Accessibility review of chemistry education and practical work at Key Stage 4 and 5

Commissioned by the Royal Society of Chemistry
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Abstract

This report summarises an investigation into the challenges and opportunities in supporting disabled students in chemistry with a particular focus on how those challenges might be reduced though digital tools. Its key aims are:

- to identify and critically appraise research into the accessibility landscape for chemistry education and practical work at Key Stage 4 and 5 (age groups 14–18);
- to present an accessibility benefit assessment that will recommend good practice in presenting online resources for students with disabilities.

Executive summary

This report summarises an investigation into the challenges and opportunities in supporting disabled students in chemistry with a particular focus on how those challenges might be reduced though digital tools. The key aims of the investigation were:

- to identify and critically appraise research into the accessibility landscape for chemistry education and practical work at Key Stage 4 and 5 (age groups 14–18);
- to present an accessibility benefit assessment that will recommend good practice in presenting online resources for disabled students.

This report included a wide range of topics, whose key factors are reported below:

The number and characteristics of disabled students at Key Stage 4 and 5 (age groups 14–18) were evaluated. It was found that:

- There is no evidence to suggest that, in general, disabled students are put off chemistry at university level.
- There is evidence to suggest that disabled students regularly have to deal with inconsistent levels of support, resource, and equipment compared to their peers.

Recommendation:

- It follows that the provision of accessible resources by a platform like Learn Chemistry (or other digital platform) is more important to disabled students than it is to mainstream students.

The accessibility of chemistry practical work was considered. It was found that:

- There is some confusion between teachers, academics, and exam boards about the learning outcomes that practical work is intended to achieve.
- If performed correctly, in some cases simulated experiments are capable of achieving the educational goals of classroom practicals (where those goals are as recommended by SCORE).

Recommendation:

- Disabled students are likely to benefit more from accessible online simulated experiments than their mainstream peers.

The accessibility benefit assessment of digital resources was completed (using Learn Chemistry as an example platform) and it found that:

- There are many examples of good practice with Learn Chemistry.[1]
- A range of design principles that should be foregrounded when making future decisions have been made.

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1. The author will be using it as an example of good practice in other work

Contents

Chapter 1
Introduction

This report summarises work undertaken in 2015 to identify challenges and opportunities in supporting disabled students in practical chemistry work with a particular focus on how those challenges might be reduced though digital tools.

This work is split into two distinct parts: a research report focusing on the 'state of the nation' regarding chemistry accessibility and an accessibility benefit assessment.

This chapter provides information on the Royal Society of Chemistry and on the overall disability landscape. It discusses the motivation for the work, in terms of being able to shape how resources are created and distributed in the future, and gives an overview of the rest of the report. It finishes with a short discussion of some methodological aspects of the work.

1.1 The Royal Society of Chemistry

The Royal Society of Chemistry is the world's leading chemistry community, advancing excellence in the chemical sciences. The organisation was formed in 1980 from the merger of the Chemical Society, the Royal Institute of Chemistry, the Faraday Society and the Society for Analytical Chemistry with a new Royal Charter and the dual role of learned society and professional body. As the professional body for chemistry in the UK, the Royal Society of Chemistry has the ability to award the status of Chartered Chemist. The organisation also carries out research, publishes journals, books and databases, as well as hosting conferences, seminars and workshops.

With particular regard to education, to implement its mission to advance excellence in the chemical sciences, the Royal Society of Chemistry's goals are to:

- consider and provide guidance and information on content criteria (including scientific skills and ideas) for chemistry qualifications;
- consider and provide guidance and information on appropriate assessment models for chemistry qualifications and advise on responses to external consultations on curriculum, qualification and assessment matters;
- advise the staff, Education Division Council, Science, Education & Industry Board and Council on any matters associated with the chemistry curriculum.[2]

It is with regard to these three goals that this report was written.

1.1.1 Learn Chemistry

Learn Chemistry is the Royal Society of Chemistry's online platform for chemistry education and contains almost 4,000 resources and exercises for both students and educators. A major focus of this report is on how well Learn Chemistry and the Royal Society of Chemistry support learning in a disability context.

1.2 Disability in Key Stage 4 and 5 (age groups 14–18)

Section 2.1 will go into a large amount of detail on how the number of students affected by disability is estimated. However, it is clear that a large proportion of students are affected by disability.

1.3 Challenges and opportunities

The Royal Society of Chemistry have commissioned this report to examine the challenges and opportunities in supporting disabled students in practical chemistry work and the accessibility of online digital tools aimed at supporting chemistry education. As discussed in Section 3.3, the Royal Society of Chemistry's resources already reflect an organisation with an inclusive mind-set; however, it is also clear to the organisation that this is a complex area, requiring specialist knowledge to properly direct staff and funds.

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[2] http://www.rsc.org/campaigning-outreach/policy/education-policy/

Some of the challenges are extremely clear: a number of the resources on the Learn Chemistry site are all but unusable to a particular subset of students studying chemistry and clearly such cases should be minimised or eliminated.

The opportunities, although less obvious, are extremely valuable. As discussed in later chapters, there are students who find studying chemistry in a traditional school setting extremely limiting due to disability. By providing accessible resources for disabled students and their teachers, the Royal Society of Chemistry would support them to move forward with their chemistry education. Through this work the Royal Society of Chemistry can be more than just 'accessible' to students with disabilities, it can be exactly the support they need to compensate for a lack of support in education (see Section 2.2).

Making the Royal Society of Chemistry's resources as accessible as possible is likely to be a long term goal; however, given the nature of the Royal Society of Chemistry as an organisation, it is unlikely to be an expensive process because most of their existing materials are reasonably accessible. With the current design process already incorporating consideration of accessibility, the focus for future work will be on optimisation of these approaches.[3]

This report represents one stage towards that goal; in addition to surveying the opportunities, it will both make a wide range of specific recommendations and give general principles to allow the Royal Society of Chemistry's accessibility strategy to become more nuanced.

This report follows on from accessibility audits performed by the Royal National Institute of Blind People (RNIB) who evaluated Learn Chemistry against the WCAG 2.0 standard of website design [10]. These audits assess websites against a specific set of standards for web-accessibility. These standards are a vital part of modern web design and should be adhered to; however, they focus on recommendations to designers and web developers rather than the people who lead and manage organisations.

This report allows the process to progress further by taking a much more targeted view of disability[4] and drills directly down into the effectiveness of chemistry education within this population.

The report will also identify gaps in our knowledge of both prevalence of disability and of best practices for education in the Royal Society of Chemistry's specific context. Chapter 4 provides details of future work, and elaborates on how this report might sit within a broader framework.

1.4 Overview of work

This work comprises four chapters:

- Chapter 1 provides a brief background and motivation for the study, along with a detailed description of the scope, requirements and intended outcomes of this study. It also deals with administrative matters.
- Chapter 2 focuses on the 'state of the nation' report and deals with such issues as finding an accurate and useful assessment of the numbers of students affected by disability issues, the context around which changes may be made and a literature search for processes that have been successful in the past.

[3] Here we include such factors as a relatively technically savvy workforce, a naturally accessible subject matter, and a strong base of accessibility to build on.

[4] The demographics of disabled chemistry students under 18 are very different to the broader population of disabled people.

- Chapter 3 introduces a set of overall recommendations, grounded in data and experience, for designers and managers to consider when producing online resources. It goes on to produce a set of targeted recommendations for online resources produced by the Royal Society of Chemistry, including estimation of how many users each recommendation is likely to affect and how significantly it is likely to affect them.
- Chapter 4 summarises this work and identifies candidate areas for examination by later studies.

1.5 Methodological factors

Readers familiar with disability research more generally can disregard this section as it provides background to some of the relevant processes that were used whilst carrying out this work.

1.5.1 Models of disability

Initially coined as a term in 1983, the *social model* has gradually become the dominant model for almost all activities relative to disability.

The *medical model* focuses on an individual – with the intent that curing or at least managing illness or disability is the key target. The social model, by contrast, accepts the central tenet that it is the way that society and the physical environment are arranged that is ‘disabling’. An example might be that blind people are not disabled in the dark, nor are wheelchair users disabled while answering emails.

This manifests itself in terms of design strategies, methods of engagement and language – moving from terms such as ‘wheelchair-bound’, which has an implicit assumption that it is the fault of the individual for being ‘different’, to terms like ‘wheelchair-user’.

> The social model of disability […] was a move against viewing disabled people as dependent and in need of care. Disability was viewed as stemming from the failure of the social and physical environment to take account of disabled people’s needs. The problems of disabled people were therefore not seen as within the individual person, but within society. According to the social model, it is not the individual with a disability that needs to be changed, but society. In the early years of the social model, impairment as a concept or experience was rejected for fear of weakening the argument that altering the environment would solve the difficulties that disabled people faced. There is now, however, a growing acceptance by disability activists and those working in relative fields that acknowledging that impairment does not necessarily undermine the social model.

Quote 1: The history of the social model from Seale [43]

1.5.2 Use of terms

This report uses the term ‘disabled people’ as a shorthand for ‘people disabled in the context of a chemistry education’; it should be clear from context if it is being used in a more general sense.

There are several other cases where we unite somewhat confusing terminology. For example, what are called web labs [6], virtual labs [20] or distributed learning labs [22] in different studies are referred to by us, without loss of generality, as ‘remote labs’. There are several other instances in the report where somewhat confusing use of different terminology has been unified for clarity.

1.5.3 Ethical issues

This report is largely based on desk research of publicly accessible research. In such cases there are no ethical issues to be aware of.

A range of interviews with stakeholders were conducted to inform and direct the research. Each stakeholder was informed in advance of the purpose of the report and approved any text relating to them that appeared in the report. We defaulted to anonymity unless the stakeholder expressly allowed their name to be used.

Within disability, because of the small size of the communities it is extremely difficult to anonymise effectively. For example, a layman might assume that a subject described as ‘A 30 year old man with Cri-du-chat Syndrome in the North of England’ is entirely anonymous. However, that information is sufficient to precisely identify the author’s younger brother.

