# RNIB Centre for Accessible Information (CAI)

# Literature review #6

# Teaching STEM subjects to blind and partially sighted students: Literature review and resources

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**Author:**

Heather Cryer (Research Officer, CAI)

Tel: 0121 665 4211

Email: [heather.cryer@rnib.org.uk](mailto:heather.cryer@rnib.org.uk)

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# Teaching STEM subjects to blind and partially sighted learners: Literature review and resources

## RNIB Centre for Accessible Information (CAI)

### Prepared by:

Heather Cryer (Research Officer, CAI)

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### Executive Summary

Technical subjects such as Science, Technology, Engineering and maths (STEM) have often been cited as difficult for blind or partially sighted students. This literature review aims to highlight some of the specific challenges faced by this group in these subjects, and to identify good practice and resources which can improve access to these subjects.

Key challenges:

* Accessing technical notation: the conversion of equations to accessible formats is not straightforward, and the presentation of non-linear information into linear formats such as braille or audio is challenging
* Accessing visual resources: many STEM subjects rely heavily on visual resource such as graphs, diagrams and charts, which can be inaccessible to blind/partially sighted students unless presented in an alternative format
* Understanding visual concepts: the comprehension of ideas that cannot be easily explained in words or through 2D images may also pose a challenge for those without vision, and more work is needed to identify effective ways of teaching such concepts
* Experimenting without vision: some aspects of engaging in classroom activities such as experiments may be difficult for blind/partially sighted students with a lack of appropriate resources and clear explanation
* Teaching methods: STEM subjects are commonly (and effectively) taught through ‘chalk and talk’ methods which involve listening to the teacher and working through examples on the board. Without appropriate support, these methods can be inaccessible to students who can’t see the board
* Teaching strategies: various research highlights the need for teacher training to equip teachers to overcome these problems

Many resources are available online relating to involving blind/partially sighted students in STEM subjects. These are signposted in Part 2 of this report. However, some gaps are evident – particularly in the fields of engineering and technology.

Other groups are also investigating this area, and it is hoped we can work together and identify solutions to improve access to STEM subjects for blind/partially sighted students. Key recommendations from this report are as follows:

* Document good practice guidance on the conversion of technical information into accessible formats, and where such guidance is already available (such as work already done by University of Bath), ensure it is widely publicised and used
* Document good practice relating to the presentation of visual resources to blind/partially sighted students
* Investigate the effectiveness of tactile materials and whether students are equipped with the right skills and support to use these effectively
* Publicise existing guidance relating to verbal descriptions of non-text Science content
* If further guidance is needed, make use of the development principles shown by Gould and Ferrell (2009) involving end users in the development of guidance
* Provide guidance on teaching ‘visual concepts’ to students without sight, perhaps through case studies or examples to stimulate ideas
* Publicise existing guidance on involving blind/partially sighted students in practical lessons such as experiments and observations
* Identify or provide guidance on teaching methods to optimise the experience of blind/partially sighted students in the classroom
* Develop training to increase the confidence of teachers/lecturers in teaching blind/partially sighted students technical subjects. This could be done through networking teachers, getting them to share ideas and good practice, workshops or online courses
* Investigate the potential of interventions found in research to be beneficial, such as bringing together specialists in visual impairment and specialists in STEM subjects to work together on access solutions
* Improve communication between students and teachers so teachers are aware of what blind/partially sighted students need
* Conduct and publish further scientific research on effective interventions in teaching STEM subjects to students with visual impairments

### Part 1: Literature review

#### Introduction

It is a long held belief that technical subjects such as Science, Technology, Engineering and Maths (STEM) can be particularly challenging for blind or partially sighted learners. For example, **Beal and Shaw (2008)** report that achievements in maths by blind and partially sighted learners tend to be below their performance in other academic subjects. **Rapp and Rapp (1992)** report that visually impaired students - particularly those who used braille - were less likely to participate in advanced mathematics classes. Similar findings for science were reported by **Dunkerton (1997)**.

Despite this supposed difficulty, there is evidence that blind and partially sighted learners can perform well in STEM subjects, and even excel at them. **Klingenberg, Fosse and Augestad (2012)** found that in a longitudinal sample over 40 years, the majority (57%) of blind/partially sighted learners were taught mathematics at grade level (the same level as their sighted peers). **Jackson (2002)** reports on various blind mathematicians who excel in their fields. He concludes that some may benefit from their blindness in terms of dealing solely with their imagination of shapes and planes rather than being distracted by two-dimensional depictions of them as sighted students are. Indeed, **Fletcher (2011)** reports on a blind student who views his disability as an advantage in his studies of organic chemistry.

So what are the challenges in STEM subjects for blind and partially sighted learners?

This has been a topic of discussion among professionals from as far back as 1934, when an article in The New Beacon highlighted two problems for blind learners of maths – the lack of a comprehensive system of notation for mathematics, and suitable apparatus (**The New Beacon, 1934**). Both of these problems remain a challenge today.

#### Accessing technical notation

The need for a system by which to access technical notation - such as mathematical equations, chemical formulae and so on - remains a challenge. Indeed, **Cahill, Lineham, McCarthy, Bormans and Engelen (1996)** report that the 'mechanical aspects' of mathematics - reading the questions, dealing with long and cumbersome braille materials, manipulating information - caused more difficulty for blind and partially sighted students than did the conceptual side of mathematics.

There are various issues with accessing technical information in alternative formats. Accessing equations via braille or audio formats is challenging because these formats are by nature linear, whilst a printed equation gives more of an overview (**Rowlett and Rowlett, 2009**). Similarly, with large or magnified print, it is difficult for a student to access a whole equation at once, meaning they are using their memory as well as trying to work out the equation, perhaps placing them at a disadvantage (**Beal and Shaw, 2008**). Further difficulties with large print versions of resources include where to break equations which do not fit on a single page (**Rowlett, 2008**). This can also be a problem in electronic formats (such as Word, LaTeX and MathML) which have limited automatic line breaking of equations. This means if some notes are made accessible at one size, and then need to be altered to a different size, the whole document may need re-typesetting (**Cliffe, 2009**).

