The role of
technical knowledge
in design & technology

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Gwyneth Owen-Jackson and Torben Steeg

What is technical knowledge?

Before we could begin to write this chapter we spent some time discussing what we understand by the term 'technical knowledge'. The Cambridge Dictionary (2006) defines it as *'knowledge of machines and methods used in science and industry'* or *'knowledge and methods of a particular subject or job'*. Well, this helps a bit, but what technical knowledge is relevant in school design & technology and how does such knowledge contribute to pupils' ability to design and make well?

> Think for a moment about something you have designed and made; this might be from your school education, your degree or something you have produced during your professional life.
> Take about 5 minutes to list the technical knowledge you needed to design and make this product.

The images overleaf show products produced by pupils; one was made in year 8 and one in year 11 and each represents good quality work for its level.

> Reflect on the technical knowledge that the pupils would have needed in order to design and make as successfully as this and for each artefact make a list of the technical knowledge you think each pupil would need to have mastered.
> Because the two products arise from different areas in the design & technology curriculum, you may approach this task as an expert for only one of them, or perhaps neither; this is fine, just use common sense and intuition.

What do your lists tell you about what 'technical knowledge' might mean?
What, in fact, does it mean for knowledge to be technical?

01 A year 8 food project.

02 A year 11 resistant materials project.

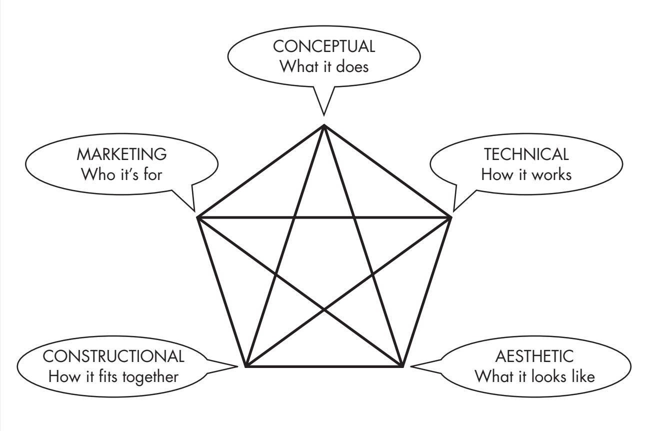
Thinking about technical and technological knowledge

The study of knowledge is a branch of philosophy called epistemology, and within epistemology the study of technical and technological knowledge has increasing stature thanks to the writings of authors such as Don Ihde (1997), Alistair Jones (1997), Robert McCormick (1997), Marc de Vries (2005) and John Dakers (2006). The ideas that have arisen from this study include:

- That technological knowledge includes both 'knowing-that' (propositional knowledge) and 'knowing-how' (procedural knowledge). This allows us to include skills (knowing-how) as relevant technical knowledge alongside facts (knowing-that).
- That much technological knowledge can't be expressed in words but arises in the 'mind's eye' and is best articulated visually, in two and three dimensions. On the other hand, some technical concepts are best expressed mathematically and others require the use of precisely defined language.
- That much effective work in design & technology relies on tacit knowledge; these are things that we have an instinct about but do not formalise as explicit knowledge (or we may have long forgotten such a formalisation). This may mean that pupils need opportunities to 'play around' with materials and ideas, to model and test out proposals, so that knowledge becomes embedded through the 'doing'.
- That those engaged in designing and making are generally more focused on practical than theoretical reasoning. For this reason technical knowledge is more often related to 'what works well' than to 'what is true'. Technical knowledge, therefore, is inextricably linked to value judgements; as soon as you ask 'what works well?' you are asking a value-laden question.
- Technology draws on knowledge from a wide range of other disciplines and, in the technical domain, especially science and mathematics. To become technically useful this knowledge usually needs to be re-worked into a form that allows it to answer 'what works well' type questions. This is not a trivial task and pupils are unlikely to transfer their knowledge between subjects without a great deal of support.
- It is sometimes useful to consider knowledge required for effective designing as two sorts of knowledge; knowledge of the problem or design situation (so it is fully understood) and knowledge required in order to create an effective design solution.

From this, we therefore suggest that technological knowledge includes all the aspects of knowledge that pupils may need in order to design and make, including technical knowledge, as shown in the illustration above right.

The interconnecting lines suggest that decisions in the technical (or any other) area will affect and be affected by decisions made in the other areas.