Where necessary, anonymisation in the report may include some reasonable simplification for the reader. In Section 2.2.3 we refer to ‘Tom’ as having autism. This is factually incorrect but achieves the balance of giving the reader enough information to understand the overall point while protecting Tom’s identity. For more on the ethical aspects of complex disability see, for example, references [8], [34] and [9].

Chapter 2
State of the nation

As discussed in Chapter 1, the Royal Society of Chemistry possesses little information on the accessibility landscape of its users as a whole. This includes both the number and requirements of those users that identify as disabled, and also the most effective ways to meet those requirements in the context of chemistry education.

For many institutions, organisations and businesses, disability awareness and accessibility are relatively simple: the process of making a building accessible to wheelchairs or a handout available electronically is known and understood. By contrast, the nature of chemistry education, particularly with regard to practical experiments and *what exactly students are intended to learn from them*, is subtle and complex. By being proactive about engaging students, the Royal Society of Chemistry finds itself somewhat ahead of the wider community.

This chapter examines the nature of chemistry education in Key Stage 4 and 5 (age groups 14–18), the proportion of practical work involved and the challenges inherent in that practical work for disabled students. It goes on to examine the learning outcomes expected from practical work and evaluates if these outcomes can be provided by digital online resources.

Following estimation of the size of the relevant population, a series of interviews with stakeholders is conducted to properly contextualise the report in terms of the UK educational system, before completing a full literature review of relevant academic research.

2.1 Disability by numbers

This section contextualises results presented later in the report by summarising existing information about the numbers, demographics and choices made by students with disabilities in the United Kingdom. As discussed later, there are a range of wildly different estimates that depend greatly on the nature of the research being undertaken.

2.1.1 Measurement challenges

The wide spectrum of conditions that are encompassed by the term ‘disability’ make it difficult to source accurate figures on the size of the relevant population – ‘disabled in the context of employability’ and ‘disabled in the context of chemistry education’ are two very different populations.

2.1.1.1 Self-reporting compared with counting assessments

There are two obvious ways to assess the number of students with disabilities: by surveying students (or a wider population) or by counting the students that are already receiving some form of assessed support.

Table 2.2, which was compiled from survey-based census data, illustrates that 9.25% of undergraduates are disabled, whereas Table 2.3, which was compiled from data on students receiving Disabled Students’ Allowance [DSA], finds that 6.9% are disabled (these figures are discussed in more detail below). While one should be a subset of the other, that doesn’t happen in practice (See Quote 3 for an example).

Similarly, students at secondary schools can be given an official ‘statement’ of their needs, and 2.8% of pupils in schools in England have such statements of Special Educational Needs (SEN).[5] These figures look incompatible with the figures for university level (or at least suggest that disabled students are much more likely to go to university) except that the majority of students considered to have SEN in the secondary school age group (ages 11–16) are ‘unstatemented’ (discussed in more detail below).

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5. www.gov.uk/government/uploads/system/uploads/attachment_data/file/362704/SFR26-2014_SEN_06102014.pdf

2.1.1.2 Nongranular data

A second problem with gathering data relevant to disability in chemistry education is ‘granularity’. While there are breakdowns of subjects preferred by disabled students (such as Table 2.3), and there are breakdowns of the nature of impairment amongst students – there is almost no information on the relationship between individual subjects and individual disabilities.

At university level there is anecdotal evidence to suggest, for example, that dyslexic and autistic students are much more likely to study subjects like Mathematics or Physics, while students with mobility impairments are much more likely to prefer subjects like English or History that have very few contact hours in a teaching week. Unfortunately, there is a serious lack of quantitative data on the topic. Even if such data were available, the small sample size would make the results unreliable.

This is a particular problem in terms of creating educational resources. While it is possible to roughly estimate how many students accessing Royal Society of Chemistry resources have special needs, it is not possible to determine from available data what those needs might be, other than to assume that they roughly follow the disability profile of a similarly aged population.

2.1.2 At secondary level

At secondary level[6] there are three levels of identified SEN: school action; school action plus; and statement.

Students in the *school action* category have been identified by their teachers or the special education staff as benefiting from extra support. Students in the *school action plus* category have also worked with, or been the subject of a consultation with, an expert outside the school. Statemented students have been though a formal assessment process that has identified their needs and the best ways of moving forward. School action is by far the largest category, partly because of the cost of going through the process, but also because it includes a large amount of temporary issues: 10 and 11 year olds are the most likely to be recipients of school action; however they lose this label after a period of time. Students that are statemented very much stay within the special education framework. In general, 15.4% of pupils in schools in England have identified SEN whereas only 2.8% of pupils in schools in England have statements of SEN.

2.1.2.1 Nature of Need

Table 2.1 shows a breakdown of needs identified at secondary level. It includes only those students in the school action plus and statemented categories as teachers are not qualified to accurately assess need (indeed, a 2010 Ofsted review found that half of those identified by teachers at the *school action* category did not have SEN[7])

The categories included in Table 2.1 are standard terms from education rather than disability. In more detail:

- Specific Learning Difficulty – a particular difficulty in learning to read, write, spell etc.
- Moderate Learning Difficulty – achievements well below expected levels in all or most areas of the curriculum, despite appropriate interventions.
- Severe Learning Difficulty – significant intellectual or cognitive impairments.
- Profound and Multiple Learning Difficulty – severe and complex learning needs; in addition, other significant difficulties, such as physical disabilities or a sensory impairment.

[6] We focus on state funded secondary schools partly because they have the richest data, but also because this is likely the area in which the resources provided by Learn Chemistry are likely most effective.

[7] www.gov.uk/government/uploads/system/uploads/attachment_data/file/350129/SFR31_2014.pdf

Table 2.1 State funding secondary schools number and percentage of SEN pupils by type of need from [14]

	School Action Plus		Statement of SEN		Total	
	Number	%	Number	%	Number	%
Specific Learning Difficulty	30,060	17.3	6,505	10.9	36,565	15.6
Moderate Learning Difficulty	38,410	22.0	9,180	15.4	47,590	20.3
Severe Learning Difficulty	630	0.4	1,385	2.3	2,015	0.9
Profound & Multiple Learning Difficulty	60	0.0	220	0.4	280	0.1
Behaviour, Emotional & Social Difficulties	53,340	30.6	9,230	15.5	62,575	26.7
Speech, Language and Communications Needs	15,625	9.0	9,995	16.7	25,620	11.0
Hearing Impairment	4,995	2.9	2,130	3.6	7,125	3.0
Visual Impairment	2,410	1.4	1,465	2.5	3,875	1.7
Multi-Sensory Impairment	140	0.1	125	0.2	265	0.1
Physical Disability	4,870	2.8	4,495	7.5	9,360	4.0
Autistic Spectrum Disorder	11,645	6.7	13,445	22.5	25,090	10.7
Other Difficulty/Disability	12,050	6.9	1,525	2.6	13,575	5.8
Total	174,235	100.0	59,700	100.0	233,935	100.0

Several of the larger categories in Table 2.1 are somewhat outside of the scope of this report. Students with behaviour, emotional, and social difficulties benefit from a range of approaches; however, the resources the Royal Society of Chemistry provides will not affect those approaches. Similarly, for students with autistic spectrum disorder, the *presence* of the Royal Society of Chemistry's resources is probably extremely useful; however, there are few changes that are likely to be necessary.[8]

These categories together approach almost a third of the students included in Table 2.1; however, it is clear that there are a wide range of students whose needs are outside of mainstream educational practices and who may benefit from the use of accessible resources.

2.1.2.2 Attainment

There is a sizable attainment gap between students with and without SEN. Of mainstream students, 70.4% achieved five or more GCSEs (C and above), compared to only 23.4% of pupils with SEN.

There were substantial differences between the various SEN needs. Those with visual (45%) or hearing (42.7%) impairment performed very highly, whereas those whose primary need is behaviour, emotional and social difficulties were much lower at 18.4% – it's also worth noting that this latter group is large enough to significantly affect the average [15].

2.1.2.3 Summary

Within secondary education there are an extremely large number of students with identified special needs, of which a large proportion could be helped by the universal availability of accessible resources. No information examining subject breakdowns for special needs was found; however, it is clear that many of the impairments listed in Table 2.1 would have a direct effect on chemistry education for both written and practical work.

> 8. The autistic spectrum should more properly be understood as an ‘autistic space’ given its size and its variance but the remarks here are accurate for the majority of cases.

2.1.3 At undergraduate level

As mentioned in Section 2.1.1, Table 2.2, which was compiled from census data, finds that 9.25% of undergraduates are disabled, whereas Table 2.3, which was compiled from data on students receiving DSA, finds that 6.9% are disabled. There are several caveats to highlight with these data.

Table 2.3 merges chemistry and physics – the differing nature of the subjects may be masking some results; however, given that biological sciences show an extremely similar proportion, we can assume that it is unlikely to be significantly different. Furthermore, Table 2.3 is based on assessed students rather than self-reported students. If taken at face value, it is tempting to conclude from these tables that students with ‘milder’ disabilities are likely to avoid chemistry, whereas students with assessed disabilities choose it exactly as often as mainstream students.

As a result of the lack of granularity in the data, the information we have is likely to be swamped by particular signals. The prevalence of dyslexia means that far more students would be considered dyslexic than any other condition. All of the movement in Tables 2.2 and 2.3 can simply be read as the choices made by dyslexic students rather than any other condition. This is particularly difficult for this work, as we would like to consider particularly those disabilities that affect practical work directly.

Table 2.2 Choice of subjects by disabled students from reference [12]

	Disability recorded (2011)
General population	8.71%
Undergraduate population	9.25%
Chemistry undergraduate population	6.92%

The performance of individual students is also a factor. Table 2.3 illustrates that disabled students are less likely to be high performing ones. However, those disabled students that are high performing show almost half the variance in which subjects they take. Indeed, high performing disabled students are *more* likely to take a physical science than average. Much of the choices made around chemistry appear to be more closely related to its reputation as a hard subject rather than its purpose as a hard science.