Using audio - either via technology or using a human reader - can be ambiguous. **Rowlett and Rowlett (2009)** give the example of a lecturer saying "a plus b over c" which could mean "a plus b, all over c" or "a plus [stop] b over c".

A further challenge in accessing complex equations in accessible formats is the technical conversion of such information. **Cliffe (2009)** highlights how symbolic subjects such as mathematics are significantly more difficult to provide accessible resources for than other more literary-based subjects. Cliffe suggests that the two dimensional nature of equations, non-linear reading order and large symbol set of mathematics all contribute to the complexity of conversion.

In order to convert information from one format to another, the meaning of a visually presented equation must be captured and then delivered in a format that the learner can access and understand.

One technical solution to this problem is a page layout language called LaTeX (**Unwalla, 2006**). LaTeX is a typesetting system which allows authors to focus on the content of their writing, whilst inputting commands to deal with the presentation. This splitting of content and presentation means the visual aspects of the presentation are removed and meaning is maintained, making LaTeX a linear format. LaTeX is familiar to many academics in technical subjects (as it is widely used in technical publishing), therefore this system offers a possible means of communication between readers of different formats (**Spybey, 2012).**

Whilst this seems like a neat solution, the second step of delivering the information in a format the learner can understand remains a challenge. LaTeX is not designed to be 'human readable' – the commands relating to presentation make it complicated to read (**Cliffe, 2009;** **Williams and Irving, 2012)**. Therefore receiving a copy of a textbook in LaTeX, for example, could be seen as a starting point rather than an end in itself (**Rowlett and Rowlett, 2012)**. There are a number of instances of individuals developing ad hoc solutions starting with LaTex. For example, **Williams and Irving (2012)** describe a method for converting LaTeX source files into more usable code either for use with a refreshable braille display or to listen to in spoken English (see <http://latex-access.sourceforge.net/> for further information).

Another technical solution is MathML (mathematical markup language) which aims to capture both content and structure of mathematical equations. MathML was designed for machine to machine communication of mathematics (for example, displaying mathematical formula on a webpage) (**W3C, 2011**). The system helps users to access maths electronically. However, MathML is a less well known format among academics, and less widely used than LaTeX (**Cliffe, 2009; Cooper, 2012**), therefore using this format would still require time consuming conversion from original files.

The difficulty of producing technical material in accessible formats makes it difficult for learners of technical subjects not only to access key materials such as lecture notes, but also to carry out further reading around the subject (**Rowlett and Rowlett, 2009**). As conversion to accessible formats is very time consuming and costly, blind/partially sighted learners only tend to have access to materials they really need to be produced, such as core texts. This means they may fall behind their sighted peers who can read around the subject, carrying out independent research and so on.

Work is being carried out to identify and publicise solutions to these problems. A project lead by the University of Bath has developed comprehensive guidance for Higher Education staff on the subject of producing accessible learning resources in maths (see [Maths Resources](#_UK)).

#### Accessing visual resources – diagrams, graphs and charts

Not only is technical notation difficult to access in STEM subjects, but these subjects are also known for the large number of visual resources used, such as diagrams, graphs and charts (**Gardner, Stewart, Francioni and Smith, 2002; Gould and Ferrell, 2009)**.

In science education, students report difficulty in learning about topics that they can’t experience directly, such as cell structures at one extreme and volcanoes at another (**Jones, Minogue, Oppewal, Cook and Broadwell, 2006**).

**Smith and Smothers (2012)** suggest that a key issue in STEM fields is data analysis, which often relies on visual presentation of data. **Fisher and Hartmann (2005)** highlight guidance for teaching mathematics which states that ‘representations are fundamental to understanding and applying mathematics’.

**Cahill et al (1996)** found that blind students rated aspects of mathematics that were more graphical-spatial as being the most difficult (such as graphs, tables and trigonometry). **Krizack (2000)** reports anecdotal evidence that many blind/partially sighted students are put off scientific subjects due to poor methods of representing molecular and cellular structures. The traditional options of descriptions of print diagrams or use of raised line drawings have been found wanting, and led to the development of specialist models using textures and small raised symbols to convey information.

**Ramloll, Yu, Brewster, Riedel, Burton and Dimigen (2000)** described the predominance of tactile graphics for accessing representations in a number of Scottish institutions educating blind students. However, **Ramloll et al** observed that the production of tactile graphics always required the input of a sighted person, and they felt a system could be developed to give blind/partially sighted students more independence. Their paper describes the initial development of a computer system to combine tactile and audio information which would allow blind users to access line graphs.

Audio methods can be used to access visual resources, such as through ‘tone plots’ which offer a qualitative overview of a graph through mapping the x axis to time and the y axis to a tone which is high for large y values or low for small y values (**Bulatov and Gardner, 1998)**. More recent developments in this area allow for active exploration of a graph, with different types of sounds giving information as the user accesses different areas of the graph, for example, using a tablet computer and pen. **Cohen, Meacham and Skaff (2006)** developed such a system, which used continuous tones which varied in pitch and loudness as the user explored the features and edges of the graph. Pre-recorded information in synthetic speech was also accessible through clicking on particular features. Initial testing showed blind users found the system easy to use and were able to answer comprehension questions about the graphs displayed. This system has been developed to display more complex graphics such as algorithm animations of computer science concepts (**Calder, Cohen, Lanzoni, Landry and Skaff, 2007**).

An example of using both graphis and audio together can be found in the Touch Graphics tactile pen and STEM binder (**Touch Graphics, not dated**). This product combines both quality tactile and visual resources and a pen-like device which delivers audio information when put in contact with the graphics.

