The Association for Science Education
Promoting Excellence in Science Teaching and Learning
ASE Health & Safety Group

Topic 16: Working with DNA

This Topic is an updated version of Topic 16, which appeared in the 3rd edition of Topics in Safety (ASE, 2001). The updating has been necessary because of changes in the way work with DNA is regulated, and the availability of a greater range of practical activities, particularly from the USA. The Topic was further updated in August 2016, with the latest changes left in green text.

16.1 Introduction

Work with DNA is central to much current research in the biological sciences and to developments in modern biotechnology. There is widespread public awareness of DNA technologies, their present and potential applications and the issues that these engender.

The science upon which DNA technologies are founded, and the wider concerns associated with them feature in every UK course specification in biology or science. A limited but increasing range of practical work is possible, but it is essential that the relevant legal and safety regulations, particularly those governing genetic modification, are adhered to.

Many practical educational activities in this field originate in the USA, which has a different and in several respects a more-permissive regulatory regime than that which applies in the UK and throughout the European Union. Care must therefore be taken when selecting materials or protocols that their use is permitted in UK schools.

16.2 Hazards and risks

DNA gains a biological function by being inserted into a living cell. Hence work with DNA itself ('naked' DNA) is not generally thought to constitute a hazard even if new nucleic acid molecules are formed. Risks associated with most activities that are undertaken with DNA in school laboratories, such as gel electrophoresis can therefore be controlled by normal good laboratory practice (see Table 1).

The one exception to this is full-length copies of viral DNA that are infectious in their own right. These are legally regarded as microorganisms even when they are not encapsulated or enveloped. This means that if full-length viral DNA (such as DNA from phage lambda) were to be combined with DNA from other sources, a genetically-modified organism would have been created. For such work to be undertaken legally, the premises would have to be registered with the Health and Safety Executive (HSE) and several additional requirements would have to be met. A summary of the regulations governing such work is given in Section 16.4.

16.2.1 DNA extraction

Practical tasks such as the extraction of DNA from microorganisms, plant or animal tissue, such as fish roe, may all be carried out in schools, adopting relevant laboratory health and safety precautions. For instance, where microorganisms are involved, it is important to observe good microbiology laboratory practice.

Both the source material and crude extracts of DNA may contain allergens or toxins and they must therefore be handled appropriately, or avoided by susceptible individuals. For example, crude preparations that are said to contain DNA are sometimes extracted from kiwi fruit (*Actinidia* spp.). Reports of allergies to kiwi fruit are increasingly common and reactions to even small amounts can be severe, especially in children. In fact, such 'kiwi DNA' is mainly pectin, not DNA. Fortunately, an almost identical procedure may be used to extract DNA from onions. Onion cells contain a lot of

DNA (about five times more DNA per cell than a human cell), and serious allergies to onions affect very few people in the UK [1].

The extraction of DNA from calf thymus tissue has occasionally been referred to in school texts. Since the advent of BSE and variant CJD, there is a risk (albeit small) of accidental exposure to the infectious agent while the extract is being prepared. Beef thymus is, however, classified as 'specified offal' under the *Specified Bovine Offal Order 1995*, which means that butchers and abattoirs are very unlikely to supply this tissue to schools.

If DNA is to be extracted from human tissue*, e.g.*, cheek cells, for use in a DNA pendant, the sampling procedure must be designed to minimise the risk of the transmission of any infective agents between participants (for example, individuals should work only with their own DNA samples and suitable disinfectants should be used when disposing of material and cleaning up). The parts of the pendant should be firmly glued together after the DNA extract has been inserted. See also the guidance on human DNA sampling in Section 16.3.

16.2.2 DNA from laboratory suppliers

DNA from a variety of organisms is available from molecular biology and school suppliers. Sources include bacteriophage lambda, herring, salmon, calf thymus and even human DNA. These can generally be regarded as safe for use in schools, although full-length viral DNA that has been genetically modified must not be used without prior registration with the HSE or an equivalent organisation (see Section 4).