What should be drawn from this is not the difficulty of chemistry at university (see Chapter 4 for relevant future work). Instead, as illustrated by Quote 2, we should consider this as a proxy for how ready students with disabilities are to choose chemistry courses in the UCAS options. It follows from the data we have examined that students are as likely to choose chemistry as any other similar subject.

> In my case [dyslexia], and I suspect for most others, for you to have got as far as university, you’ve already learned to cope, you’ve learned the little tricks and you’ve managed to get though exam after exam, coursework after coursework on your own. At that point, the DSA is like a parent who just came back after leaving when you were five: “Sorry I wasn’t around when you needed me for all those years, how about this shiny laptop?”. You take the laptop, but you’ve already made your choices.

Quote 2: A former undergraduate DSA recipient discusses its effect

In conclusion, there is no evidence that disabled people in general are being driven away from chemistry in particular. However, we do expect that individual subsets of the population may have radically different experiences.

Table 2.3 Full-time first degree students in receipt of Disabled Students' Allowance (DSA) by subject and entry qualifications [1]

Entry qualifications	A level/VCE/Advanced Higher grades AAAA or Scottish Highers grades AAAAAA	All qualifications
Medicine & dentistry and veterinary science	3.2%	5.9%
Subjects allied to medicine	3.9%	6.7%
Biological sciences	5.1%	6.4%
Agriculture & related subjects	3.0%	9.7%
Physical sciences	4.9%	6.7%
Mathematical sciences	3.8%	4.5%
Computer sciences	3.6%	6.4%
Engineering & technology	4.1%	6.1%
Architecture, building & planning	4.7%	7.6%
Social studies	4.1%	7.6%
Law	2.8%	4.8%
Business & administrative studies	2.8%	4.8%
Mass communications & documentation	5.0%	6.6%
Languages	3.1%	4.8%
Historical & philosophical studies	4.7%	7.3%
Creative arts & design	5.4%	12.0%
Education	4.8%	7.2%
Combined subjects	7.1%	8.6%
All subjects (Standard Deviation)	3.9% (1.1%)	6.9%(1.9%)

2.2 Interviews

One of the key goals of this work was to map the accessibility landscape for chemistry education and practical work at Key Stage 4 and 5 (age groups 14–18). This process is greatly aided by consulting with the eventual beneficiaries of the process. This section begins by providing details of the representatives contacted and goes on to discuss their points of view in more detail. Where appropriate, names and some aspects of individual disability have been changed to protect confidentiality.[9]

Interviewees were selected from a range of backgrounds and groups to ensure triangulation of issues to the extent possible. These included teachers and parents of students with special needs and experts in examinations and accessibility of practical assessment.

2.2.1 Academic

Dr Martyn Cooper is a Senior Research Fellow at the Open University, with a research and internal consultancy role on access for disabled students to teaching and learning, especially eLearning. He was interviewed for this report both with regard to his well-known expertise in terms of education for disabled students, and because he was the Project Director of the PEARL (Practical Experimentation in Accessible Remote Learning) project, which was designed to examine ways of allowing students to conduct remote experiments. His expertise in the design of remote interfaces contributed to the results in Chapter 3.

> 9. Due to the universe of one problem (discussed in Section 3.2.1) anonymisation often has to be more drastic than simply changing names.

It is important to note that the PEARL project was focused at university level students. Unlike the entirely simulated experiments in Learn Chemistry, PEARL gave students remote control access use to real equipment housed in a university lab. Such remote control experiences clearly trade expense for accuracy compared to simulated experiments.

> Experiments should be experiments in the real world – you learn from mistakes and you learn from finding out what went wrong.

Quote 3: Dr Martyn Cooper on real world experiments

> We demonstrate that all of the control necessary could be done by keyboard control. Even in partner work (for example, blind people).

Quote 4: Dr Martyn Cooper on accessibility within remote experiments

From Dr Cooper's point of view there are two key takeaways from this. The first (Quote 4) is that for university level study, Dr Cooper believes all of the necessary control to conduct the experiment is possible from the computer keyboard, meaning that effectively all science experiments can be made accessible. The second is a more philosophical issue. From the perspective of Dr Cooper (and it is understood to be broadly representative of university science as a whole), the fact that the experiment was 'real' in the sense that the scientific principle was really being tested, was key (Quote 3).

2.2.2 Teachers

A selection of mainstream and specialist teaching staff was interviewed during this process. Teachers are, as expected, in favour of more accessible science in general, although not necessarily in all cases, and provision varies wildly, by school.

There are examples, such as Quote 5, of schools doing all they can to make experiments accessible, and there are examples of students being gently moved to other topics; there are also examples of students being 'written off' (Quote 6).

> One of our year 7's is a wheelchair user and we have a 'working plan' for science. We had someone from the [a local special school] come in and examine the area and do a needs assessment; they recommended adjustable height benches, clearing out a much wider space, a special chair for her to use during the experiment and a Teaching Assistant to work with her for safety […] we'll do a new working plan every year because the setup changes.

Quote 5: A teacher discussing adjustments made for a wheelchair-using student

Something that is perhaps unexpected to readers but that came up repeatedly in conversation with teachers is that some disabled students are often quite keen to avoid experiments as they are much more stressful. A mainstream student knows that if they accidentally knock over a Bunsen burner, they can jump out of the way. A wheelchair user knows that they can't and that the classroom is set-up in a way that assumes people can. For students with sensory disorders or autism, the nature of experiments for chemistry, in particular, can be quite upsetting.

> My kids don't do science, they can't.

Quote 6: A teacher in a non-mainstream school on the potential for science in the classroom

> For year 7–9 experiments are fewer, you could go half a term without doing any chemistry at all but you do some practical in physics. Lessons are generally more book-led....or should I say listen and watch a PowerPoint/use computers to do own research and answer questions.

Quote 7: How often practical work occurs in a secondary school

2.2.3 Parents

Parents were a key aspect of the interview strategy. The nature of disability is such that special needs parents are, almost by default, much more involved in their children's education. Moreover, parents have much more experience in knowing how their children learn effectively out of the classroom. The parents of 'Tom' made an extremely interesting example. Tom has several learning differences (without loss of generality the reader can assume autism) and has been outside of education for several years due to the local authority being unable to provide services for him. Tom is now (largely self-) educated at home, meaning that he must choose 'book learning' subjects like maths over topics that require regular feedback or that require experimental work.

Tom's case is far from an isolated example: Ofsted has reported there are 10,000 children 'missing' from the education system [29], and a large proportion will be for the same reason as Tom. As made clear in Quote 8, such students are in a position of missing out on practical experiments in science due to being educated at home and may be actively prevented from studying science at home. In such cases there is a clear need to deliver (and even assess) the learning outcomes that students would normally gain from experiments in some different format.

> It was that Tom could not attend a practical exam in physics at some unknown point in the future that the Council's solicitors made long and aggressive opposition to our proposals for distance learning in Tribunal.

Quote 8: A parent discusses the issues with practical work for children outside of mainstream education

2.2.4 Exam expert

Andrew Harland of the Examination Officers' Association (EOA) was consulted to provide a general context of how students with disabilities are treated during practical chemistry exams. Two particularly salient points stand out:

- There are proportionally very few students being examined on their practical work.
- The most common system for enabling students with disabilities to perform experiments under exam conditions is to do so with a technician working as, in effect, a 'chemical scribe'. For the example of a visually impaired user, the technician is given instructions ('Heat the solution with the burner'), and asked questions ('What reading is shown?').

There are two tensions here. One is that experimental skills are perhaps overcompensated for. A science technician can be relied upon to operate the equipment far more effectively than a mainstream school student. The other is that this setup is only effective if the same system was used in teaching. Because it is very common for a school/college to provide scribes, it is simple to transfer that method over to an exam. Having a technician attend all science lessons is much less reasonable.

> The exams system is exclusive rather than inclusive, and this means that in many cases disabled students just aren't given a fair chance.

Quote 9: Andrew Harland, of the Examination Officers' Association on the accessibility of the exams system

2.2.5 Interview summary

These interviews have given a broad overview of the landscape in terms of chemistry education. The most salient points from the interviews are related above and their content was vital in shaping the overall structure and content of this report. One issue that came up again and again is that almost no two cases were alike; a topic we discuss in more detail in Section 3.2.1.

The clear conclusion is that the presentation of accessible resources online via platforms like Wikipedia, YouTube and Learn Chemistry may be the best resource that some disabled students have in their whole education.

2.3 Review of related work

The combination of the evaluation of need carried out in Section 2.1 and the interviews in Section 2.2 gives a context into which it is possible to start looking at effective approaches in chemistry education for disability.

Within this context the existence of a large population of disabled students has been established. In addition, this report has found no evidence that chemistry lags behind other subjects in disability access in terms of students arriving at university. Interviews have shown that these statistics cover wildly varying levels of support from education (see, for example, Quotes 2, 9, 8, 6 and 7), with many students getting very little support. It is clear that the provision of accessible resources is vital for the education of disabled students.

This section examines academic research to identify best practice approaches for improving accessibility in chemistry education.

Although there is a lack of research conducted on science teaching to students with disabilities in the UK, the broader academic literature, mostly focusing on the United States, is much more significant. Regardless, this is still far from ideal and sources from university-level education have been used liberally.

2.3.1 Theoretical learning

As touched on in Section 2.2.2 and made explicit in Quote 7, chemistry in secondary education has a wide range of teaching modes. Although much of the focus of this report will be on the practical aspects of chemistry education, it is worth examining other aspects, particularly as that is where students spend the majority of their time.

