and 9 did not find diagrams easy to understand (57% year 8: 53% year 9; Table 1). In contrast, in the primary school class over 58% stated that they found diagrams easy to understand. Overall, just over half of the total sample (63/120) stated diagrams were easy to use. Given the visually impaired contingent made up less than 10% of the convenience sample, our findings suggest that a significant number of sighted pupils (nearly 50% of our sample) also struggle to understand diagrams in science.

| Table 1. Students’ response to: “Diagrams in science are easy to understand”. |
|-----------------|--------|-----------------|-----------------|
| Class           | Year   | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
| Primary A       | 5      | 15/26           | 1/1             |
| School B        | 8      | 3/4             | 3/4             |
| Secondary C     | 8      | 6/14            | 0/1             |
| Secondary D     | 9      | 9/23            | 1               |
| Secondary E     | 9      | 11/20           | 0/1             |
| Secondary F     | 10     | 13/24           | unknown *       |
| Secondary G     | 11     | 6/9             | 0/1             |
| Total           | 63/120 | 5/9             |                 |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.
Our findings (Table 2) show that the only visually impaired student who found diagrams boring was in School B. Less than 20% of the total sample found diagrams in science boring.

Interestingly (bearing in mind that less than 20% found diagrams ‘boring’), about 25% of the students in mainstream secondary school classes found that the diagrams used in their science lessons were exciting. There was a marked difference between the responses from primary school students and the responses from secondary school students, with 61% of the primary students indicating that they found the diagrams exciting (while two of the four students in the school for visually impaired found diagrams exciting: Table 3.)

In the school for the visually impaired (School B) 75% of the students found diagrams in science hard work. In the mainstream schools, only the visually impaired students in the lower band found them hard work. Overall, over 50% of our sample of visually impaired students found diagrams hard work, whilst only 23% of the total sample of students found them to be hard work (Table 4).

Our findings (Table 5) show that only 21% of the overall sample of students and 33% of the visually impaired students thought diagrams would be easier to understand when they use small words to explain concepts. Thus, it could be argued that language accompanying the diagrams does not appear to present a barrier for the pupils.

**Table 2. Students’ response to: “Diagrams in science are boring to use”**.

| Class       | Year level | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
|-------------|------------|-------------------------------------------------------|-------------------------------------------------------------|
| Primary A   | Year 5     | 2/26                                                  | 0/1                                                         |
| School B    | Year 8     | 1/4                                                   | 1/4                                                         |
| Secondary C | Year 8     | 0/14                                                  | 0/1                                                         |
| Secondary D | Year 9     | 8/23                                                  | 0/1                                                         |
| Secondary E | Year 9     | 5/20                                                  | 0/1                                                         |
| Secondary F | Year 10    | 6/24                                                  | unknown                                                    |
| Secondary G | Year 11    | 1/9                                                   | 0/1                                                         |
| Total       |            | 23/120                                                | 1/9                                                         |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.

**Table 4. Students’ response to: “Diagrams in science are hard work”**.

| Class       | Year level | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
|-------------|------------|-------------------------------------------------------|-------------------------------------------------------------|
| Primary A   | Year 5     | 10/26                                                 | 0/1                                                         |
| School B    | Year 8     | 3/26                                                  | 3/4                                                         |
| Secondary C | Year 8     | 1/14                                                  | 1/1                                                         |
| Secondary D | Year 9     | 2/23                                                  | 0/1                                                         |
| Secondary E | Year 9     | 2/20                                                  | 0/1                                                         |
| Secondary F | Year 10    | 9/24                                                  | unknown                                                    |
| Secondary G | Year 11    | 1/9                                                   | 1/1                                                         |
| Total       |            | 28/120                                                | 5/9                                                         |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.

**Table 3. Students’ response to: “Diagrams in science are exciting”**.

| Class       | Year level | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
|-------------|------------|-------------------------------------------------------|-------------------------------------------------------------|
| Primary A   | Year 5     | 16/26                                                 | 1/1                                                         |
| School B    | Year 8     | 2/4                                                   | 2/4                                                         |
| Secondary C | Year 8     | 3/14                                                  | 0/1                                                         |
| Secondary D | Year 9     | 0/23                                                  | 0/1                                                         |
| Secondary E | Year 9     | 5/20                                                  | 1/1                                                         |
| Secondary F | Year 10    | 4/24                                                  | unknown                                                    |
| Secondary G | Year 11    | 1/9                                                   | 0/1                                                         |
| Total       |            | 31/120                                                | 4/9                                                         |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.