Another example of technology being used to develop new ways for blind/partially sighted students to access visual resources is described by **Jones et al (2006)**. They report on a haptic device using a pen-like stylus which simulates fingertip contact with virtual objects. The stylus is used with a computer program containing virtual models which can be zoomed in and out of, and explored by touch using the stylus. This device was tested with blind and partially sighted science students to explore cell structure, and findings showed that students could name more parts of the cell after testing, and found the experience engaging.

**Fraser and Maguvhe (2008)** highlight the importance of tactile stimuli in learning science, to help blind learners to perceive size and shape, for example. However, they also note some key areas for consideration when using tactile graphics, such as clear labelling, spatial orientation of the diagram, and not using over complicated or ‘busy’ images (see [General resources](#_Rest_of_world) for links to guidance on the production of tactile graphics). Indeed, other research with both teachers and students found that the use of tactile graphics in school education had both benefits and pitfalls (**Aldrich and Sheppard, 2001; Sheppard and Aldrich, 2001**). Aldrich and Sheppard found that whilst many young pupils were keen on tactile graphics and found them fun and interesting, older pupils found them more difficult, likely due to the content they were studying. Examples of successful tactile graphics included a diagram of waves to help students understand what a wave is. Examples of unsuccessful graphics included a diagram of the structure of the brain, which was overwhelming with too much information. **Sheppard and Aldrich (2001)** report teachers highlighting benefits of tactile graphics such as helping pupils to think in a different way, and to get across information which couldn’t be explained in words. However, many teachers reported that pupils struggled to understand diagrams. **Cryer and Gunn (2008)** highlight the importance of users being equipped with the right skills and strategies to explore tactile graphics, to ensure that they get the most out of materials presented to them.

Another way in which visual resources can be accessed by blind/partially sighted students is simply through description.

**Gould and Ferrell (2009)** describe a process of developing research based guidelines for the effective description of non-textual science content. They began with a survey of blind/partially sighted scientists/professionals in related fields to find out current practice and preferences for description of scientific images/charts/tables etc. A list of good practice was created which was then refined by blind/partially sighted professionals and students in STEM fields as well as sighted describers. Key findings included that users were most keen on brevity of descriptions and wanted descriptions to focus on the data and not on description of visual elements.

This work by Gould and Ferrell demonstrates good practice in developing guidance based on the needs and preferences of those who will use it. Further work like this could improve access to visual resources for blind/partially sighted people in STEM fields.

#### Understanding visual concepts

Not only are visual resources widely used in STEM subjects, but various concepts in these fields could be also described as ‘visual concepts’. **Fisher and Hartmann (2005)** discuss the importance of representations in mathematics (e.g. tables, graphs, symbols). They focus on guidance from the Principles and Standards for School Mathematics by the National Council of Teachers of Mathematics, which defines representations as “processes and products that are observable externally as well as those that occur internally in the minds of people doing mathematics” (**NCTM, 2000, p. 67, cited in Fisher and Hartmann, 2005)**. **Fisher and Hartmann (2005)** consider concepts in geometry, such as comprehension of two dimensional representations of three dimensional objects, and how this process is different for someone without vision.

Indeed, **Kubiak-Becker and Dick (1996)** report on a blind mathematician who had difficulty grasping spatial concepts without practical experience of them, the example being having to stand on a chair to investigate how walls meet the ceiling.

RNIB are currently investigating the potential of 3D printing for use in education - see [Resources Section](#_UK_3).

Lack of vision isn’t always a hindrance to understanding spatial concepts. **Fletcher (2011)** reports on a blind chemist who finds his blindness an advantage over his sighted peers, as he feels his experience of having to visualise everything in his mind (such as street maps) means he is well practiced for conceptualising complex arrangements of double helixes and so on.

#### Experimenting without vision

Some aspects of engagement with classroom practice in science can be difficult for blind/partially sighted students without appropriate resources and instruction

According to **Jones, Forrester, Robertson, Gardner and Taylor (2012)**, learning to estimate measurements is an important skill in science and in life. Making measurements tends to rely on visual perception, therefore this is an area which can be difficult for blind/partially sighted students. **Jones et al (2012)** tested the estimation skills of blind/partially sighted students. Tasks involved the students showing with their hands how long they thought various measurements were (e.g. millimetre, centimetre, metre), and feeling wooden rods and estimating their length. Results showed that whilst blind/partially sighted students were reasonably good at estimating measurements related to their real-world experience (such as pacing the length of a hallway), they were less able to estimate small distances (such as millimetres and centimetres).

According to **Erwin, Perkins, Ayala, Fine and Rubin (2001)** a key part of scientific discovery involves taking risks, something which children with visual impairments may be discouraged from doing. **Erwin et al (2001)** report on the development of a science curriculum for children which aims to demonstrate the connection between children’s play and scientific investigation. Observation of children taking part in the activities outlined by this curriculum showed that children were enthusiastic, persistent in their investigations, developed positive relationships with peers, used scientific language and made connections between their studies and the real world. This study demonstrates the importance of engaging children in science at an early age, and shows that children with visual impairments can be involved just like their peers.

Various ideas have been documented for adapting science experiments/curriculum for students with visual impairments, to allow them to become more involved and excited by science. See [Science Resources](#_2.1_Practical_guidance/resources) for further information.

#### Teaching methods

Another area which may be inaccessible to blind/partially sighted students without appropriate support is the way in which STEM subjects are taught. **Rowlett and Rowlett (2009)** highlight the fact that maths is often taught using the ‘chalk and talk’ method of teaching, focussing primarily on what the teacher is saying, and worked examples on a board. This can be difficult for blind/partially sighted learners as they are not able to see these worked examples and concept development on the board, but need the practice just like any other student (**Rowlett, 2008**). Whilst perhaps a simple conclusion would be to use a more accessible teaching method, the Quality Assurance Agency (QAA) for Higher Education has found chalk and talk methods to have substantial merit in mathematics teaching (**QAA, 2007**).