There is a clear tension here in that the disabilities that cause difficulties with written work (dyslexia for example) cause few problems for experimental work and vice versa (powered wheelchair-users for example). This would imply that chemistry may suffer more from a loss of disabled students than other subjects simply because such a range of disabilities has problems with *some* aspect of chemistry. Conversely, it may be the case that the subject has at least one area in which a student can excel, which is much more motivating. However, the evaluation of need carried out earlier in this chapter would suggest that any motivating element of chemistry as a subject for students with disability is relatively small. Overall the subject will suffer more from a loss of disabled students unless special provisions are taken by each school.

However, it does follow that by improving the accessibility of written work, a greater proportion of students with disability may find access to chemistry improved even without changes made to practical work.

There are many things that can be done within written materials to improve accessibility for disabled students, and a wide range of sources are available (see, for example, references [41], [36], [4], [18] and [2] for general examples and [24] for science specific recommendations).

Recommendations commonly include:

- releasing handouts as early as possible, preferably at the start of term;
- displaying information in multiple modes, such as with text and graphically;
- checking that typefaces are accessible (sans-serif is often recommended);
- using appropriate font sizes for both handouts and presentations;
- aligning text to the left rather than justifying;
- making handouts electronically available;

- using Microsoft Word's styles to allow navigation by screen reading software;
- if a document is printed on coloured paper, choosing light blue, cream or yellow rather than green, pink or red, which are less accessible for dyslexic readers.

Many of the above recommendations were taken from Rodrigue [35]; however, there are many equivalent sources.

2.3.2 Practical work

There is no doubt that lab-based courses play an important role in scientific education [22]. Their proponents go as far as to claim that "hands-on experience is at the heart of science learning" [26] or that laboratory experiences "make science come alive" [7]. This section examines the educational value of different approaches to practical work, concentrating on the potential value that can be realised from online resources such as those on Learn Chemistry.

> […] a review of the literature on engineering and science education and a survey of educators in these subject areas within the four universities participating in the project were undertaken. This work is available in public deliverables of the project and has been summarised in previous publications. This confirmed that experimental work is a vital part of science and engineering teaching at all levels. There were no dissenting voices from this.

Quote 10: Summary of the PEARL project [11] on the topic of practical experiments in science

> Taking part in practical work is an integral and essential part of learning in the sciences. It provides experiences through which students can develop their understanding, enabling them to make the link between subject content and the physical and living worlds by experiencing and observing phenomena; practical work teaches techniques and skills for handling equipment and materials safely; as well as promoting the development of scientific reasoning, so that students can understand, through direct experience, the importance of evidence in supporting scientific explanations and theories. Therefore it is essential that practical work is properly resourced and that all students have access to the equipment, facilities and opportunities necessary for a complete and authentic education in the sciences.

Quote 11: SCORE [40] on the topic of practical experiments in science

Learn Chemistry has invested substantially into producing a range of online experiments. Intuitively, such experiments should be an excellent resource for those students that have challenges with in-person real practical experiments.

However, there are two concerns with online experiments:

- Is there any research supporting the ability of online experiments to deliver the same learning outcomes as in-person real practical experiments?
- Are the online experiments delivered in a way that disabled students can take full advantage of them?

Chapter 3 is devoted to answering the second concern by recommending a range of improvements. This section is devoted to answering the first concern.

It would be poor practice to compare 'hands-on' laboratory work with simulation without taking notice of the intermediate option: remote access laboratories, which were introduced and discussed briefly in Section 2.2.1.

In general, there are not many studies available to inform decisions by educators on the appropriate use of laboratory technology [27]; however, there is enough academic work to begin to answer some of the most pressing questions. Indeed, it is possible to find studies that show any one of the three approaches are superior. Simulated labs were found to be effective by Shin *et al*. [44]; Parush *et al*. [32] point out that "the students using a simulator are able to stop the world and step outside of the simulated process to review and understand it better".

Grant [16] is clear that data from simulated labs are not real and therefore, the students fail to learn by trial-and-error. However, Sicker *et al*. found that students thought hands-on labs were restrictive, in that experiments could not easily be re-run [45]. Realistic simulations are expensive to design and might still fail to be accurate enough [31]. It is pointed out by Ma and Nickerson [22] that what students learn from simulations is primarily how to run simulations.

Much of this apparent confusion is resolved by Ma and Nickerson [22] who performed a full review of the area and found that the tendency of groups to favour one approach over another was largely determined by what that group thought the value of experimentation was.

Ma and Nickerson found that the educational value of the different methodologies was assessed by any of the following outcomes:

- conceptual understanding (how much does the experiment help students solve problems related to key concepts taught in the classroom);
- design skills (how well can students solve open problems by designing their own experiments and processes);
- social skills (how well do students learn how to solve engineering problems in groups); and
- professional skills (how do students become familiar with the skills they would be expected to have as a professional).

Broken down in this way, the results indicate that hands-on labs are clearly superior at establishing a student's social skills. The three different approaches to experiments are effectively equal in terms of developing a conceptual understanding and (somewhat unexpectedly) professional skills.

Hands-on labs showed a lead over simulated labs in terms of teaching experimental design skills, although both clearly outperformed remote labs. Although it may be counterintuitive that simulated labs outperform remote labs in this way, consider that Learn Chemistry's simulated experiments contain exercises that allow the user to select equipment for an experiment.[10] By contrast, the PEARL project discussed in Section 2.2.1 could only let students operate on equipment that had been previously set up.

What are the requirements of the UK educational system?

The advantages and disadvantages of simulated experiments for various educational outcomes have been established and it is now possible to compare with exactly what educational outcomes are being tested for in the UK educational system. Unfortunately, this is less simple in practice.

SCORE is a partnership organisation between the main organisations for science in the UK, including the Royal Society of Chemistry. It advocates for evidence-based science education policy. SCORE's guidelines state that effective practical work comprises:

- Technical and manipulative skills: there should be an expectation that on completing the course students are able to perform a range of scientific procedures with due regard for accuracy and risk management. They should have hands-on experience of conducting specific technical and manipulative tasks.
- Extended investigation: students should be given the opportunity to undertake work in which they make their own decisions, for example through an investigation of their choosing over an extended period of time. They should be assessed on their ability to plan, observe, record, analyse, communicate and evaluate through this activity.

- Development of conceptual understanding: a range of practical activities should be incorporated into the teaching of scientific ideas to enable students to develop their understanding through interacting with apparatus, objects and observations [38].

10. The correct equipment must be selected to move forward with the experiment, and the purpose of each piece of equipment is explained.

However, SCORE's own reports point out that there is a wide range of skills assessed by different exam boards [39].

In general, particularly given the use of scribes during examples (Section 2.2.4), we can assume that simulated experiments are, if designed and used correctly, capable of achieving the educational goals of classroom practicals. Perhaps even more so in the case of disabled students.

2.4 Summary

This chapter has, from a broad remit, covered a large amount of content. Its examination of the size of the relevant population and the available information around university education found no evidence that students were being driven away from chemistry as a degree choice, although it identified a number of areas where further research was needed to confirm findings.

The interviews that were conducted painted a picture of a highly varied level of support for disabled students, including those outside of mainstream education, and showed a clear and present need for accessible information in education.

The third part of the chapter evaluated evidence that simulated experiments are increasingly becoming a valid teaching technique at all levels. In particular, it has been shown that this evidence is much stronger for conceptual understanding than design skills or professional skills. Following discussion with educational professionals it has been shown that, in practical terms, students with disabilities are indeed examined on their conceptual understanding rather than their professional skills. However, we also note that it is unclear how many students with disabilities learn the skills that they are to be examined on.

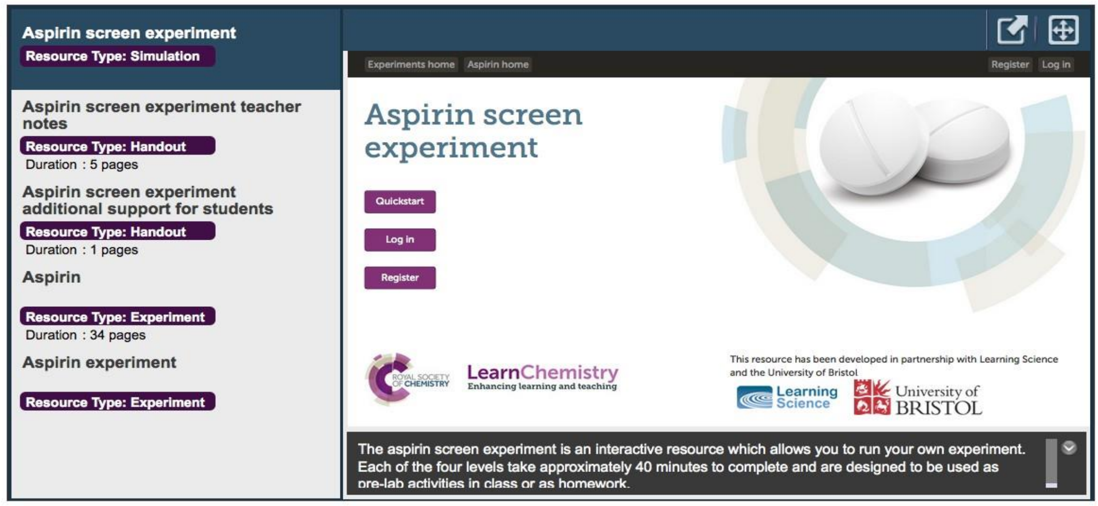
Chapter 3

Accessibility benefit assessment

This part of the report contains an *accessibility benefit assessment*. An accessibility benefit assessment examines a process, object or concept and identifies any difficulties that users may have accessing it.

Unlike a typical accessibility audit (in which an object is measured against a set of standards), the accessibility benefit assessment includes contextual information on each issue, particularly the proportion of potential users that may be affected by the issue and how badly they are affected. In this way, organisations that have limited staff time or funding can identify those issues that could create the greatest improvement for their limited resources.