**Table 5. Students’ response to: “Diagrams in science are easy to understand when they use small words to explain things”**.

| Class       | Year level | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
|-------------|------------|-------------------------------------------------------|-------------------------------------------------------------|
| Primary A   | Year 5     | 9/26                                                  | 1/1                                                         |
| School B    | Year 8     | 1/4                                                   | 1/4                                                         |
| Secondary C | Year 8     | 3/14                                                  | 0/1                                                         |
| Secondary D | Year 9     | 2/23                                                  | 0/1                                                         |
| Secondary E | Year 9     | 5/20                                                  | 0/1                                                         |
| Secondary F | Year 10    | 3/24                                                  | unknown                                                    |
| Secondary G | Year 11    | 2/9                                                   | 1/1                                                         |
| Total       |            | 25/120                                                | 3/9                                                         |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.
Just under a quarter (24%) of the sample indicated that diagrams are easy to understand when they are colourful (Table 6). Just over 50% of the visually impaired sample indicated that diagrams were easy to understand when they are colourful. Only one student from School B did not support this view, probably because that student is unable to distinguish colours.

All the visually impaired students in School B felt that diagrams in science were easy to understand when they were not messy (Table 7). But just under a third of the total sample (39/120) agreed that diagrams were easy to understand when they were not messy.

All of the students in the school for the visually impaired and 77% of year 5 (including the visually impaired student) found diagrams in science easy to understand when someone explained what they meant (Table 8). Interestingly, the mainstream classes were mixed, ranging from 78% of year 11 students down to 29% of year 8 students, found it easy to understand diagrams if they were explained. Overall in the sample, 78% of the visually impaired students found it easy to understand diagrams when someone explained it to them, as did 53% of the total sample of students in the seven classes.

Our findings (Table 9) show that 25% of the overall sample of students found diagrams in science easy to understand when they are simple compared to nearly 50% of the visually impaired students in all seven classes.

### Table 6. Students’ response to: “Diagrams in science are easy to understand when they are colourful”.

| Class       | Year level | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
|-------------|------------|------------------------------------------------------|-------------------------------------------------------------|
| Primary A   | Year 5     | 5/26                                                 | 1/1                                                         |
| School B    | Year 8     | 1/4                                                  | 1/4                                                         |
| Secondary C | Year 8     | 3/14                                                 | 1/1                                                         |
| Secondary D | Year 9     | 6/23                                                 | 1/1                                                         |
| Secondary E | Year 9     | 3/20                                                 | 1/1                                                         |
| Secondary F | Year 10    | 7/24                                                 | unknown *                                                  |
| Secondary G | Year 11    | 4/9                                                  | 0/1                                                         |
| **Total**   | **29/120** | **5/9**                                              |                                                             |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.

### Table 7. Students’ response to: “Diagrams in science are easy to understand when they are not messy”.

| Class       | Year level | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
|-------------|------------|------------------------------------------------------|-------------------------------------------------------------|
| Primary A   | Year 5     | 15/26                                                | 0/1                                                         |
| School B    | Year 8     | 4/4                                                  | 4/4                                                         |
| Secondary C | Year 8     | 1/14                                                 | 0/1                                                         |
| Secondary D | Year 9     | 6/23                                                 | 0/1                                                         |
| Secondary E | Year 9     | 4/20                                                 | 0/1                                                         |
| Secondary F | Year 10    | 9/24                                                 | unknown *                                                  |
| Secondary G | Year 11    | 0/9                                                  | 0/1                                                         |
| **Total**   | **39/120** | **4/9**                                              |                                                             |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.

### Table 8. Students’ response to: “Diagrams in science are easy to understand when someone explains what they mean”.

| Class       | Year level | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
|-------------|------------|------------------------------------------------------|-------------------------------------------------------------|
| Primary A   | Year 5     | 20/26                                                | 1/1                                                         |
| School B    | Year 8     | 4/4                                                  | 4/4                                                         |
| Secondary C | Year 8     | 4/14                                                 | 0/1                                                         |
| Secondary D | Year 9     | 7/23                                                 | 1/1                                                         |
| Secondary E | Year 9     | 9/20                                                 | 0/1                                                         |
| Secondary F | Year 10    | 13/24                                                | unknown *                                                  |
| Secondary G | Year 11    | 7/9                                                  | 1/1                                                         |
| **Total**   | **64/120** | **7/9**                                              |                                                             |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.