16.2.3 Manipulation of DNA *in vitro*

With the exception of the use and/or production of genetically-modified, full-length viral DNA mentioned above, restriction and ligation of plasmid or other DNA with enzymes, DNA gel electrophoresis, the polymerase chain reaction (PCR) and similar DNA amplification techniques may all be performed in a school laboratory. It is important to follow good laboratory practice when doing such work, however, and care must be taken to ensure that hazards from electrical equipment, buffers, stains for DNA *etc,* are understood and the risk of harm is adequately controlled (see Table 1).

Table 1: Hazards and risks associated with some educational activities involving DNA. Adapted from Richardson, J. (1995) [2].

Type and source of hazard	Nature of the hazard	Type of activity in which risks may arise	Means of limiting risks (control measures)
CHEMICAL HAZARDS			
Antibiotics	Sensitiser /allergen; health hazard to allergic individuals Possibly irritant.	Preparation and use of media for maintaining microbial cultures that harbour plasmids; selective media for transformation experiments	Selection of appropriate antibiotics. Scale of use and dilution. Care in handling powdered antibiotics when preparing solutions to avoid contact and raising dusts, e.g. use a fume cupboard and wear eye protection and suitable gloves. Destruction before disposal by autoclaving.
Buffer solutions	Possibly corrosive / irritant, harmful or reproductive toxin (Cat 1B)	Making up solutions for extracting or dissolving DNA or for gel electrophoresis	Choice of buffer type; use of prepared solutions needing only dilution; limited scale of use. Precautions such as the use of a fume cupboard and gloves where appropriate. Working strength buffers are low hazard.
Detergents	Allergen Harmful / irritant	Making up solutions from concentrates or powders. Use to break down membranes when extracting DNA, etc.	Detergent type SDS (sodium dodecyl sulfate (also known as sodium lauryl sulfate) as used in domestic detergents, shampoos, etc.); dilution; limited scale of use.
DMF (N,N-dimethyl formamide)	Harmful / irritant Reproductive toxin Cat 1B	DMF is a solvent for X-Gal which is often employed as an indicator in microbiological media used for transformation experiments.	Prepare solutions using a fume cupboard. Wear eye protection and suitable gloves. Limit the scale of use.
Dyes and stains	Possibly harmful / irritant	Staining DNA fragments on electrophoresis gels.	School kits typically use thiazin dyes such as methylene blue, Azure A or B, Nile blue sulfate or Toluidine blue O for staining DNA. Avoid breathing in the powders when making up solutions. Keep dyes off the skin; gloves of an appropriate type may be needed. Avoid the use of other stains such as ethidium bromide (which is toxic and mutagenic). *Note that some recently introduced stains, such as 'RedSafe®' are not in themselves hazardous, but have to be visualised under UV light which may be harmful.*
Enzymes	Sensitiser / allergen	Restriction enzymes used to cut DNA. DNA ligase used to join DNA and DNA polymerase used in the PCR. Proteases used when extracting DNA.	Only very small quantities of the enzymes used to modify DNA are required and present no hazard. Proteases used for bulk DNA extraction *e.g.*, from onions must be handled with care. Spills of protease should be rinsed with water and wiped up promptly.