03 Knowledge domains in technology.
(© D. Barlex, 2007.)

04 1998 Apple iMac.
(Based on photograph from Flickr (http://www.flickr.com/photos/motoe/86835191) by Masashige Motoe. http://creativecommons.org/licenses/by-sa/2.0/)

This chapter focuses on technical knowledge; pupils' knowledge of how things work and how to make things work. We have taken this to include knowledge about the materials they use, the scientific and mathematical concepts related to materials and methods and, in some areas of design & technology, knowledge of structures and control systems. We don't deny the importance of the other vertices of the pentagon in the illustration above, but they are dealt with elsewhere in this book.

> ? Think about that first question again (the technical knowledge you needed to design and make a product); do you still think the things you jotted down were technical knowledge?

What technical knowledge might pupils need?

So, having considered what we mean by technical knowledge, how do we decide what technical knowledge to teach?

When Jonathan Ive and the design team at Apple computers started to work on what would become the first Apple iMac, what technical knowledge would they have needed?

The brief was multifaceted, including a desire to hark back to Apple's classic 'all-in-one' computer, a move away from 'beige boxes', a smaller computer that was easy to pick up and move, and improved ease of use through such things as minimising the number of leads and making setup intuitive.

The design decisions the team made took them into areas of technical knowledge they couldn't have predicted. For example they needed help with specifying the translucent colours to ensure consistency during high volume manufacture. Who has expertise in high volume production of translucent coloured items? Sweet manufacturers do, so that is where they went for advice. Similarly, keeping the computer quiet by dispensing with the fan led to rearrangement of the internal construction and the need to design in natural air circulation and venting.

Food product development often requires the development of existing products, and this brings its own demands. In developing the Crispy Savoury Pudding for Marks and Spencer, the manufacturers had to develop technical knowledge relating to the crispy outer layer of the product. Tests were undertaken to find out how this could be achieved then a way had to be found of doing this in quantity. The problem proved challenging and required many tests and experiments before a solution was found. Further challenges were presented by

05 Marks & Spencer had to develop technical knowledge in order to create their crispy savoury bakes.

06 Kevlar bulletproof vest.

07 Kevlar helmet.

08 Kevlar firefighter's jacket.

MARKS & SPENCER

the packaging of the product, again requiring research and testing. Food products are also driven by the need for food safety and consumer appeal, so the original concept and design brief had to be tightly adhered to whilst developing a product that had a 'home-produced' quality in which crispiness was combined with the chewiness more usually associated with puddings. (See www.foodforum.org.uk for further details).

With some products, it is the discovery of new technical knowledge that leads to the development of the product, as was the case with Kevlar (a synthetic fibre). In the 1960's Stephanie Kwolek, a chemist at DuPont, found whilst experimenting with fibre molecules that one experiment produced unexpected results. However, instead of throwing away the solution and starting again, Stephanie tried spinning the solution into fibres - and discovered that it created a fibre that was extremely stiff, yet lightweight and five times stronger than steel, and it could absorb energy by stretching rather than breaking. Kevlar is now used in products ranging from bulletproof vests to bridge cables.

Each of these case studies illustrates an important feature of the relationship between technical knowledge and designing and making. The process of creating a design brief will give you a broad idea of the kinds of technical knowledge that you are likely to need to draw on, but specific design decisions can lead you into completely unexpected areas of technical knowledge. Alternatively, looking for the solution to one problem could provide the answer to a completely different one. The conclusion is that it is not possible to know in advance what it is that you need to know to complete a brief. For many designers this is one of the attractive aspects of the job; designing becomes an expedition into unexplored territory where the route is not, and can not be, fully known.

In school, of course, we don't have the luxury of time and money to spend researching technical solutions to problems. Part of our role as design & technology teachers has to be helping pupils discover what they need to know and where to go to find it. They probably won't make new discoveries, as Stephanie Kwolek did, or create design icons, as Jonathan Ive did, but they will learn something new for themselves. We think that technical knowledge in design & technology should enable pupils to:

- Understand how things work so that they have knowledge on which to draw when making their own design decisions;
- Develop novel (for the pupil) and interesting ways for things to work;
- Understand what might be going wrong when something isn't working, and be able to consider ways in which to put it right.