### Table 9. Students’ response to: “Diagrams in science are easy to understand when they are simple”.

| Class       | Year level | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
|-------------|------------|------------------------------------------------------|-------------------------------------------------------------|
| Primary A   | Year 5     | 7/26                                                 | 1/1                                                         |
| School B    | Year 8     | 2/4                                                  | 2/4                                                         |
| Secondary C | Year 8     | 1/14                                                 | 1/1                                                         |
| Secondary D | Year 9     | 3/23                                                 | 0/1                                                         |
| Secondary E | Year 9     | 7/20                                                 | 0/1                                                         |
| Secondary F | Year 10    | 8/24                                                 | unknown *                                                  |
| Secondary G | Year 11    | 2/9                                                  | 0/1                                                         |
| **Total**   | **30/120** | **4/9**                                              |                                                             |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.
Over 50% of the visually impaired students (the majority of whom were from the school for visually impaired) found diagrams in science easy to understand if the same ones are used often. Only 14% of the total sample felt that repeated encounters with the same diagrams made those diagrams in science easy to understand (Table 10).

Over 50% of the visually impaired students found diagrams in science easy to understand when they had seen or used them before (Table 11). However, the majority of those were from the school for visually impaired students. Only 16% of the overall sample felt diagrams were easy to understand if they had seen them before.

### Table 10. Students’ response to: “Diagrams in science are easy to understand when we use the same ones often”.

| Class      | Year level | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
|------------|------------|------------------------------------------------------|-------------------------------------------------------------|
| Primary A  | Year 5     | 6/26                                                 | 1/1                                                         |
| School B   | Year 8     | 3/4                                                  | 3/4                                                         |
| Secondary C| Year 8     | 1/14                                                 | 1/1                                                         |
| Secondary D| Year 9     | 2/23                                                 | 0/1                                                         |
| Secondary E| Year 9     | 2/20                                                 | 0/1                                                         |
| Secondary F| Year 10    | 2/24                                                 | unknown *                                                   |
| Secondary G| Year 11    | 1/9                                                  | 0/1                                                         |
| **Total**  |            | **17/120**                                           | **5/9**                                                     |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.

### Table 11. Students’ response to: “Diagrams in science are easy to understand when I’ve seen or used them before”.

| Class      | Year level | Respondent students/Total number of students in class | Respondent VIP students/Total number of VIP students in class |
|------------|------------|------------------------------------------------------|-------------------------------------------------------------|
| Primary A  | Year 5     | 9/26                                                 | 1/1                                                         |
| School B   | Year 8     | 2/4                                                  | 2/4                                                         |
| Secondary C| Year 8     | 0/14                                                 | 0/1                                                         |
| Secondary D| Year 9     | 1/23                                                 | 1/1                                                         |
| Secondary E| Year 9     | 2/20                                                 | 0/1                                                         |
| Secondary F| Year 10    | 4/24                                                 | unknown *                                                   |
| Secondary G| Year 11    | 1/9                                                  | 1/1                                                         |
| **Total**  |            | **19/120**                                           | **5/9**                                                     |

* Please note we use ‘unknown’ in the tables if the VIP student did not identify her/himself when s/he completed the questionnaire.

**Discussion**

Our findings showed that in mainstream schools significant numbers of students found that diagrams were not easy to understand regardless of whether they were sighted or visually impaired. Our findings also showed that visually impaired students at the school for the visually impaired thought that diagrams in science were easy to understand. This may be because the classes were smaller in that school, and our observation of the classes (see McDonald & Rodrigues, 2016) showed that the strategies and skills used by the teachers were more individually focussed.

However, visually impaired students at the school for the visually impaired found diagrams hard work and felt that they were more able to understand them if the diagrams were not messy. This could be for several reasons. Our observation showed that in the school for visually impaired students, the teacher ensured that the students engaged with the diagrams and that the students had to take responsibility for making sense of the information; in mainstream classes the classroom assistant engaged with the diagram and acted as a type of interpreter, translated their viewing into a verbal account for the relevant student. Another reason may stem from the fact that in the school for the visually impaired the teacher spent a great deal of time ensuring the whole class understood the diagrams, which made it ‘hard work’ given the effort required by the students to understand the diagrams. Another reason may arise from the fact that the students observed in the school for the visually impaired were congenitally blind, whereas the visually impaired students in mainstream classes were partially sighted and the majority had 1:1 learning support assistants who explained the diagrams and assisted in answering questions. This might also account for why the visually impaired students in the mainstream classes did not find the diagrams ‘hard work’, or even notice if they were messy! Talking specifically about special education Kumar et al. (2001) cited the work of Kamii & DeVries (1993) who argued a constructivist principle: that a teacher should not serve as a source of knowledge but should see their role as helping the student to construct their knowledge. During our project the teachers commented on the need to cover an increasing amount of subject content and identified the role of assessment in driving and determining goals. This may inadvertently mean that life skills such as learning how to interpret diagrams become overwhelmed by other goals.