Ethanol	Harmful (if IDA) Highly flammable	Stains such as methylene blue used in ethanolic solution. Precipitating DNA extracts.	Limited scale; small volume technique. Keep off skin; use gloves of a suitable type. Consider alternatives such as aqueous solutions of Toluidine blue O. When preparing cold ethanol, ensure that it is placed in a sealed, vapour-tight container to avoid explosions in non-spark-proof freezers.
Electrophoresis gels	Toxic (if polyacrylamide gels are cast). Burns or scalds from molten gels.	Making up and using gels.	Make agarose gels only and follow good practice in preparation. Exercise caution if using a microwave oven to liquefy gels – do not use sealed containers and beware of superheated liquids which may froth up unexpectedly. If polyacrylamide gels are used, do not make up or cast your own; buy them ready-made.
MICROBIAL HAZARDS			
Bacteria, fungi	Infection; genetic transfer; accidental release of a GMO into the environment.	Transformation.	The use of appropriate non-pathogenic strains, and non-mobile genetic elements, coupled with good microbiological practice. All cultures must be destroyed by autoclaving after use. **IMPORTANT** Non-self-cloning work requires registration with the HSE *etc*; see Section 4.
Pathogenic microbes, including viruses	Infection	Collection and handling of human DNA samples, e.g., from cheek cells for amplification by the PCR. Preparation of DNA extracts from bovine thymus glands.	Ensure that the sampling method is non-invasive and the procedure is explicitly designed to prevent cross-infection. Since the occurrence of BSE and variant CJD, bovine thymus tissue should no longer be available and should not be used in schools.
ELECTRICAL HAZARDS			
Gel electrophoresis tanks and power supplies	Electric shock, burns and fire	Connecting and disconnecting power supplies and using gel tanks. The buffer solution is highly conductive and gels are directly handled within it. Gels may have to be run unattended overnight.	Use low voltage (<40 V) supplies from alkaline or zinc-carbon batteries or a low voltage DC power supply (note the output current required will be much less than 1 amp). If higher voltages are used to shorten run times, and unless the current is limited to less than 5 mA, shrouded connectors must be used and it must not be possible to accidentally or deliberately make contact with the gel when it is live.
OTHER PHYSICAL HAZARDS			
Centrifuges	Physical injuries	Centrifuging extracts and DNA, *e.g.*, in the extraction of plasmid, nuclear and chloroplast DNA.	Use the centrifuge with the correct type of tubes, observing the usual precautions such as balancing the centrifuge. Seal tubes to prevent the formation of aerosols. Ensure that centrifuges conform to the relevant the British and International Standard (BS EN 61010-2-020).

Microwave ovens	Explosion of sealed containers. Burns and scalds.	Preparation of microbiological media and agarose gels.	Ensure that containers are not sealed and that hot containers and liquids are handled with great care, *e.g.*, wear heat-proof gloves.
Ultraviolet radiation (UVR)	Carcinogenic effects on skin. Damage to eyes.	Examining stained gels using UVR. Illuminating transformed cells expressing green fluorescent protein.	Use transilluminators with interlocked filters so that there is little risk of looking directly at the unfiltered source. Where possible, choose stains which fluoresce under UVA (or even blue light).

16.3 Human DNA

Wider issues, including ethical and legal concerns associated with the analysis of human DNA are largely beyond the scope of this Topic. Teachers should be aware, however, that some practical activities using students' DNA may be considered to be 'genetic tests' and that the provisions of the *Human Tissue Act 2004* (which covers England, Wales and Northern Ireland) and the *Human Tissue (Scotland) Act 2006* may apply [3].

These regulations require that consent is obtained from a person whose DNA or RNA is to be analysed. Children (in this context those aged under 18 in England, Wales and Northern Ireland, or under 16 in Scotland) *are able to consent* themselves, provided that they are informed and can understand the purpose for which the DNA is being analysed and the issues involved. While there is no legal obligation to obtain parental permission where the child is deemed 'competent' to consent, some schools may wish to do so or to inform those with parental responsibility of the proposed practical activity. A model consent form is provided below.

16.3.1 Phenotypic tests

Introductory educational activities in genetics may include the observation of traits such as mid-digital hair (the hair on the middle knuckles of fingers), type of ear wax and ear lobes, eye colour, tongue-rolling and so on. Some such traits (e.g., tongue-rolling) are often wrongly described as being determined by single genes. As the genetics underlying an increasing range of phenotypic traits is beginning to be understood, it may be possible to draw from such phenotypic tests, conclusions (erroneous or otherwise) about the parents of an individual, an individual's propensity to develop a disease, and other characteristics. Although these are not 'DNA tests' and do not therefore fall within the purview of the *Human Tissue Act*, caution should be exercised when selecting, discussing and carrying out such activities, that family relationships or other potentially sensitive information are not inadvertently revealed.