Another problem is that it is difficult to take in a lot of spoken information, and trying to take in large amounts of spoken mathematics – without reference to what is happening on the board, or written notes – can place high demands on memory (**Cliffe, 2009**). Spoken instruction can also be ambiguous, with teachers using gestures and referring to ‘this equation’ for example (**Rowlett and Rowlett, 2009; Cliffe, 2009**).

Some students have someone to help them such as a notetaker/class aide, which can be of use. However, a notetaker cannot explain what is happening on the board whilst the teacher is talking, and working through examples with a notetaker reading them aloud is a slow process, and can be difficult to concentrate on whilst the rest of the class are discussing the work as well (**Rowlett, 2008**). Furthermore, the presence of a notetaker/assistant may be a barrier to interaction with peers, potentially isolating the blind/partially sighted student and preventing true integration.

In some cases, class notes are provided ahead of time and can be produced in accessible formats for blind/partially sighted students. Many students value this, to the extent that some are reported to think there is no point attending lectures without notes (**Cliffe and White, 2012**). Indeed, Cliffe and White suggest that access to full notes in the right format enables students to focus on engaging with the class rather than trying to write down information given. However, there remain problems even with pre-prepared notes. Firstly, if lecturers don’t follow the notes or change the order without warning, this can confuse students (**Cliffe and White, 2012**). Secondly, where PowerPoint slides are provided, the print copies only show the full slide and don’t give the opportunity to work out answers/fill in tables as is often done in class by revealing the slide a bit at a time (**Rowlett, 2008**).

These findings demonstrate that there are many difficulties faced by blind/partially sighted students in terms of the way teaching is delivered. **Rowlett and Rowlett (2009)** suggest that these difficulties may cause some students to seek extra one to one tuition.

#### Teaching strategies

This review has highlighted many challenges facing blind and partially sighted learners in STEM subjects. But what can be done by teachers to aid their students in these fields?

Various researchers have highlighted the need for further training for teachers to better equip them to teach STEM subjects to blind/partially sighted students. **Fraser and Maguvhe (2008)** report that many teachers – even some of those working in specialist schools for the blind/partially sighted – have only had general teacher training, and therefore lack the skills and ideas for adapting the curriculum for those without sight. This results in students missing out on participating in class (for example, class observations) with detrimental effects on their learning.

Indeed, a survey of American teachers by **Norman, Caseau and Stefanich (1998)** revealed that at all levels (elementary school up to university) over half of teachers reported having received no training specific to teaching disabled students.

According to **Norman et al (1998)**, science is widely seen as a subject suitable for disabled students to be included in mainstream classes, but few science teachers have specialist training in supporting students with disabilities. Furthermore, few ‘special education’ teachers have specific science knowledge, meaning some disabled students slip through the gaps and receive very little relevant science education.

**Penrod, Haley and Matheson (2005)** describe an intensive programme aimed at improving science instruction, which involved both specialists in visual impairment and specialists in science coming together to explore the benefits of using the natural environment to teach science to blind/partially sighted students. Penrod et al found this approach to be beneficial to improve the scientific knowledge of one group and the understanding of visual impairment for the other.

**Giesen, Cavenaugh and McDonnell (2012)** report finding a relationship between the level of academic support available in schools (such as extra tuition, mentoring or after school programmes) and mathematics achievement for blind/partially sighted students. Blind/partially sighted students at schools with higher levels of academic support had higher achievements in mathematics than those in schools with less support. These findings suggest that there is benefit to extra input which may help students to achieve their potential.

Research evidence relating to teaching STEM subjects to blind/partially sighted students is difficult to come by. According to **Ferrell, Buettel, Sebald and Pearson (2006)** it is difficult for studies in this field to meet strict criteria for ‘scientifically based research’ due to low prevalence of visual impairment which makes it difficult to recruit suitable samples of students to take part in studies. **Ferrell et al (2006)** conducted a meta analysis of literature on maths instruction for students with visual impairments. (Meta-analysis is a statistical procedure used to synthesise findings from a body of literature and identify trends in their findings. As a statistical procedure there are rigorous criteria for the inclusion of studies in a meta-analysis, meaning non-scientific research cannot be included). Ferrell et al found just 10 studies meeting their criteria published between 1955-2005. They conclude that more scientific research is required in the area of teaching maths to blind/partially sighted students, in order to ensure that teaching practices are evidence based and effective.

Whilst scientific research in this area may be limited, there is a wealth of guidance and practice-based advice on teaching technical subjects to blind/partially sighted students. An example is an article by **Kumar, Ramasamy and Stefanich (2001)** which offers suggestions for teachers of students with visual impairments in science subjects. The article includes general guidance (such as providing accessible materials and offering orientation in the science lab) as well as examples specific to physical, chemical and biological science. The article also suggests implications for educational policy, in terms of educating teachers on accessibility issues, changes to science assessments and integration of educational technology.

In this age of the internet, it is possible to share good practice, resources and ideas easily across the world. Part 2 of this report highlights resources relating to the teaching of STEM subjects to blind and partially sighted people.

#### Summary and recommendations

This literature review has highlighted various challenges of STEM subjects for blind/partially sighted students. It must be noted that there is other work underway in this area, considering similar issues. A report is currently in preparation following a workshop in September 2012 at the University of Bath exploring barriers to Higher Education in STEM subjects for students with visual impairments. It is hoped that these two reports together will clarify the current situation around STEM subjects for blind/partially sighted students and identify clear next steps to improve access to STEM subjects.

Key issues identified here include accessing technical notation, accessing visual resources, understanding visual concepts, experimenting without vision, teaching methods and teaching strategies.