As the teacher in the school for visually impaired students commented, sighted students can “flit” back and forth on the diagram, whereas for a visually impaired student who can only see or touch a small part of the diagram at a time to “flit” would mean losing their place and orientation within the diagram. It can also be very confusing to a visually impaired person to read a tactile diagram where an element goes behind another element and then reappears. To a visually impaired person there are three entities not two. Not surprisingly then, reading a tactile or large print diagram requires a great deal of memory to hold a current interpretation and understand the position with regard to the complete diagram. This supports an argument for simplicity in diagrams. Sighted students incidentally learn how to interpret visual information from a young age. Students who acquire sight loss need to learn the different
rules associated with reading tactile diagrams, or large print and those who are congenitally blind do not have visual memories to rely upon.

The fact that only 16% of the students in our convenience sample found that diagrams were easier to understand if they had encountered them before suggests that increased viewing does not result in better familiarity. Interestingly, in the school for the visually impaired the students did find that using the same diagrams often made the diagrams easier to understand. Access to assistance may also be a factor, for the two visually impaired students in mainstream classes who found using the same diagram often made the diagrams easier to understand did not have a 1:1 classroom assistant support.

In our sample of visually impaired students, a majority felt that colour would benefit their understanding of diagrams. The one visually impaired student, who did not support this view, has difficulty with colour. Thus it should be noted that one solution might not suit all visually impaired students. As Kevin Carey (Chair, Royal National Institute for the Blind group) said, “the root philosophical problem is the confusion between treating people equally and identically.”

**Data availability**
All source data relevant to this study are presented in Table 1–Table 11.

**Author contributions**
SR conceived the study, CM and SR designed the research, CM carried out the research, CM and SR analysed the data, produced drafts and the final version of the manuscript and agreed to the final content.

**Competing interests**
No competing interests were disclosed.

**Grant information**
This work was supported by the Wellcome Trust [109272].

---

### Supplementary material

**Student Questionnaire**

1. Diagrams in science are:
   - □ easy to understand
   - □ boring to use
   - □ exciting
   - □ hard work

2. Diagrams in science are easy to understand when:
   - □ they use small words to explain things
   - □ they are colourful
   - □ they are not messy
   - □ someone explains what they mean
   - □ they are simple
   - □ we use the same ones often
   - □ I’ve seen them before

3. If your friend found it hard to understand a diagram in science what would you do to make it easier to understand?
References

Agarwal A, Jeeawoody S, Yamane M: 3D Printed Teaching Aids for Students with Visual Impairments Final Report. Corporate Partner: benetech, 2014.

Ainsworth S: DeFT: A conceptual framework for considering learning with multiple representations. Learn Instr. 2006; 16(3): 183–198.

Bartholomé T, Bromme R: Coherence formation when learning from text and pictures: What kind of support for whom? J Educ Psychol. 2009; 101(2): 282–293.

Bergkey BW, Cromley JG, Newcombe NS: Teaching high school biology students to coordinate text and diagrams: Relations with transfer, effort and spatial skills. Int J Sci Educ. 2015; 37(15): 2476–2502.

Carey K: A strange debit of gratitude. Speech at St. Vincent’s School, Liverpool and the CBI AGM, 2013.

Cromley JG, Perez AC, Fitzhugh S, et al.: Improving students’ diagrammatic reasoning: A classroom intervention study. J Exp Educ. 2013; 81(4): 511–537.

Cromley JG, Synder-Hogan LE, Lucier-Dubas UA: Cognitive activities in complex science text and diagrams. Contemporary Educational Psychology. 2010; 35(1): 59–74.

Gilbert J, Reiner M, Nakhlé M: Visualization: Theory and Practice in Science Education. The Netherlands: Springer, 2008; 3.

Gov.UK: The National Curriculum. Retrieved 21st October, 2016.

Harlen W: Principles and big ideas of science education. Hatfield: Association for Science Education. 2010.

Karni C, DeVries R: Exceptional Children: Introduction to Special Education. Englewood Cliffs NJ: Prentice-Hall, Inc. 1993.