16.3.2 Data protection

Certain types of practical work with human DNA may also raise data protection concerns. Genetic information that can be related to an individual should not be published without that individual's express permission and it is strongly recommended that no such information is published in any circumstances. What may currently appear to be innocuous information may in the future prove to be more revealing than was intended. This includes the publication of photographs of electrophoresis gels on the internet and teachers should take steps to avoid students photographing their gels using a mobile device for possible later publication on social media.

Table 2 shows some examples of school practical activities with human DNA and summarises the potential issues involved.

Table 2: Examples of educational activities with human DNA.

Practical activity	Consent required?	Comments / Concerns
Extraction of cheek cell DNA for use in a 'DNA necklace'. Individual students extract a crude preparation of DNA from their own cheek cells and suspend the material obtained in a 'necklace' vial.	Consent is not required, since no genetic test or analysis is being undertaken. It would, however, be sensible to obtain verbal consent from the participants. An information leaflet for parents might be useful here, if only to reassure them that a genetic test is not being undertaken.	Students should handle only their own DNA. Contaminated materials should be disposed of into disinfectant. It should not be possible to open DNA 'necklaces' after adding the DNA extract. This activity presents an opportunity to explain what DNA is, what sort of information could be obtained from DNA, why legislation is needed and how the analysis of human genetic material is regulated by law.
Amplification of mitochondrial DNA by PCR. Students extract their own DNA from cheek cells using a mouthwash, then amplify a 500 base pair (bp) fragment of mitochondrial DNA from the sample by PCR. The DNA is run on a gel and stained. The gels are disposed of at the end of the practical session.	Consent should be obtained from the students themselves. Students doing this work should have a basic understanding of both genetics and the issues involved.	The DNA fragment that is amplified has been chosen to reveal nothing about the individual; all students have exactly the same gels because the fragment is common to all living humans and no further analysis is done (i.e., no restriction analysis or sequencing). The results do not reveal anything about family relationships.
Amplification of an *Alu* repeat in the TPA gene on Chromosome 8. Students extract their own DNA from cheek cells using a mouthwash, then amplify by PCR 300 bp fragments of DNA from chromosome 8. The DNA is run on a gel and stained. The gels are disposed of at the end of the practical session. No further analysis is done (i.e., no restriction analysis or sequencing).	Students doing this work should have a basic understanding both of genetics and of the issues involved. Consent would be required as the analysis will reveal genetic differences between individuals.	TPA-25 insertions are inherited in a Mendelian fashion and can give indications of family relationships. Technically, a single locus polymorphism could not prove or disprove relatedness, but it could reveal inconsistent inheritance if siblings or other family members were tested. This sort of task should not be undertaken in a school, as there is a risk of revealing information about family relationships. In addition, many *Alu* insertions are markers for specific diseases.

16.3.3 Code of practice

We suggest that the following 'Code of Practice' is adopted by schools and colleges wishing to work with human DNA.

Code of practice for the use of human DNA in schools and colleges

1. The purpose of the DNA sampling (and analysis, if performed) must be made clear to students before the work is done. Depending upon the circumstances, it may also be prudent to advise parents or those with parental responsibility for the students of the nature of the work/test.
2. Informed consent must be obtained from each individual from whom DNA is to be taken. Such consent must be given voluntarily and the student giving consent must be competent to do so (that is, they should be able to understand the purpose for which the DNA is being collected and the issues involved).
3. Consent can be verbal, although schools may wish to obtain written consent from the students from whom DNA samples are to be taken.
4. Teachers should ensure that the results of the test can be interpreted by the students and are comprehensible to them.
5. The DNA must be used only for the purpose for which it was collected.
6. Any physical material such as the DNA sample itself and electrophoresis gels that may contain a DNA sample should be destroyed after use, or should become the property of the students who donated the samples (e.g., DNA in a DNA 'necklace' might be taken home by students).
7. DNA tests that provide information about paternity and other family relationships must not be carried out.
8. DNA tests that provide potentially sensitive personal information e.g., about disease susceptibility or sex chromosomes must not be carried out.
9. Teachers should be able to provide documentary evidence, such as a published protocol, that the DNA test does not provide information about family relationships or disease status. (Before a test is carried out, teachers should check that the evidence relating to this has not changed.)