Recommendations for further work to improve the accessibility of STEM subjects for blind/partially sighted students are as follows:

* Document good practice guidance on the conversion of technical information into accessible formats, and where such guidance is already available (such as work already done by University of Bath), ensure it is widely publicised and used
* Document good practice relating to the presentation of visual resources to blind/partially sighted students.
* Investigate the effectiveness of tactile materials and whether students are equipped with the right skills and support to use these effectively
* Publicise existing guidance relating to verbal descriptions of non-text Science content
* If further guidance is needed, make use of the development principles shown by Gould and Ferrell (2009) involving end users in the development of guidance
* Provide guidance on teaching ‘visual concepts’ to students without sight, perhaps through case studies or examples to stimulate ideas
* Publicise existing guidance on involving blind/partially sighted students in practical lessons such as experiments and observations
* Identify or provide guidance on teaching methods to optimise the experience of blind/partially sighted students in the classroom
* Develop training to increase the confidence of teachers/lecturers in teaching blind/partially sighted students technical subjects. This could be done through networking teachers, getting them to share ideas and good practice, workshops or online courses.
* Investigate the potential of interventions found in research to be beneficial, such as bringing together specialists in visual impairment and specialists in STEM subjects to work together on access solutions
* Improve communication between students and teachers so teachers are aware of what blind/partially sighted students need
* Conduct and publish further scientific research on effective interventions in teaching STEM subjects to students with visual impairments

### Part 2: Available teaching resources, guidance and research

There is a wealth of information, research and resources available online regarding access to STEM subjects for blind and partially sighted learners. Some resources are subject specific, whist others are more general or relate to STEM subjects as a whole or other similar groupings (for example, there is a group within higher education in the UK called the Maths, Statistics and Operational Research (MSOR) Network who have a subsection focussing on accessibility of these subjects). It is of interest that for some subjects (maths and science) there are many resources, whilst for others (technology and engineering) there are not. This finding may highlight areas for further work.

Here follows a list of relevant resources, starting with general STEM links followed by subject specific links. UK based resources are given first, followed by links from around the world. Where applicable, ‘Key resources’ are highlighted which offer good practice examples of organisations who have provided comprehensive support and information relating to supporting blind/partially sighted learners in their subject.

All links are current as of May 2013.

#### 1. General resources

##### 1.1 Practical guidance/resources

###### UK

* HE STEM professional development e-learning package: a collection of resources aimed at higher education professionals to support visually impaired students in STEM subjects  
  <http://stem.ecs.soton.ac.uk/>
* The STEM Diversity and Equality Toolkit: resources to help promote STEM subjects to 11-16 years olds from diverse backgrounds (including those with disabilities).   
  <http://www.stem-e-and-d-toolkit.co.uk/home/welcome-the-equality-and-diversity-toolkit>
* STEM disability committee (STEM-DC): a group made up from various UK professional bodies in STEM subjects with a special interest in promoting STEM, and improving access to STEM for disabled people. Website includes information on STEM-DC projects as well as a portal with links to information for students, teachers, employers, researchers and so on.  
  <http://www.stemdisability.org.uk/default.aspx>
* Disabilities Academic Resources Tool (DART): An online resource aiming to help educational institutions to assess the accessibility of their provision for disabled students and to provide advice on improvements. Includes detailed case studies of students with disabilities’ experiences of higher education and an auditing and diagnostic tool to suggest accessibility improvements. Project completed December 2005, based at Loughborough University (UK).   
  <http://dart.lboro.ac.uk/index.htm>
* QATRAIN2 – a web-based resource aiming to enable disabled learners to participate fully in Vocational Education and Training. Aimed at teachers/trainers and those involved in course planning/assessment. Includes resources relating to numeracy.  
  <http://uk.qatrain2.eu/>
* Load2Learn: Learning resources in downloadable,  
  accessible formats for students who have  
  difficulty reading standard printed books, including books and images, and training and guidance for staff in creating and using accessible curriculum resources  
  <http://load2learn.org.uk/>
* UK Association for Accessible Formats (UKAAF) guidance on producing accessible materials, including guidance on describing various kinds of images  
  <http://www.ukaaf.org/formats-and-guidance>

###### Rest of world

* Access2Science - a website run by blind volunteers working in STEM fields offering practical information and links to accessible materials (USA).  
  <http://www.access2science.com/index.html>
* SciTrain – website offering free online training courses in making high school level science/maths/computer science accessible to students with disabilities (USA).  
  <http://www.catea.gatech.edu/scitrain/index.php>
* SciTrainU – website offering free online training in making university level STEM subjects accessible to students with disabilities. Also includes a searchable knowledge base with links to many articles on this subject (USA).  
  <http://www.catea.gatech.edu/scitrainU/index.php>
* Guidelines and Standards for Tactile Graphics (2010): a comprehensive manual developed in North America for the production of tactile graphics  
  <http://brailleauthority.org/tg/web-manual/>
* Tactile graphics – A how to guide: guidance on the production of tactile graphics (USA)  
  <http://www.tactilegraphics.org/index.html>

##### 1.2 Technical/Products

###### Rest of world

* Touch Graphics STEM binder: a kit combining high quality tactile graphics and a talking pen device which gives relevant audio information when touched onto the graphics.  
  <http://www.touchgraphics.com/research/STEM.html>

##### 1.3 Research/development

###### UK

* Links to articles published in Maths, Stats and Operational Research (MSOR) Connections (newsletter of the MSOR network) on the subject of supporting students with disabilities (UK).  
  <http://www.mathstore.ac.uk/node/126>
* Investigating the Potential of 3D printing for creating tactile objects for use in education: report in preparation from RNIB’s Centre for Accessible Information. Contact [accessibleinfo@rnib.org.uk](mailto:accessibleinfo@rnib.org.uk)

#### 2. Science

##### Key resource: National Center for Blind Youth in Science (NCBYS) United States

A key resource is the National Center for Blind Youth in Science (NCBYS) run by the National Federation for the Blind in the United States (NFB).

<http://www.blindscience.org/>

The NCBYS aims to be a centre for excellence for information and resources around blind learners engaging in STEM subjects, to promote opportunities for blind youth in science, to support projects aiming to improve access to science/maths subjects, and to co-ordinate ongoing research in this area.