Kumar DD, Ramasamy R, Stefanich GP: Science for students with visual impairments: Teaching suggestions and policy implications for Secondary C educators. Electronic Journal of Science Education. Retrieved 3rd March, 2001; 5(3).

Khooshabeh P, Hegarty M: Inferring cross-sections: When internal visualizations are more important than properties of external visualizations. Human Computer Interaction. 2010; 25(2): 119–147.

Kress G, Van Leeuwen T: The Grammar of Visual Design. London:Routledge. 1996.

Kumar DD, Ramasamy R, Stefanich GP: Science for students with visual impairments: Teaching suggestions and policy implications for Secondary C educators. Electronic Journal of Science Education. Retrieved 3rd March, 2001; 5(3).

Kress G, Van Leeuwen T: The Grammar of Visual Design. London:Routledge. 1996.

Leopold C, Leutner D: Science text comprehension: Drawing, main idea selection, and summarizing as learning strategies. Learn Instr. 2012; 22(1): 16–26.

Maneki A: The Dawn of the Age of Tactile Fluency Let the Revolution Begin! Braille Monitor. 2013; 56(10): 728.

McDonald C, Rodrigues S: Education for Global Citizenship: Approaches that help us to understand the teaching and learning processes for visually impaired students. Paper presented at TEESnet Conference Liverpool, 21st September 2016. 2016.

Ponchillia PE, Ponchillia SV: Foundation of rehabilitation teaching with persons who are blind or visually impaired. New York: American Foundation for the Blind. 1996.

Ponchillia PE, Ponchillia SV: Foundation of rehabilitation teaching with persons who are blind or visually impaired. New York: American Foundation for the Blind. 1996.

Unsworth L: Teaching Multiliteracies Across the Curriculum. Buckingham Open University Press. 2001.
Open Peer Review

Current Peer Review Status: ✔️ ✔️ ✔️ ✔️

Version 1

Reviewer Report 09 December 2016

https://doi.org/10.21956/wellcomeopenres.10743.r17574

© 2016 Holbrook J et al. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Jack Holbrook
Centre for Science Education, University of Tartu, Tartu, Estonia

Miia Rannikmae
Centre for Science Education, University of Tartu, Tartu, Estonia

This research article is based on a simple questionnaire administered to students seeking perspectives on non-written text such as illustrations, diagrams, etc. The article is well written and easy to follow, leading to clear and justified conclusions.

The title of the article is very appropriate and the abstract provides a useful overview of the research. The study design is kept simple, but is very suitable for the intended research, well executed and the analysis, although limited, is very suitable for the intended investigation.

Although the questionnaire items are very clear and appropriate, the limitation for the reader is in the appreciation of the difficulty difference in dealing with diagrams, etc. between well sighted and visual impaired students. It is suggested here that an example of such a diagram is helpful as well as insights into how the gaining of the holistic picture by sighted students is an advantage versus the building up of parts by visually impaired students (apart from the speed of operation which is well alluded to in the research).

It is noted that the coverage of the discussion is not for a specific diagram, set of diagrams, or for a specific educational level of student. This means that it looking at the findings in a generalised sense and aspects such as validity of the diagram, or the reliability of responses are not entertained. In this respect the paper does not lead to how good diagrams are recognised or how developers of teaching materials need to pay attention to diagrams, charts, etc.

As a final point, the article is easy to read and could thus serve as a useful source for PhD students as they seek to build their own studies, especially non-native English readers.

Competing Interests: No competing interests were disclosed.
We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 09 Dec 2016

Susan Rodrigues, Liverpool Hope University, Liverpool, UK

Thank you for that comprehensive review of our article. Your feedback is appreciated more so given PISA findings show that Estonia appear to have done rather well in School Science! We take on board your comments regarding the challenge in appreciating the difficulty for sighted and visually impaired students in making sense of diagrams. We are hoping that our coverage of the research reported in this paper (drawing on the questionnaire) will be complemented by the papers/articles in production that draw on observation of classroom practice, taking into consideration working memory capacity, positioning theory and teacher and student agency in order to discuss specific diagrams, sets of diagrams, and specific student educational levels.

We have also opted to provide guidance with regard to creating accessible diagrams based on our research findings, in the form of a short vodcast that is available at: https://www.youtube.com/watch?v=cmj0QXJA3Iw

Competing Interests: No competing interests were disclosed.