16.3.4 Model consent form for work with human DNA

Note that this is merely an example, which would need to be adapted according to the exact procedure used.

Dear Parent/Guardian

As part of his/her studies, your child will have the opportunity to conduct an experiment with his/her own DNA.

The DNA sample will be collected from cheek cells that are present in the saliva, using a sterile mouthwash. The DNA sample will be 'amplified' using a process called the polymerase chain reaction (PCR) and examined for specific DNA sequences, which vary from person to person.

The DNA sequences being examined play no part in determining health, nor do they provide any information about family relationships.

The DNA samples will be destroyed after the experiment and will not be used for any other purpose.

The *Human Tissue Act (2004)* requires that tests on human DNA must not be conducted without the willing consent of the donor, who understands the purposes for which their DNA is being used. Your child is therefore able to consent to take part in this work him- or herself, but should you wish to know more, please contact.

16.4 Genetic modification

16.4.1 What is genetic modification?

Genetic modification is officially defined as 'the alteration of genetic material (DNA or RNA) of an organism by means that could not occur naturally through mating and/or recombination' [4].

16.4.2 EU Directives and UK Regulations

All practical work that involves the production or use of genetically-modified organisms (GMOs) is strictly regulated by law throughout the European Union. There are two relevant sets of EU regulations (Directives) governing genetic modification. Laws in the United Kingdom have been enacted to comply with these directives. In England, Wales and Scotland, genetic modification of organisms in containment, *e.g.*, work in a laboratory, is governed by the *Genetically Modified Organisms (Contained Use) Regulations, 2014* [4]. Northern Ireland has its own separate but virtually identical legislation. Similarly, within Great Britain and Northern Ireland there are separate regulations covering deliberate releases of GMOs into the environment, *e.g.*, field trials of genetically-modified crops. It is important to note that it is not the *techniques* of genetic modification that are controlled, but rather *activities with living organisms that are produced by these techniques.*

In general, anyone carrying out work with GMOs must do so only on premises that have been registered with the relevant authority. In the UK, this is principally the Health and Safety Executive (HSE), which charges a fee (currently about £500 for the least-restricted type of work) for registration. The organisation, such as a school, university or research facility, under whose auspices the work is to be done may also have to set up a local expert safety committee (a Genetic Modification Safety Committee; GMSC) and procedures to oversee and control the work with GMOs. Records of risk assessments must be retained for at least 10 years after the relevant activity has ceased. These requirements would seem to preclude any work with GMOs in the majority of schools. There is, however, a limited amount of practical work that *can* be done in schools.

16.4.3 Microbial transformation

In the school context, genetic modification is most likely to involve the 'transformation' of microorganisms (usually bacteria). Transformation is the introduction of DNA into microorganisms by 'artificial' means. For pre-university educational work, this almost always involves the use of plasmid DNA. Plasmids are small rings of DNA comprising just a few genes that are found in bacteria and yeasts. They are not normally essential for the microbes, but they may help them to survive in certain environments. For instance, some plasmids enable the bacteria that carry them to resist the toxic effects of heavy metals or antibiotics. Sequences of DNA can be 'spliced' into plasmids, allowing such plasmids to be used as vectors for transferring genes between organisms.

16.4.4 Self-cloning

Microbial transformation in which genetic material is returned to a species in which it could naturally occur is known technically (and rather confusingly) as 'self cloning'. Here, 'cloning' means making copies of DNA within an organism. Originally, the definition of self-cloning was restricted to taking DNA from one species and making copies of it (cloning it) in the *same* species, hence the term *self*-cloning. Later, this definition was widened slightly to include DNA which might have come from other species in the form of 'reporter' or 'marker' genes and control sequences. To comply with the definition of self-cloning inserted DNA must have *a long history of safe use in the recipient organism*.