This assessment covers the whole range of resources using Learn Chemistry by way of example. It concentrates particularly on screen experiments because they are an excellent case study and because, by nature, they are slightly less accessible than other online resources.



Aspirin screen experiment
Resource Type: Simulation

Aspirin screen experiment teacher notes
Resource Type: Handout
Duration : 5 pages

Aspirin screen experiment additional support for students
Resource Type: Handout
Duration : 1 pages

Aspirin
Resource Type: Experiment
Duration : 34 pages

Aspirin experiment
Resource Type: Experiment

Aspirin screen experiment

This resource has been developed in partnership with Learning Science and the University of Bristol

The aspirin screen experiment is an interactive resource which allows you to run your own experiment. Each of the four levels take approximately 40 minutes to complete and are designed to be used as pre-lab activities in class or as homework.

Figure 3.1 The aspirin screen experiment from Learn Chemistry.

The screen experiments incorporate videos, activities, questions and scoring systems. Each level of the screen experiments replicates an activity of relevance to the syllabus for students in full time education.

3.1 Framing

A key element of this research is to examine the online resources and consider their level of accessibility, in general and in the specific case of users who may have difficulties performing the original hands-on real experiment.

However, at this point, it is worth highlighting that we are framing the accessibility issue not in the context of a stand-alone website, but in the general context of a high-quality science education. As a result, more weight and consideration have been given to disabilities like manual dexterity and visual impairment compared to examples like dyslexia and autistic spectrum disorder.

This chapter begins by outlining some general points that back this assessment and the suggested courses of action, and then we deliver a set of possible improvements, concentrating particularly on the online screen experiments within Learn Chemistry.

The Royal Society of Chemistry's aspirin screen experiment[11] (Figure 3.1) is used as the main example to highlight issues found more generally with online resources.

[11] http://www.rsc.org/learn-chemistry/resources/screen-experiment/aspirin/experiment/1/1

3.2 Design principles

While the benefit assessment is the main contribution of the chapter, there are a wide range of issues that are worth considering beforehand – both as general design principles for accessibility and to contextualise later recommendations.

3.2.1 Universe of one

Disability assessments and disability research more generally must contend with what is known colloquially as the ‘universe of one’ problem. It is impossible to pick out, for example, a ‘typical disabled person’ because there is such a dramatic range of conditions, levels of impairment, levels of function, levels of staff support and a wide range of other factors. It follows that it is also extremely difficult to cover all of the possible angles for accessibility of any given resource. What organisations *can* do is be flexible.

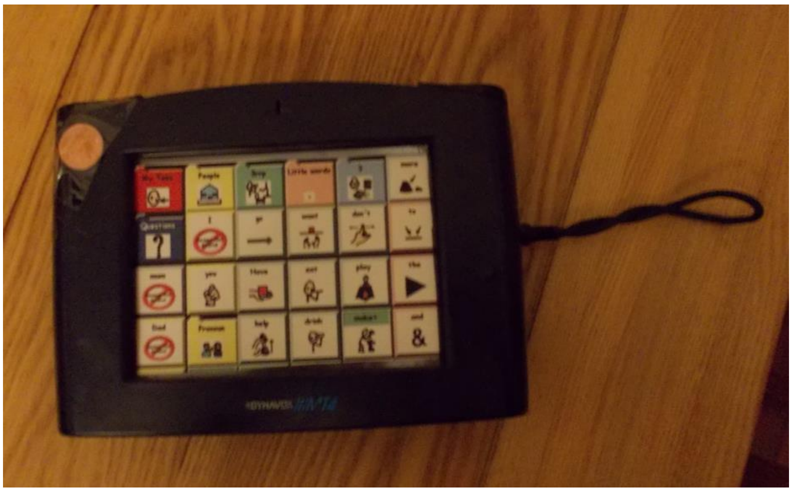


Figure 3.2 An extremely specialised communication device illustrating the universe of one problem.

It is difficult to overstate the nature of the universe of one problem. As an illustration, Figure 3.2 shows an extremely specialised piece of accessibility equipment, the Dynavox MT4. This device is designed to help users who cannot talk and is designed to service those users who also are preliterate and who have very specific weight/battery life requirements. The T4’s software contains an extremely large range of options to adjust every aspect of the interface to a user’s needs. Even given the intense specialisation of this device, the family using it have had to make their own modifications including removing the power button and adding new control hardware.

There isn’t necessarily any design response for the Royal Society of Chemistry to the universe of one problem because the requirements are often specific to an individual. However, delivering content via multiple methods, for example websites transferred to word or pdf documents, is increasingly considered good practice.

Parents of children with special needs often need to make requests of places like restaurants that the staff had not anticipated. This might include “can we have the drink half in a plastic cup and half in a glass cup?”, “is it possible to have a seat where the sign with the fish on it is blocked from view?”, and “there are four of us coming but can we have a table for six in a corner?” In the case of physical facilities these are things that are easy to accommodate by allowing the staff a certain amount of flexibility so that they can be responsive to customer needs.

For an online resource, where changes are far more difficult to make for a single individual, this flexibility must manifest as providing as much of the information, both raw and final, as possible. Users can then make use of the different formats in whatever way suits their circumstances.

In the case of screen experiments by the Royal Society of Chemistry, this might range from providing a printable PDF version that models the interactive approach as effectively as possible, to providing the captions for the video as a separate file, to providing references so that users can track down the materials that the original design was based on.

3.2.2 Open data

Something that has improved overall accessibility on the internet significantly in recent years is the emergence of open source software, open data and the general ‘openness’ philosophy [13]. Open source software tends to actively welcome people making accessibility improvements and information released in open accessible formats has been a boon to internet users with accessibility needs. The preeminent example is of course Wikipedia, which is highly accessible to both its users and editors and is the most used educational resource in the world.

The nature of open data is such that many key elements to following an open agenda, such as releasing resources in non-propriety formats, releasing the transcripts of videos and putting raw data online, are all things that can only improve accessibility of a resource – often for users whose needs are rarely met.

This approach has the advantage that it is intuitively understandable by technical staff who may have no direct experience of disability but who are keen to make things accessible where possible.

There is a subtle tension here. While releasing all content on a site in a non-proprietary format would allow many users to access the information in a way that would never have been possible before, this can only be part of an overall accessibility strategy. It is always easier to use a properly designed and accessible resource than download the raw files and process them yourself, and requiring disabled people to do this for every resource is equivalent to treating them as second-class citizens.[12] Nonetheless, it is extremely difficult to make something less accessible by making it more open.

3.2.3 The end user and the first user

A guiding principle to bear in mind is that users who have accessibility issues with the web are much less likely to ‘browse’ the internet for resources outside of a few sites that are known to be accessible (Wikipedia, for example, and for many disabled students, YouTube).

The key fact to absorb is that, rather than many disabled students accessing the site and leaving due to accessibility issues,[13] students with accessibility issues simply aren’t arriving at the site at all.

Instead, they are much more likely to visit if someone else: a parent, a personal assistant, a friend and, often in this case, a teacher, finds a website that they judge to be accessible for the student. Often it isn’t enough to simply *be* accessible, one has to *look* accessible as well.

A clear overall recommendation for an online presence is to think not only ‘how can we make this accessible to everyone?’ but also ‘how can we make it obvious to teachers that this is worthwhile for *all* their students?’

3.2.4 Case-study: captioning

Captioning is included within the main benefit assessment; it’s been foregrounded here because it is an excellent case study that often catches people out.

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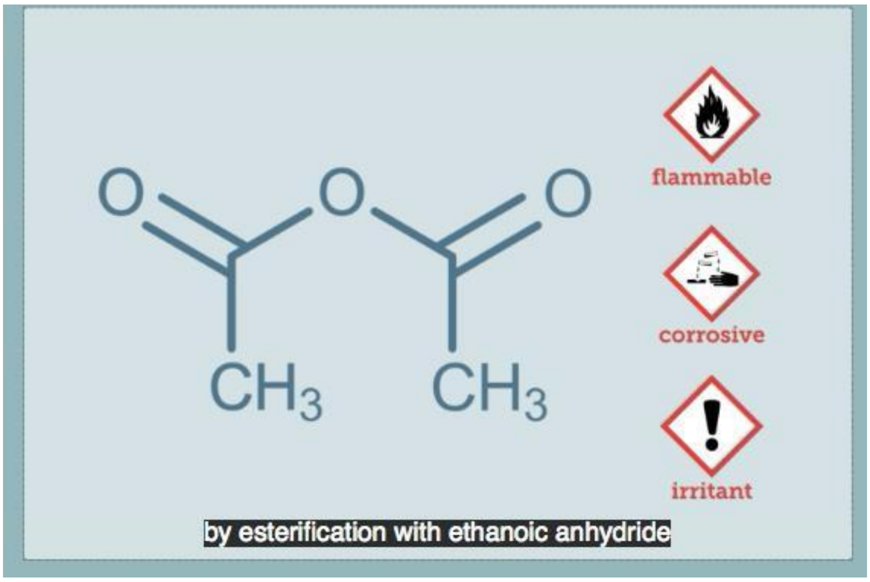
[12] It also assumes a relatively high level of IT-literacy, which although reasonable for key stage 4 and 5, is far from universal.

[13] Although this does happen, particularly with sites that are failing to adhere to web standards; however, this is precisely the issue that the Royal Society of Chemistry already addressed with its RNIB audit.



by esterification with ethanoic anhydride

Figure 3.3 Captioning in the aspirin screen experiment.

People unfamiliar with the area can be surprised to find is that there is a significant difference between being deaf and being Deaf, including with regard to many aspects of education [30]. Almost uniquely in the disability space, people who are Deaf and communicate with British Sign Language have strong incentives to spend time with each other as part of a community.[14] This community has its own language and a rich culture, heritage and network.[15] Members of this culture would consider themselves Deaf rather than deaf.