Reviewer Report 28 November 2016

https://doi.org/10.21956/wellcomeopenres.10743.r18020

© 2016 Varughese V. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Varughese K Varughese
Department of Vocational Heath and Sciences, Royal Melbourne Institute of Technology, Melbourne, VIC, Australia

- The title is appropriate for the content of the article.
- The abstract and discussion are well documented.
- The study is described in enough detail to replicate it.
- Data collection was conducted with appropriate ethical approval.
- The result section describes the data and the Tables 1 to 11 are self-explanatory. However, one observation is that Table 10 & Table 11 depict more or less the same data. In my view
this could confuse students and Table 11 could have been avoided altogether or changed to ‘science becomes boring when the same diagrams are repeatedly used’.

○ The research article throws light on the measures to be taken for the enhancement of learning and teaching processes for visually impaired students in STEM subjects.

○ The article depicts the challenges faced in catering for the need for visually impaired students.

○ Proper referencing is done.

**Competing Interests:** No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

**Author Response 09 Dec 2016**

Susan Rodrigues, Liverpool Hope University, Liverpool, UK

Thank you for the review of our article. Not sure that collapsing the statements that resulted in data we presented in table 10 and table 11 is the way to go! For changing them to ‘science becomes boring when the same diagrams are repeatedly used’, fails to account for other reasons why diagrams becomes boring! Also, what our findings suggest is that diagram familiarity does not necessarily make it easier to understand.

**Competing Interests:** No competing interests were disclosed.

**Reviewer Report 22 November 2016**

https://doi.org/10.21956/wellcomeopenres.10743.r17573

© 2016 Taylor N. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Neil Taylor
School of Education and Social Work, University of Dundee, Dundee, UK

The title is appropriate and abstract provides a good summary of the article. The article is of importance to teachers involved in science education as it clearly demonstrates the challenges faced by sighted and visually impaired pupils as they try to interpret IDDs. The article also draws to the attention of practitioners the further challenges visually impaired learners face. The article illustrates the ways in which pupils find interpreting IDDs difficult and indicating more effective ways for pupils to engage with IDDs.

There are claims though on p4 which state that, “over 50% ...... did not find diagrams easy to
understand". My challenge to this claim is that the authors are including responses such as "boring to use" and "exciting" as part of the total not responding to "easy to understand". Boring and exciting do not necessarily imply 'not easy to understand'.

This a very accessible piece of work and will be of interest to practitioners.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 22 Nov 2016

Susan Rodrigues, Liverpool Hope University, Liverpool, UK

Thank you for the review. We agree, boring and exciting do not necessarily imply easy to understand- that is why the data is reported in individual tables for each statement. So Table 1 on page 4 (and the percentage) only refers to the responses related to diagrams are easy to understand (it does not include responses to the other statements such as boring to use or exciting in that total). The responses to diagrams in science are boring are reported in Table 2 and the responses to diagrams in science are exciting are reported in Table 3. Thank you again for your review.

Competing Interests: No competing interests were disclosed.

Reviewer Report 21 November 2016

https://doi.org/10.21956/wellcomeopenres.10743.r17576

© 2016 Reid N. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Norman Reid
University of Glasgow, Glasgow, UK

The overall presentation is clear, with adequate referencing.

I think ‘constructivist views' should be stronger. The evidence that learners construct understandings idiosyncratically is overwhelming. Perhaps replace ‘views' by ‘findings'.

In interpreting the findings, the key possibly rests in table 7. Working memory is overloaded when a diagram is too cluttered. There is considerable circumstantial evidence that diagrams can have a positive or negative value in understanding and that limitations of working memory explain the differences. The work of Sweller (1999) might be worth considering. This insight might
strengthen the discussion section, which is largely descriptive.

References
1. Sweller J: Instructional design. Australian Educational Review. 1999.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 22 Nov 2016

Susan Rodrigues, Liverpool Hope University, Liverpool, UK

Thank you for your review. We will certainly take on board the issue of working memory (a lack of working memory on our part). We will consider using Sweller’s work and the research on working memory in future reports that may arise during the life time of this project. Thank you for your insight.

Competing Interests: No competing interests were disclosed.

Comments on this article

Version 1

Author Response 22 Nov 2016

Susan Rodrigues, Liverpool Hope University, Liverpool, UK

Thank you for your comment. Much appreciated.

Competing Interests: No competing interests were disclosed.

Reader Comment 16 Nov 2016

John Pearson, Royal New Zealand College of General Practitioners (retired), New Zealand

Fascinating research, well conceived and carried out. Useful findings for all of those who have visually impaired students in their classes and a reminder how difficult many students find understanding diagrams.

Competing Interests: no competing interests