09 Aberfeldy suspension bridge is constructed using Kevlar cables.
(© Robert Cortright, Bridge Ink.)

10 Tyres use Kevlar as it offers superb puncture, abrasion and tear resistance.

Defining essential technical knowledge

If possible, carry out the following exercise with colleagues.

Select a focus area (eg. food, electronics, textiles, resistant materials) and use a table to list the areas of technical knowledge that you think a year 11 pupil really has to know to understand how things work.

Now, for each of those areas that you have identified in your table, spend some time thinking about what you would include in the area. Add a further column so that you can expand the area to say what each is about.

Before you write a piece of knowledge in, ask yourself:

- Is it really necessary for every pupil to know this? Perhaps it could be knowledge that some pupils might need but can find out for themselves when necessary.
- Is the level of detail right? It is easy to specify knowledge at a high level of detail when most pupils will never use the detail in their designing and making. Can you substitute the detail for some more general principles, coupled with advice on how to access the detail should they need it? Try not to be too influenced, during this part of the task, by what you know of the content of examination specifications; these are clearly important in defining what should be learned to pass an examination but not all their content is necessarily fundamental.

Once you have a reasonably comprehensive list of what you think is the essential knowledge content for the field you have chosen, you should put it to the test.

> First, discuss your list with a colleague who has done the same exercise. You will probably find much on your lists that is essentially the same but this may raise issues to discuss:
> - Do you agree on the level of detail specified?
> - Have you placed it in the same row of the table; i.e., do you agree about the aspect of design & technology that this knowledge supports? And does this matter?

It is also likely that you will each have items of knowledge on your list that are not on your colleague's list. Some of these you will instantly agree should be there; one person may simply have not thought of it. It is the remaining items, those for which there is disagreement, that are the most interesting. You may be able to resolve some items through discussion, but it is likely that there will be some irreconcilable differences of opinion on what counts as essential technical knowledge. Don't fall out over this, instead recognise that you have got to the heart of what is a very difficult issue; what you count as essential depends ultimately on your underlying beliefs about aspects of education and aspects of design & technology.

You could also compare your list with a relevant GCSE specification. Are there any knowledge areas that you would consider to be essential at this level that are not in the specification? This would be quite surprising and might lead you to revise your own views of what is essential - or to question the comprehensiveness of the specification.

Remember that examination specifications are not written on tablets of stone; they are as subject to the errors of human thinking as any other document (including this one). Where there is technical knowledge in the specification that is not on your essential list, consider whether its presence is justified as a part of what pupils should learn at Key Stage 4.

The examination specifications direct much of what is taught in design & technology, but this may not always be what pupils need or want to learn. Over twenty years ago, the Department for Education and Science recognised that:
'The designer does not need to know all about everything so much as to know what to find out, what form the knowledge should take, and what depth of knowledge is required for a particular purpose' (DES, 1981).

An examination specification that reflected this would be more in the spirit of design & technology!

How is technical knowledge best taught?

Given that we can identify appropriate technical knowledge for design & technology in schools - this leads to the questions 'how should we teach technical knowledge?' and 'when should we teach it?'

Constructivism and constructionism
Constructivism is a collection of theories about how learning happens (see Wood, 1998, for a clear introduction). These theories, which are currently accepted by many educationalists - including us - include the following principles:

- Learners interact with the world around them and construct their own knowledge models based on their experiences; these include models of how the physical and the social worlds operate.
- Social interaction has a significant role in establishing and supporting mental models.
- The constructed models are usually 'correct' in the sense that they account rationally for the experiences of an individual, but they may be based on restricted data or false assumption, so may not agree with scientific models. An example of such a misconception is that many children, and adults, believe that a heavier object will fall with greater speed and hit the ground before a less-heavy one.
- Because these models are based on experience they are remarkably robust once they have been established. Change to a well-established cognitive model will only happen if there is sufficient evidence that it is incorrect. This suggests that a model of teaching based on telling pupils things is likely to be much less successful than one in which they experience things and interact with materials.

Constructionism is a constructivist theory of learning developed by Seymour Papert and others (Papert, 1980, 1994, Kafai & Resnick, 1996). The core argument of 'constructionism' is that people learn best when they are making something, be it a sandcastle on the beach or a theory in physics, because of the powerful interaction between thinking and action during construction. Learning is most powerful when two conditions apply; the construction environment is rich and there is ample opportunity to view the success of one's construction efforts (feedback).