> Counterintuitively [d/D]eaf children often have difficulties with print media and the written word [46, 23] as a result of language differences.
> Across caption conditions, comprehension test scores of students who are deaf were consistently below the scores of hearing students.

Quote 12: Lewis [21] on captioning for deaf students

Indeed, as Quote 12 shows, [d/D]eaf users may process subtitles less well than their hearing colleagues.[16] It follows that in addition to making sure that subtitles are available, they must also be clear, as simple as possible, and allow the reader to process them in their own time.

There is a second key point in this example, which is that by making a transcript available in addition to captioning you also support dyslexic children, and even visually impaired users may find it easier to run though the transcript with high-speed text-to-speech rather than wait for the whole video. Moreover, particularly with chemistry videos that use many technical terms (Figure 3.3), mainstream students may find it useful to be able to find any terms they are unfamiliar with and copy/paste them into a search engine.

In almost all cases, improving accessibility for one group will likely improve it for several others, including mainstream students. For Table 3.1 we assume all videos have subtitles, the issue listed focuses on improving them and making transcripts accessible.

For an excellent and easily implementable example of subtitles done well, the TED (Technology, Entertainment and Design) conference uploads its videos with a full transcript below them. Clicking on a sentence in the transcript takes the user to that point in the video and the text can be copied, saved and manipulated at the user's choice (See Figure 3.4).

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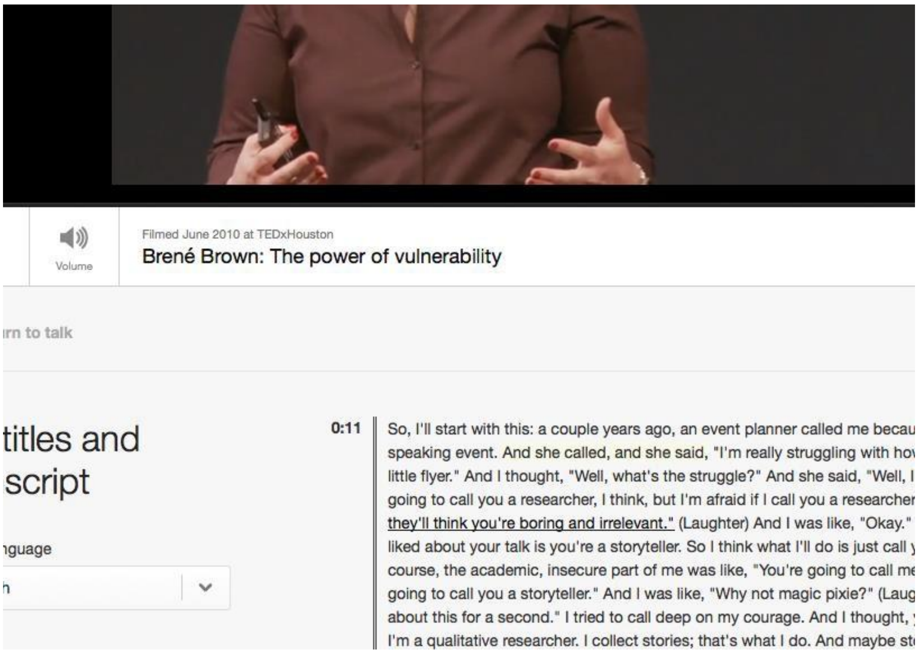
[14] Deaf scuba diving clubs are an excellent example of how disability is a function of the environment.
[15] Along with its own controversies, such as cochlear implants.
[16] There is, of course, a strong difference between people born without hearing and those who lost hearing later; in the case of school children we are normally focused on the former.



Filmed June 2010 at TEDxHouston

Brené Brown: The power of vulnerability

0:11 So, I'll start with this: a couple years ago, an event planner called me becau
speaking event. And she called, and she said, "I'm really struggling with ho
little flyer." And I thought, "Well, what's the struggle?" And she said, "Well, I
going to call you a researcher, I think, but I'm afraid if I call you a researcher
they'll think you're boring and irrelevant." (Laughter) And I was like, "Okay."
liked about your talk is you're a storyteller. So I think what I'll do is just call
course, the academic, insecure part of me was like, "You're going to call me
going to call you a storyteller." And I was like, "Why not magic pixie?" (Laug
about this for a second." I tried to call deep on my courage. And I thought,
I'm a qualitative researcher. I collect stories; that's what I do. And maybe st

Figure 3.4 Transcript sections that can be copied and pasted and that link to specific sections of the video.

3.3 Examples of good practice

The sheer amount of resources online via the Royal Society of Chemistry (Learn Chemistry) gives opportunities to many who find chemistry education difficult, including children outside the school system, students with social disabilities and a wide range of other groups. The platform in general is extremely well designed and attractive, and the dedication to providing a comprehensive source of information is impressive. Overall there is much to be said positively about Learn Chemistry, even in a disability context.

There is some discussion on disability within the site, including a resource that provides chemistry curriculum terms in British sign language (http://www.rsc.org/learn-chemistry/resource/res00002161/british-sign-language-bsl-chemistry-signs) and a website also provided via a Powerpoint presentation (http://www.rsc.org/learn-chemistry/resource/res00001693/problem-solving-tutor), which exemplifies the consideration for multiple delivery modes. Other than a few slightly old-fashioned terms, the discussion is non-patronising and sensitively handled. It is clear that there is an overall willingness to engage.

In particular, it is clear that Learn Chemistry was put together with a view that it was intended to be accessible to as many users as possible – while there are a range of improvements to make, it is unlikely that they would have been identified by a layperson.

The online screen experiments themselves constitute an excellent, deeply involved resource with beautiful design skills; although they attract the bulk of the recommendations made, it is largely as a result of accessibility practices not yet being standard in a relatively new technology.

3.4 Potential benefit areas

This section gives details on changes that could be made to online resources and use Learn Chemistry (or the screen experiments) by way of example to realise the most benefit. It accompanies Table 3.1.

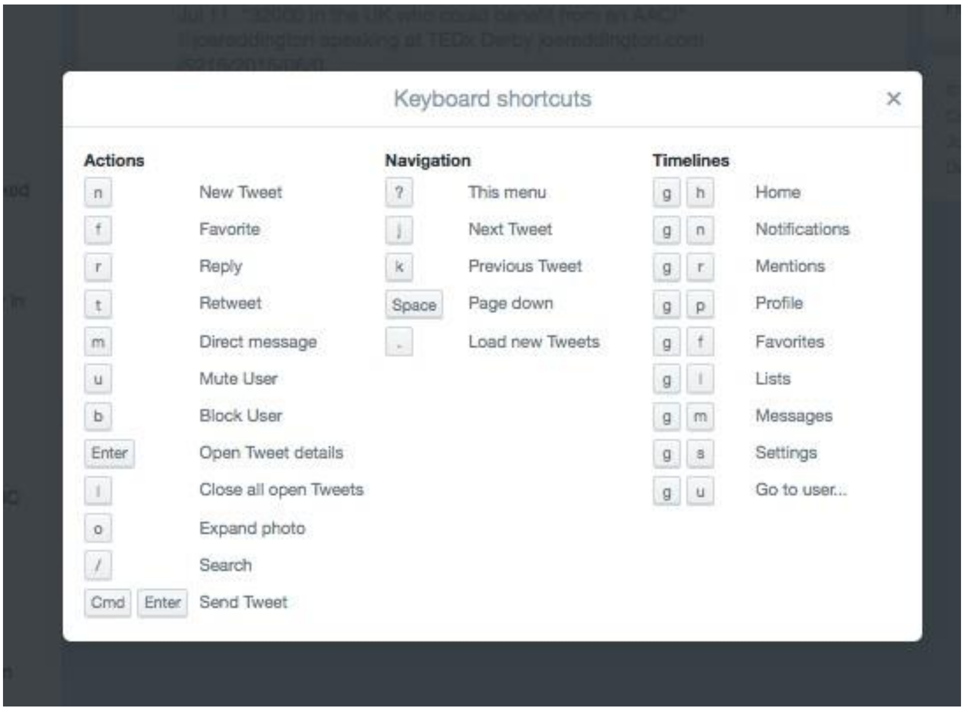
3.4.1 Keyboard shortcuts

The online screen experiments require the direct use of the mouse at all times; however, a large proportion of users with accessibility issues navigate the web with help from the keyboard [37] because use of the mouse causes significant problems.

This is an issue with many design-heavy sites, particularly those with animations or other interactive elements. A common solution (taken by Google, Facebook, Twitter and others) is to provide a set of keyboard shortcuts for navigating through the system. Figure 3.5 shows an example.

We estimate that including keyboard shortcuts on the online screen experiments would beneficially affect students with manual dexterity issues (affecting 0.9% of the total student population) [28] and visually impaired students (0.2% of the total student population) to a significant degree [19].

It is worth noting that the keyboard shortcuts in Figure 3.5 are useful for users with disabilities and for people looking for a more effective way of browsing the website. This feature is presented as a natural part of the website for people to access, rather than a 'special' thing bolted on for users with special needs.



Keyboard shortcuts

Actions	
n	New Tweet
f	Favorite
r	Reply
t	Retweet
m	Direct message
u	Mute User
b	Block User
Enter	Open Tweet details
l	Close all open Tweets
o	Expand photo
/	Search
Cmd Enter	Send Tweet

Navigation	
?	This menu
j	Next Tweet
k	Previous Tweet
Space	Page down
.	Load new Tweets

Timelines	
g h	Home
g n	Notifications
g r	Mentions
g p	Profile
g f	Favorites
g l	Lists
g m	Messages
g s	Settings
g u	Go to user...

Figure 3.5 Twitter's keyboard shortcuts.

3.4.2 Selectable text

Users are unable to select any of the text that appears on the online screen experiments. Many users, particularly those with mild to moderate conditions such as dyslexia and mild visual impairment, find it difficult to process text and will copy and paste text into a speech synthesis program or use a direct screen reader to get the full meaning from text [17].