Self-cloning using non-pathogenic microorganisms, such as weakened laboratory strains of *E. coli* (See Section 16.4.7), is *exempt* from the Contained Use regulations. Schools and others may therefore undertake such work without registering their premises with HSE or setting up a GMSC. The microorganisms produced *are,* however, covered by the Deliberate Release regulations, and it is therefore essential to ensure that an accidental 'release' of the organism into the environment does not occur. This is achieved by biological, chemical and physical containment.

16.4.5 Containment

Under current legislation it is an offence to release any GMO into the environment or to allow it to escape without prior consent of the Secretary of State. It is therefore essential that even 'self-cloned' organisms are adequately contained and that a 'release' does not occur. A key point is that an accidental release of a GMO might be considered to be deliberate if the steps taken to ensure containment are deemed to have been inadequate.

Biological containment is accomplished by the careful selection of suitable host microorganisms and of plasmids. This would usually involve, for example, using microbial strains that are weakened, coupled with 'non-mobilisable' plasmids that cannot transfer their genes into the host's chromosome, or be transferred into other organisms by natural means such as bacterial conjugation.

Physical containment can be ensured by following good microbiological practice (*e.g.*, effective aseptic techniques and autoclaving materials before disposal) and good occupational safety and hygiene.

Kits from reputable suppliers, that have been approved for use in UK schools, should comply with these requirements.

16.4.6 Alterations to procedures in commercial kits

It follows from what has been stated above that *no attempt* should be made to alter or add to the procedures described in commercial kits in a way that might bring those using them outside the umbrella of self-cloning and into the realm of Contained Use. If this was to be done without notifying the relevant authorities and following the other procedures that such work legally requires, teachers could place themselves and others at risk, and could ultimately be subject to legal action.

16.4.7 Transport of genetically-modified microorganisms

There may be circumstances in which genetically-modified microorganisms (GMMOs) have to be transported outside the laboratory. For example, you may wish to take inoculated plates from a course venue back to your school or college laboratory for incubation, later examination and, eventually, destruction.

The following advice assumes that the GMMOs you will be transporting are non-infectious, produced using the self-cloning procedures outlined in Section 16.4.4, above.

Because harmless microorganisms can look the same as infectious ones, and bearing in mind concerns over bioterrorism, it is a wise precaution to treat any cultures you are transporting as though they were infectious. Essentially this means providing an extra level of containment and providing information for anyone who might find a lost package.

The microbial culture should be labelled with the name of the organism, the owner's name and the date. A wad of absorbent material (such as paper towel) should be placed alongside the culture, to soak up any spills should the culture vessel be broken. This should be sealed inside a strong plastic bag. A note describing the contents should accompany the culture: for example: NON-INFECTIOUS BIOLOGICAL MATERIAL. DO NOT OPEN'. This should all be placed in a rigid outer

container such as a cardboard or plastic box. (Commercially-produced packages, capable of holding one or two Petri dishes, are available specifically for this purpose.)

The outside of the package should include the name, address and phone number of a responsible person who can be contacted should the package be lost. It should also include the address of the destination school or college (if different from the contact address).

When it is being transported, the package should be hidden from public view; either by placing it in the boot of the car or by carrying it in an unmarked bag such as a plastic shopping bag.

The package must not be left unattended at any time.

If the package is lost, you should attempt to find it as soon as possible. This may involve contacting rail operators, bus companies or other transport firms, who should be reassured that although there is no risk to their employees, the package should not be opened. If your contact details are on the packaging, the finder will be able to contact you.

16.4.8 Host strains

The species of bacterium that is most commonly used for cloning work is *Escherichia coli,* strain K-12. 'K-12' is sometimes assumed to be a special educational strain of *E. coli* because the usual association with the acronym 'K-12' is 'Kindergarten–12th Grade' school education in the USA. In fact, in this context, 'K-12' has nothing to do with schools. The K-12 strain of *E. coli* can be traced back to work at Stanford University in 1922. Biochemical and genetic studies by Edward Tatum in the 1940s made the strain popular with researchers and, after many generations of laboratory cultivation, it is now known to have undergone significant changes. These have altered the lipopolysaccharides that comprise the outer membrane of the bacterial cell, so that it can no longer infect mammals.