The NCBYS website offers a wealth of information and resources, including information about blind professionals in STEM careers, work placement opportunities, links to online resources, publications and much more.

##### 2.1 Practical guidance/resources

###### UK

* RNIB curriculum guide for science, including discussion of concept development, useful equipment, safety in practical sessions and so on.  
  <http://www.rnib.org.uk/professionals/education/support/guidance/schoolage/Pages/national_curriculum_subjects.aspx>
* Institute of Physics (IoP) Access for All: a disability good practice guide for university physics departments (published 2008). <http://www.iop.org/publications/iop/2008/page_42867.html>
* Teaching a physics laboratory module to blind students: Online resource outlining potential issues relating to teaching blind students in university level physics and potential solutions. Produced 2004.  
  <http://www.nottingham.ac.uk/pesl/resources/disability/teaching102/>

###### Rest of world

* Accessible science labs: A resource for experiments for junior and senior high school learners who are blind or visually impaired (Canada).  
  <http://vision.alberta.ca/resources/adaptingprograms/science.aspx>
* Effective practices for the description of science content within digital talking books (from the WGBH National Center for Accessible Media, USA).  
  <http://ncam.wgbh.org/experience_learn/educational_media/stemdx>
* Independence Science blog: blog with tips and information about access to science for blind/partially sighted high school students (USA).  
  <http://www.independencescience.com/blog.php>
* Institute for Accessible Science Hub: online community for developing and sharing tools relating to accessible science (USA).  
  <http://iashub.org/>
* Teaching chemistry to students with disabilities: A manual for high schools, colleges and graduate programs. (4th edition, 2001) Produced by the American Chemical Society. Electronic document available online (USA).   
  <http://www.adcet.edu.au/Search.aspx?f=chemistry>
* Texas School for the Blind and Visually Impaired (TSBVI): variety of materials relating to teaching science to visually impaired students, including teaching tips, guidelines for producing diagrams, and a manual for adapting science experiments (USA).  
  <http://www.tsbvi.edu/instructional-resources>
* American Chemical Society (ACS) has a committee for Chemists with Disabilities (CWD) which aims to promote opportunities for people with disabilities in both education and the workplace through networking and information sharing (USA).  
  <http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_TRANSITIONMAIN&node_id=332&use_sec=false&sec_url_var=region1&__uuid=b9521790-fa68-4330-90a6-3a8481cf2795>
* Teacher’s manual for adapting science experiments for blind and visually impaired students: Resource available online about adapting science experiments for blind/partially sighted students, with many worked examples (New Zealand).  
  <http://www.trinity.edu/org/sensoryimpairments/VI/TA/activities_toc.htm>

##### 2.2 Technical/products

###### UK

* Nothing to report

###### Rest of world

* Adapting science for students with visual impairments: A Handbook for the Classroom Teacher and Teacher of the Visually impaired (book, USA).  
  <http://shop.aph.org/webapp/wcs/stores/servlet/Product_Adapting%20Science%20for%20Students%20with%20Visual%20Impairments:%20A%20Handbook%20for%20the%20Classsroom%20Teacher%20and%20Teacher%20of%20the%20Visually_7-00000-00P_10001_11051>
* Independence Science – company specialising in access software for scientific equipment to improve access to STEM subjects for blind/partially people. Includes products to aid practical science experiments, engineering tools and mathematical packages (USA).  
  <http://www.independencescience.com/index.php>

##### 2.3 Research/development

* Nothing to report

#### 3. Technology

##### 3.1 Practical guidance/resources

###### UK

* RNIB Curriculum guide for teaching design technology. Includes discussion of concept development, practical ideas for working, ideas for useful products and so on.   
  <http://www.rnib.org.uk/professionals/education/support/guidance/schoolage/Pages/national_curriculum_subjects.aspx>

###### Rest of world

* Nothing to report

##### 3.2 Technical/products

* Nothing to report

##### 3.3 Research/development

* Nothing to report

#### 4. Engineering

* Nothing to report

#### 5. Maths

##### Key resource: Texas School for the Blind and Visually Impaired (TSBVI) United States

The Texas School for the Blind and Visually Impaired has many resources relating to maths teaching.

<http://www.tsbvi.edu/math>

Of particular interest are:

* Teaching strategies page - containing advice on strategies, discussion of some of the challenges of maths for visually impaired learners, and discussions of specific aspects of maths and how to make them accessible to learners with little or no vision   
  <http://www.tsbvi.edu/resources-math/3237-teaching-strategies>
* Project Math Access - web pages offering many practical tips on teaching various mathematical concepts to children with little or no vision <http://s22318.tsbvi.edu/mathproject/>

##### 5.1 Practical guidance/resources

###### UK

* RNIB Curriculum guide for maths, including discussion of concept development, ideas for presenting data and so on.   
  <http://www.rnib.org.uk/professionals/education/support/guidance/schoolage/Pages/national_curriculum_subjects.aspx>
* Methods to produce flexible and accessible learning resources in mathematics: online resource aimed at staff in Higher Education to enable them to produce resources which can easily be made accessible/converted into different formats.  
  <http://www.bath.ac.uk/study/mash/maths-access/>

###### Rest of world

* Touching maths: a European project aiming to support braille users in maths in mainstream schools. Website includes information on technical aids, braille codes and much good practice guidance.  
  <http://touchingmaths.net/>
* One two take off my shoe - A Canadian resource aimed at improving maths literacy for young blind/partially sighted children (aged 2.5-5 years).   
  <http://vision.alberta.ca/resources/adaptingprograms/math.aspx>
* Flowchart explaining the process of creating accessible versions of mathematics materials containing equations.  
  <http://www.inftyreader.org/flowchart.htm>
* BlindMath mailing list: discussion list on all aspects of blind access to maths  
  <http://www.nfbnet.org/mailman/listinfo/blindmath_nfbnet.org>
* Math accessibility study: report by Portland Community College (USA) on making maths more accessible online to students with disabilities  
  <http://www.pcc.edu/resources/instructional-support/access/Math-Accessibility.html>