Including selectable text in the Royal Society of Chemistry screen experiments would beneficially affect students with dyslexia (7% of the total student population) to a mild degree [33] and visually impaired students (0.2% of the total student population) to a critical level [19]. Although outside the scope of this report, it is worth noting that a significant proportion of students at key stage 4 and up have English as an additional language and often find it helpful to be able to copy and paste text into translation programs.

3.4.3 Fine motor control

Several sections of the screen experiments require extremely high levels of fine motor control: one section requires dragging text to particular area; another requires dragging equipment into precise *unlabelled* areas. In this particular example, it can take several attempts to get the equipment into the intended area.

There are two issues here. Firstly, the action of dragging is difficult for users with particular forms of physical disability, and secondly, the process can take a lot longer for such users – in the order of tens of seconds rather than seconds. When it takes such a long time to complete an action, multiple attempts to work out exactly where the item is to be dragged can be extremely frustrating. Of course, given the keyboard shortcuts discussed in an earlier section, this would be a non-issue.

Altering the screen experiments so that there were alternatives to fine motor control would beneficially affect students with manual dexterity issues (0.9% of the total student population) [28] and visually impaired students (0.2% of the total student population) to a significant degree [19].

3.4.4 Inconsistent contextual clues

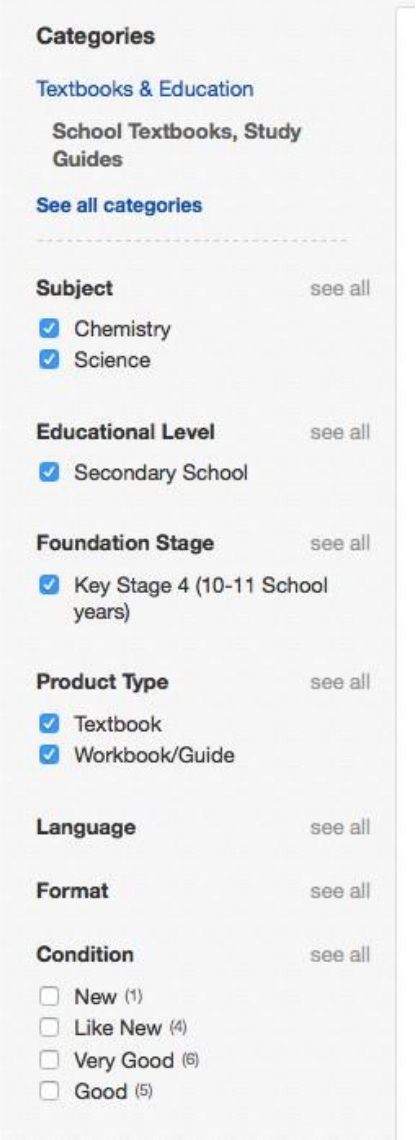
There are some design choices that might raise issues for users who are finding their way around the design. For example, Figure 3.6 has a cross that closes the window and Figure 3.7 has a cross that triggers no action at all; the window in that case is closed by the ‘Ok’ button. No prevalence information is presented for this issue; however, it is noted that the more intuitive the design the better, particular for students with common learning differences like dyslexia and autistic spectrum disorder.

Figure 3.6 Using a cross to close a dialog box.

Figure 3.7 Using a cross to decorate a dialog box.

3.4.5 Flexible resource selection

Learn Chemistry, for example, has almost 4,000 resources online. This, of course, presents a problem in the context of educators and students correctly finding the approach they are seeking. The current design allows selection of only one option from each category so it is difficult, for example, to see resources for several different age groups. Figure 3.8 shows a different approach: the online platform eBay allows users searching for chemistry resources to select a wide range of options and select several options at once for a more nuanced query. As above, no prevalence information for this issue is presented; however, again, the more intuitive the design the better, particular for students with common learning differences like dyslexia and autistic spectrum disorder.



Categories

Textbooks & Education

School Textbooks, Study Guides

See all categories

Subject see all

☑ Chemistry
☑ Science

Educational Level see all

☑ Secondary School

Foundation Stage see all

☑ Key Stage 4 (10-11 School years)

Product Type see all

☑ Textbook
☑ Workbook/Guide

Language see all

Format see all

Condition see all

☐ New (1)
☐ Like New (4)
☐ Very Good (6)
☐ Good (5)

Figure 3.8 Selecting chemistry resources on a popular online platform.

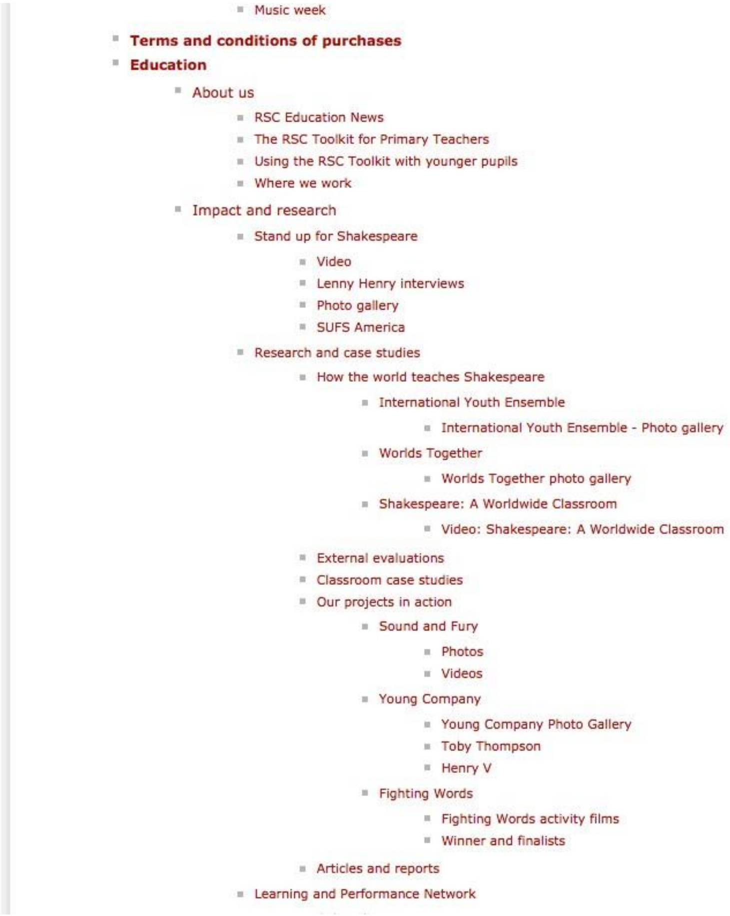
3.4.6 Sitemap

The wide range of pages that make up the Learn Chemistry online presence can be overwhelming, particularly to users with an accessibility issue. Moreover, the somewhat confusing approaches to reaching resources mean that vital ones may be missed.

A common recommended solution is a ‘sitemap’, which shows as many of the pages and resources as possible.[17] An equivalent design would be from the Royal Shakespeare Company, who also have a great deal of dynamically updating resources – their sitemap is shown in Figure 3.9.

Adding a sitemap would beneficially affect students with manual dexterity issues to a mild degree (0.9% of the total student population) [28], enabling them to navigate the website more easily with fewer mouse clicks, and visually impaired students (0.2% of the total student population) – who would be able to see the structure and content in one place in a meaningful way, enabling them to identify an activity of interest with minimal navigation and effort – to a significant degree [19]. We believe this would also have a mild effect on students with autistic spectrum disorder, but this is largely speculation.

[17] The Royal Society of Chemistry website itself shows evidence of a sitemap as linked from, for example, http://www.rsc.org/cpd/training but the sitemap link redirects to the legal guidance page.



        - Music week
- **Terms and conditions of purchases**
- **Education**
    - About us
        - RSC Education News
        - The RSC Toolkit for Primary Teachers
        - Using the RSC Toolkit with younger pupils
        - Where we work
    - Impact and research
        - Stand up for Shakespeare
            - Video
            - Lenny Henry interviews
            - Photo gallery
            - SUFS America
        - Research and case studies
            - How the world teaches Shakespeare
                - International Youth Ensemble
                    - International Youth Ensemble - Photo gallery
                - Worlds Together
                    - Worlds Together photo gallery
                - Shakespeare: A Worldwide Classroom
                    - Video: Shakespeare: A Worldwide Classroom
            - External evaluations
            - Classroom case studies
            - Our projects in action
                - Sound and Fury
                    - Photos
                    - Videos
                - Young Company
                    - Young Company Photo Gallery
                    - Toby Thompson
                    - Henry V
                - Fighting Words
                    - Fighting Words activity films
                    - Winner and finalists
            - Articles and reports
        - Learning and Performance Network

Figure 3.9 A small portion of the Royal Shakespeare Company’s sitemap.

3.4.7 Clickable areas unidentifiable

As part of the design of the screen experiments, there are a range of areas that can be clicked on to either provide more information (Figure 3.10) or advance the experiment. Unfortunately, many of these areas are unmarked, which makes it extremely difficult for users of assistive technology to know they are available.