Many strains of *E. coli* K-12 have been developed for transformation work. Usually these do not harbour any extra-chromosomal DNA of their own, but can be transformed efficiently by plasmids. Compared to the wild type *E. coli*, these 'cloning strains' are severely weakened and would find it difficult to thrive outside the laboratory. They may have unusual nutritional requirements, and are often susceptible to damage, *e.g.*, from the ultraviolet component of sunlight.

Some bacterial strains that are commonly used for transformation experiments lack an enzyme required for DNA repair, and this means that they can be subject to mutations if they are maintained as slope cultures for extended periods. Fresh cultures should therefore be obtained as required from suppliers, rather than being maintained in school. This will ensure that the host cells are the correct species and strain and thereby avoid disappointment or the inadvertent transformation of contaminating microorganisms.

16.4.9 Incubation at 37 °C

Although model risk assessments for microbiological work normally warn against incubating cultures at 37 °C to avoid the growth of contaminating pathogens, the delicate strains of *E. coli* used for cloning work often will not grow quickly or reliably unless maintained at this temperature. Good microbiological practice, coupled with the use of selective growth media, will ensure that contaminating human pathogens are not inadvertently cultivated at this temperature.

16.5 Suppliers of plasmids, cultures etc.

Plasmids and cells for transformation experiments should be obtained only from reputable suppliers.

Many practical kits have been developed for demonstrating microbial transformation. These are particularly common in the USA where they have become a routine part of high school biology courses. Within the European Union such work is more strictly regulated, and teachers could be in breach of the law were they or their students to carry out many of the genetic modification exercises that are currently available as kits in the USA or are described on the Web. Note that even if a school was to register with the HSE so that it could undertake non-self-cloning work, many kits provide insufficient information about the host strains and/or plasmid construction for an adequate risk assessment to be made.

16.6 Synthetic biology

'Synthetic biology' is the construction of DNA sequences from pre-defined 'parts' that are assembled in a way analogous to the construction of circuits from electronic components. These DNA sequences are inserted into cells to create genetically-modified organisms with novel characteristics.

This approach has been made popular by the *International Genetically Engineered Machine* competition, more commonly known as iGEM [5]. Although it started with undergraduate students, iGEM has become increasingly popular with high school students in the USA and elsewhere. Although some UK schools and colleges have entered the high school level of the iGEM competition, they have had to do this by either registering their institution with the HSE or by working in close collaboration with an institution that is already registered with HSE, such as a university.

Educational resources and practical protocols for synthetic biology aimed specifically at high school students have also been published [6, 7], but schools in the UK should be aware that these resources cannot be used in the European Union, including the UK, without complying with the regulations governing genetic modification that are outlined in Section 16.4.2, above.

16.7 References

1. Anaphylaxis campaign. **http://www.anaphylaxis.org.uk**

2. Richardson, J. (1995) Practical work with DNA. *Education in Science*, **162**, 16–18.

3. Human Tissue Authority. Consent and DNA: Code of practice. **http://www.hta.gov.uk/licensingandinspections/sectorspecificinformation/dna.cfm**

4. *The Genetically-Modified Organisms (Contained use) Regulations 2014*. Health and Safety Executive (2014) The Stationery Office, London. ISBN 978 0 7176 6641 6.

5. iGEM competition **http://igem.org/**

6. BioBuilder **http://biobuilder.org/**

7. *BioBuilder.Synthetic Biology in the Lab* by Natalie Kuldell, Rachel Bernstein, Karen Ingram and Kathryn M Hart (2015) O'Reilly Inc., Sebastopol, California. ISBN: 978 1491904299.

Note: This document was revised on 1 October 2014 to account for the Genetically-Modified Organisms (Contained Use) Regulations, 2014, which came into force on that day.

It was further revised in May 2016 to take account of developments in synthetic biology.