##### 5.2 Technical/products

###### UK

* Nothing to report

###### Rest of world

* World Wide Web Consortium (W3C) math homepage, central point for information on MathML.  
  <http://www.w3.org/Math/>
* DAISY Consortium MathML page: includes ‘An easy introduction to MathML in DAISY in 10 small chapters’, information on MathML and sample books.  
  <http://www.daisy.org/project/mathml/>
* Infty Reader: an OCR application which translates scientific documents (including mathematical formulae) into LaTeX, MathML and XHTML.  
  <http://www.inftyreader.org/>
* ChattyInfty: talking maths editor, an extended version of Infty Reader (above) which includes voice output and can export in various formats including LaTeX, HTML, MathML, Human Readable TeX (HrTeX), Word 2007, Spoken Text and Word XML.  
  <http://www.inftyreader.org/>
* Mathtrax: software from NASA which makes audible graphs/soundscapes, aimed at school students. <http://prime.jsc.nasa.gov/mathtrax/>
* Henter Math virtual pencil: product designed to allow blind users to record intermediate answers/'working out' of a maths problem.  
  <http://www.hentermath.com/index-2.html>
* ViewPlus Audio Graphing calculator: software calculator for blind/low vision learners.  
  <http://www.viewplus.eu/products/software/math/>
* The Lamdba project (Linear Access to Mathematics for Braille Device and Audio-synthesis) was a European project which produced an accessible editor system aimed at secondary school to university students.  
  <http://www.lambdaproject.org/overview>
* Design Science: company producing software to make maths more accessible electronically and on the web.  
  <http://www.dessci.com/en/>
* MathJax: a cross-browser JavaScript library that displays mathematical equations in web browsers  
  <http://www.mathjax.org/resources/articles-and-presentations/accessible-pages-with-mathjax/>

##### 5.3 Research/development

###### UK

* The LaTeX access project: development of a means to access LaTeX source code as braille or speech output.  
  <http://latex-access.sourceforge.net/>
* Maxtract: a tool for converting PDF into formats such as LaTeX, MathML and text, currently under development  
  <http://www.cs.bham.ac.uk/research/groupings/reasoning/sdag/maxtract.php>

###### Rest of world

* Sightsavers are currently carrying out research evaluating the teaching and learning of numeracy and mathematics of children with visual impairments based in low-income settings. This includes a literature review on the subject alongside evaluations in schools in which Sightsavers have a presence. For further information contact Stacy Rowe [srowe@sightsavers.org](mailto:srowe@sightsavers.org)

### References

Aldrich, F.K., and Sheppard, L. (2001). Tactile graphics in school education: perspectives from pupils. British Journal of Visual Impairment, 19 (2), 69 – 73.

Beal, C.R., and Shaw, E. (2008). Working memory and math problem solving by blind middle and high school students: implications for universal access. Paper presented at the 19th International Conference of the Society for Information Technology and Teacher Education, Las Vegas, NV.

Bulatov, V., and Gardner, J. (1998). Visualisation by people without vision. In Workshop on Content Visualisation and intermediate representation. 1998. Montreal, CA.

Cahill, H., Lineham, C., McCarthy, J., Bormans, G., and Engelen, J. (1996). Blind and partially sighted students' access to mathematics and computer technology in Ireland and Belgium. Journal of Visual Impairment and Blindness, 90 (2), 105 - 114.

Calder, M., Cohen, R.F., Lanzoni, J., Landry, N., and Skaff, N. (2007). Teaching data structures to students who are blind. SIGCSE Bulletin, 39 (3), 87-90.

Cliffe, E. (2009). Accessibility of mathematical resources: the technology gap. MSOR Connections, 9 (4), 37 - 42.

Cliffe, E. and White, J. (2012). Methods to produce flexible and

accessible learning resources in mathematics, pp. 35-43 in Robinson, C. (Ed). (2012). Student-centred Approaches in Mathematics, National HE STEM Programme: Mathematical Sciences HE Curriculum Innovation Project. Available at:

<http://www.mathcentre.ac.uk/resources/uploaded/studentcentred.pdf> accessed 12:13 26 March 2013.

Cohen, R.F., Meacham, A., and Skaff, J. (2006). Teaching graphs to visually impaired students using an active auditory interface. Proceedings of the 2006 technical symposium on Computer Science Education (SIGCSE 2006), 279-282.

Cooper, M. (2012). Making online maths accessible to disabled students - issues and lessons for the Open University's experience. In E.Cliffe and P. Rowlett (Eds.) Good practice on Inclusive Curricula in the Mathematical Sciences. The Higher Education Academy. 39-45.

Cryer, H. and Gunn, D. (2008). Exploring Tactile Graphics. RNIB Centre for Accessible Information, Birmingham: Literature review #3. Presented at Tactile Graphics 2008, Birmingham, UK.

Dunkerton, J. (1997). The Science entitlement of visually impaired students at GCSE and A-level: a national survey (1992-1994). British Journal of Visual Impairment, 15 (1), 15 - 21.

Erwin, E.J., Perkins, T.S., Ayala, J., Fine, M., and Rubin, E. (2001). “You don’t have to be sighted to be a Scientist, do you?” Issues and outcomes in science education. Journal of Visual Impairment and Blindness, 95 (6), 338 – 352.

Ferrell, K.A., Buettel, M., Sebald, A.M., and Pearson, R. (2006). American Printing House for the Blind: Mathematics Research Analysis. National Center on Low-Incidence Disabilities, APH.

Fisher, S.P. and Hartmann, C. (2005). Math through the mind’s eye. Mathematics Teacher, 99 (4), 246 – 250.

Fletcher, E. (2011). Student has no trouble visualising a Doctorate in chemistry. The Braille Monitor, 54 (10).

Fraser, W.J., and Maguvhe, O. (2008). Teaching life sciences to blind and visually impaired learners. Journal of Biological Education, 42 (2), 84 – 89.