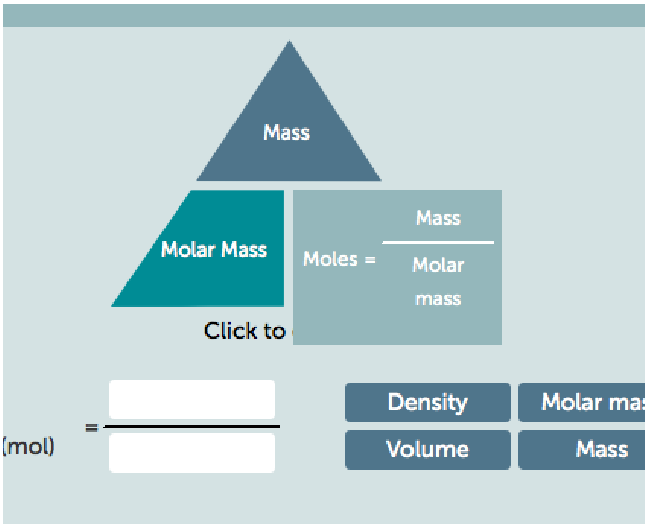
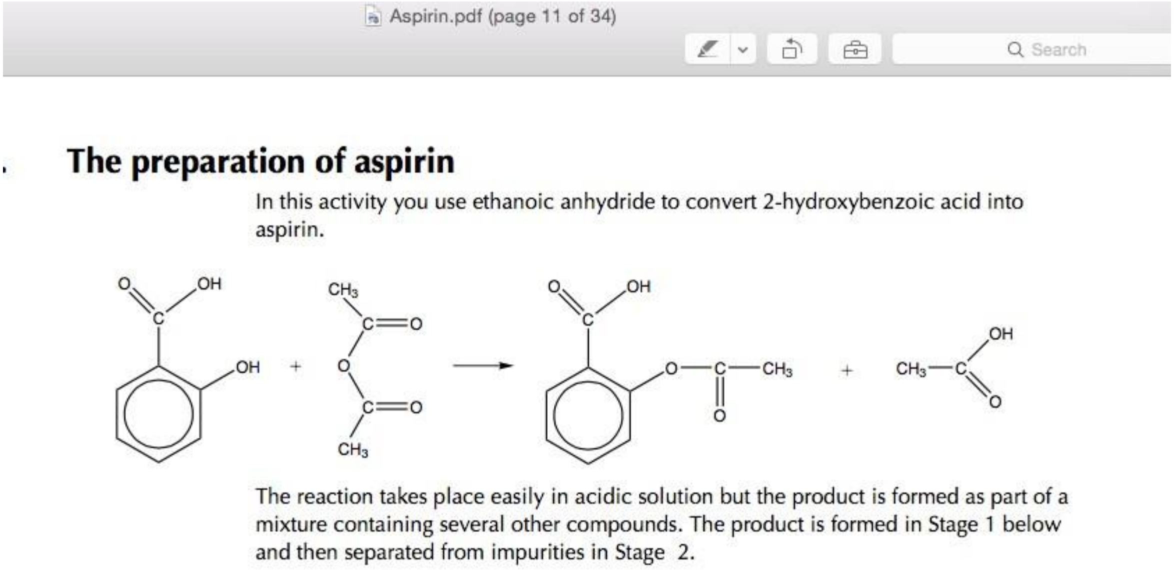


Figure 3.10 An example of an unmarked clickable area.

Making it clear which areas on the online experiments are interactive would beneficially affect students with manual dexterity issues (0.9% of the total student population) [28] and visually impaired students (0.2% of the total student population) to a significant degree [19]. It is expected that this would also have a mild effect on students with autistic spectrum disorder, but this is largely speculation.

3.4.8 Structural formulae



The preparation of aspirin

In this activity you use ethanoic anhydride to convert 2-hydroxybenzoic acid into aspirin.

The reaction takes place easily in acidic solution but the product is formed as part of a mixture containing several other compounds. The product is formed in Stage 1 below and then separated from impurities in Stage 2.

Figure 3.11 Structural formulae as they appear in a handout from Learn Chemistry.

Figures 3.11 and 3.12 show structural formulae in both an online experiment and a PDF. Clearly these diagrams are extremely inaccessible for visually impaired students. Equally clearly, structural formulae are an integral part of chemistry education. The recommendation of this report is that, where possible, resources should include (as Wikipedia does) the SMILES [3] format to describe structure. For example, writing caffeine as:

$$CN1C = NC2 = C1C(= O)N(C(= O)N2C)C$$

Again, this has the benefit of being much easier for mainstream students to gather more information about a given structure by entering the SMILES format into a search engine.

Addressing this issue would affect visually impaired students (0.2% of the total student population) to a critical level [19].

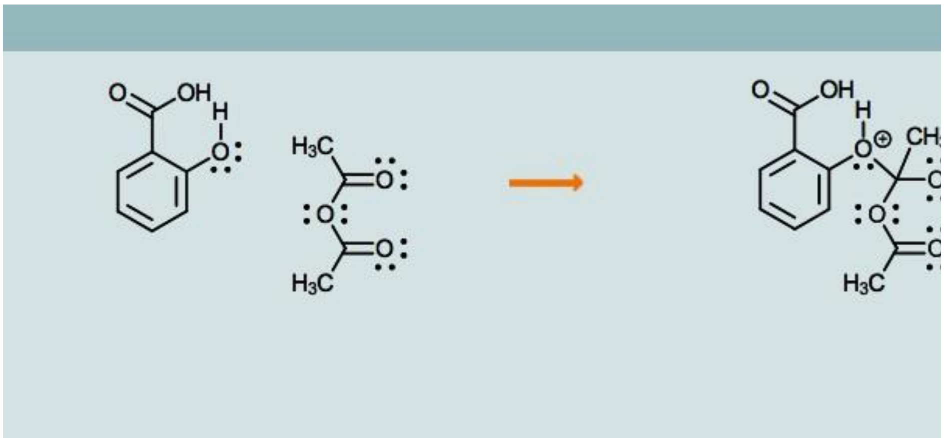


Figure 3.12 Structural formula as they appear in one of Learn Chemistry's online experiments.

3.4.9 Captioning transcripts

As previously mentioned in 3.2.4 as an example of good practice – please see this section for further discussion.

Table 3.1 Accessibility benefit assessment

Issue	Population	Size	Severity
Keyboard shortcuts	Visual impairment Manual dexterity	0.2% 0.9%	Significant Significant
Selectable text	Dyslexia Visual impairment	7% 0.2%	Mild Critical
Fine motor control	Visual impairment Manual dexterity	0.2% 0.9%	Significant Significant
Inconsistent contextual clues	—	—	Significant
Flexible resource selection	—	—	Significant
Sitemap	Visual impairment Manual dexterity	0.2% 0.9%	Significant Mild
Clickable area unidentifiable	Visual impairment Manual dexterity	0.2% 0.9%	Mild/significant Significant
Structural formula	Visual impairment	0.2%	Critical
Captioning transcripts	Visual impairment Dyslexia Deaf	0.2% 7% 0.25%	Mild Mild Significant

3.5 Summary

This chapter first discussed a set of design principles which are applicable to the design of online resources for a diverse audience and uses examples taken from around the web.

Secondly it gave a range of examples of good practice found on the Royal Society of Chemistry platforms, particularly focusing on elements that people may believe cause problems for disabled students.

Thirdly it produced a set of targeted recommendations for the Royal Society of Chemistry's online resources, including estimation of how many users it was likely to affect, and the extent to which they would be affected. These estimations can be used to effectively target developer time so as to have the greatest effect on accessibility with a limited budget.

Chapter 4
Conclusion

This report summarised investigations into the challenges and opportunities in supporting disabled students in chemistry with a particular focus on how those challenges might be reduced though digital tools. Its key aims were:

- to identify and critically appraise research into the accessibility landscape for chemistry education and practical work at key stage 4 and 5 (age groups 14–18);
- to present an accessibility benefit assessment for online resources using the Royal Society of Chemistry's web education presence (Learn Chemistry) by way of example.

4.1 Research appraisal

Chapter 2 focuses on the 'state of the nation' report and deals with such issues as finding an accurate and useful assessment of the numbers of students affected by disability issues, the context around which changes may be made and a literature search for processes that have been successful in the past.

The clear conclusions of this chapter included that:

- there is no evidence to suggest that, in general, disabled students are put off chemistry at a university level;
- there is evidence to suggest that disabled students regularly have to deal with inconsistent levels of support, resources, and equipment compared to their peers;
- it follows that the provision of accessible resources online is more important to disabled students than it is to mainstream students.

Regarding support for students excluded from practical experiments, a review of available research leads us to conclude that simulated experiments are, when designed well and used correctly, capable of achieving the educational goals of real classroom practicals. Perhaps even more so in the case of disabled students.

4.2 Accessibility benefit assessment

In Chapter 3 we introduced a set of overall recommendations, grounded in data and experience, for designers and managers to consider when producing online resources. It included a set of nine targeted recommendations for the Royal Society of Chemistry's online resources, including estimation of how many users it was likely to affect, and how badly it was likely to affect them. Rather than focusing solely on the users of the Learn Chemistry online resource, we contextualised these recommendations in terms of students who were likely to be excluded from a mainstream chemistry education.

The issues identified were, for the most part, relatively minor changes that are simple to make for a programmer and that would make a large difference to users accessing the resource. Only one of the recommendations (providing an alternative format to the structural diagrams) implies significant alterations to existing resources. Given the cost implications, it would be expected that this is mostly a consideration for new resources and resources that are periodically reviewed.

4.3 Recommendations for further work

This report represents one stage in an overall movement to greater accessibility in the production of online resources. As part of our work, we evaluated a wide range of current research and identified a set of open research questions that would inform future policy in this area. In addition, in this section we make recommendations about the development of future resources.

4.3.1 Codesign of resources

A key aspect of the development of modern accessible resources and assistive technology is co-design. This means involving end-users in the production of the resources as fully as possible. It is important to note that sending a draft to a group of accessibility 'proof-readers' is, although useful, different to co-design. Co-design is bringing the end users in at the start of the process and working with them to develop the resource. Of course, logistical constraints often preclude this; a common compromise is that co-design takes place on the first iteration of a new resource type, and future resources work from a template.

4.3.2 University experience for disabled students by subject

Although we have information on the number of students with disabilities for any given subject (Table 2.3), this doesn't tell us much about the actual experience of disabled students at university. It would be informative to have the same information broken down by year of study so as to compare drop-out/transfer rates between disabled and mainstream students.

4.3.3 A-level SEN data

Perhaps because of the wide range of potential post-16 qualifications available to take, and because of the optional nature of post-16 education, there is much less information available on SEN at A-level. In particular, future work to identify the subject choices of disabled students, and their success in those subjects, would be extremely informative.

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