Gardner, J.A., Stewart, R., Francioni, J., and Smith, A. (2002). Tiger, AGC and Wintriangle, removing the barrier to STEM education. Proceeding of 2002 CSUN Conference. Available online <http://www.csun.edu/cod/conf/2002/proceedings/csun02.htm#t> accessed 11:58 7 February 2013.

Giesen, J.M., Cavenaugh, B.S., and McDonnall, M.C. (2012). Academic supports, cognitive disability and mathematics achievement for visually impaired youth: a multilevel modelling approach. International Journal of Special Education, 27 (1).

Gould, B., and Ferrell, K.A. (2009). Accessible science: how to describe STEM images. AER Journal, Winter 2009.

Jackson, A. (2002). The world of blind mathematicians. Notices of the American Mathematical Society, 49 (10), 1246 – 1251.

Jones, M.G., Forrester, J.H., Robertson, L.E., Gardner, G.E., and Taylor, A.R. (2012). Accuracy of estimations of measurements by students with visual impairments. Journal of Visual Impairment and Blindness, 106 (6), 351 – 355.

Jones, M.G., Minogue, J., Oppewal, T., Cook, M.P., and Broadwell, B. (2006). Visualizing without vision at the microscale: students with visual impairments explore cells with touch. Journal of Science Education and Technology, 15 (5), 345 – 351.

Klingenberg, O.G., Fosse, P., and Augestad, L.B. (2012). An examination of 40 years of mathematics education among Norwegian braille reading students. Journal of Visual Impairment and Blindness, 106 (2), 93-105.

Krizack, M. (2000). Making science accessible to blind students. Disability World, 3.

Kubiak-Becker, E., and Dick, T.P. (1996). A brief historical overview of tactile and auditory aids for visually impaired mathematics educators and students. Information Technology and Disabilities Journal, 3 (1).

Kumar, D.D., Ramasamy, R., and Stefanich, G.P. (2001). Science for students with visual impairments: Teaching suggestions and policy implications for secondary educators. Electronic Journal of Science Education, 5 (3).

National Council of Teachers of Mathematics (NCTM). (2000) Principles and standards for school mathematics. Reston, VA: NCTM, 200 cited in Fisher, S.P. and Hartmann, C. (2005). Math through the mind’s eye. Mathematics Teacher, 99 (4), 246 – 250.

The New Beacon (1934) Mathematics and the blind Student. The New Beacon, XVIII No 210, 146 - 148.

Norman, K., Caseau, D., and Stefanich, G.P. (1998). Teaching students with disabilities in inclusive science classrooms: survey results. Science Education, 82, 127 – 146.

Penrod, W.M., Haley, C.D., and Matheson, L.P. (2005). A model for improving science teaching for students with visual impairments. Review: Rehabilitation education for blindness and visual impairment, 37 (2), 53 – 58.

Quality Assurance Agency (QAA) (2007). Subject benchmark statement: Mathematics, statistics and operational research. Available online <http://www.qaa.ac.uk/Publications/InformationAndGuidance/Pages/Subject-benchmark-statement-Mathematics-statistics-and-operational-research.aspx> accessed 15:03 1 May 2013.

Rapp, D.W., and Rapp, A.J. (1992). A survey of the current status of visually impaired students in secondary mathematics. Journal of visual impairment and Blindness, 86, 115 - 117

Ramloll, R., Yu, W., Brewster, S., Riedel, B., Burton, M., and Dimigen, G. (2000). Constructing sonified haptic line graphs for the blind students: first steps. In 4th International ACM Conference on Assistive Technologies, 13-15 November 2000, pages pp. 17-25, Arlington, Virginia, USA.

Rowlett, E.J. (2008). Accessibility in MSOR: one student's personal experience. MSOR Connections 8 (1), 27 - 30.

Rowlett, E.J., and Rowlett, P.J. (2009). Visual impairment in MSOR. MSOR Connections 9 (4). 43-46.

Rowlett, E.J., and Rowlett, E. (2012). Experiences of students with visual impairments. In E.Cliffe and P. Rowlett (Eds.) Good practice on Inclusive Curricula in the Mathematical Sciences. The Higher Education Academy. 9-13.

Sheppard, L., and Aldrich, F.K. (2001). Tactile graphics in school education: perspectives from teachers. British Journal of Visual Impairment, 19 (3), 93 – 97.

Smith, D.W., and Smothers, S.M. (2012). The role and characteristics of tactile graphics in secondary mathematics and science textbooks in braille. Journal of Visual Impairment and Blindness, 106 (9), 543 – 554.

Spybey, D. (2012). Mathematics for visually impaired students at A-level and the transition to degree level. In E.Cliffe and P. Rowlett (Eds.) Good practice on Inclusive Curricula in the Mathematical Sciences. The Higher Education Academy. 15-17

Touch Graphics (not dated). Talking tactile pen – STEM binder. Available online <http://www.touchgraphics.com/research/STEM.html>

Accessed 15/05/2013 14:19

Unwalla, M. (2006). LaTeX: an introduction. Communicator, Spring 2006. 33.

Williams, R.M., and Irving, A.J. (2012). On the accessibility of mathematics to visually impaired students in higher education. In E.Cliffe and P. Rowlett (Eds.) Good practice on Inclusive Curricula in the Mathematical Sciences. The Higher Education Academy, 19 - 23.

W3C (2011). W3C Math Home: what is Math ML? available online <http://www.w3.org/Math/> accessed 11:45 9 January 2013.

### About RNIB’s research

RNIB is a leading source of information on sight loss and the issues affecting blind and partially sighted people. Our Research and Knowledge Hub contains key information and statistics about blind and partially sighted people including our Sight Loss Data Tool, which provides information about sight loss at a local level throughout the UK. You’ll also find research reports on a range of topics including employment, education, technology, accessibility and more. Visit our Knowledge and Research Hub at: **rnib.org.uk/research**