Originally constructionism was used as an argument for putting children in control of computers through the use of LOGO; a programming language with a *'low floor and a high ceiling'* (easy to get into but limitless in its applications). The argument was that the child should control the computer, not the computer control the child. This work soon grew to encompass robotics, especially with the Lego 'Mindstorms' programmable brick, where the programming of the computer controlled not simply what happened on screen but also events in the real world. The link to work in design & technology should be clear; the nature of design & technology is that it is the subject most likely to have the curriculum flexibility to allow pupils to engage in constructionist activity and this makes design & technology a very good place for pupils to develop technical understanding.

Situated learning and communities of practice

Another constructivist strand of work (see Lave & Wenger, 1991) has pointed out that learning takes place in a particular context (situation) and, therefore, becomes bound to that situation. A consequence of this is that it is difficult for learners to transfer their knowledge from one domain to another. A growing body of evidence, much based on studies of the use of (especially mathematical) knowledge in the workplace, seems to support this view.

Jean Lave and Etienne Wenger also used the notion of *'Communities of Practice'* (see Wenger, 1998) to describe their understanding that social learning occurs when people who have a common interest in some subject or problem collaborate to share ideas, find solutions, and build innovations.

What are the implications of these ideas for knowledge learning in design & technology?
Think about:
- Design & technology subject documentation which seems to suggest that the transfer of knowledge from other subjects is something that pupils can be expected to do without much difficulty.
- The role of group work in design & technology.

How should we teach technical knowledge?

So what do constructivism, constructionism and communities of practice tell us about how to teach design & technology? The ideas described above seem to suggest that we should be looking for ways to provide appropriate learning environments and activities to allow pupils to develop the skills to actively co-construct their own knowledge. Approaches commonly used to support technical learning in design & technology include:
- Product analysis;
- Case studies;
- Focused tasks.

Product analysis allows pupils to learn by examining and modelling existing products. For product analysis to be useful its focus has to be clear and relevant to the work that pupils are engaged in. Typical foci include: aesthetic features; the construction materials used; how materials have been formed; how products are assembled; the effectiveness of the user interface; technical operation (how does it work?) and the suitability of the product for the market sector. In food, product analysis often focuses on sensory evaluation, the ingredients and processes used and nutritional qualities.

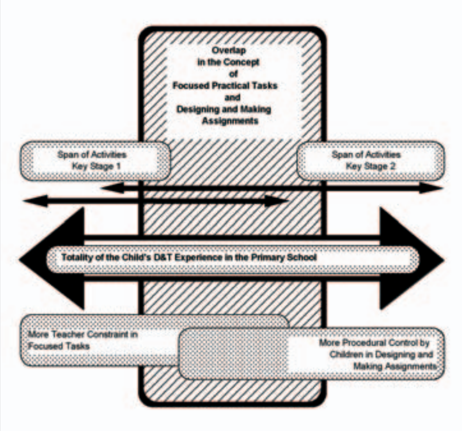
Case studies also allow pupils to engage with products, especially those from other times and other cultures as well as those too large, small, dangerous or expensive to bring to the classroom. The Design Council's "**Product Profiles**" of 11 'Millennium products' also explain the design thinking behind the products, which otherwise can only be guessed at. Critical for the success of a case study is the inclusion of tools to actively engage pupils, for example through questions that prompt reflection, discussion or further research.

Focused tasks were inspired by the Nuffield Design & Technology Project's "**Resource Tasks**" (Nuffield, 1995). The aim of a focused task is to teach a specific element of knowledge or a skill in an active and practical way. The knowledge or skill could relate to a particular material area or to 'strategic' skills relevant across all material areas. When a designing and making activity is being planned, it should be possible to include a range of focused tasks that will teach the underpinning technical knowledge and skills.

Look at a project that you have taught and sketch out how you could use the 3 approaches described above to help you focus the teaching of technical knowledge.

Systems thinking

Systems thinking is one approach to re-conceptualising scientific knowledge that has particular power. The core idea in a systems approach is that detailed concepts are abstracted to a 'higher', more useful level (See Steeg, 2000, for a detailed development of this). For example, in electronics teaching a systems approach is well-established that allows pupils engaging in introductory work to approach the design of a circuit at the level of what it should do (e.g., detect a changing light level) without having to engage in relatively complex scientific and mathematical ideas. A consequence of this is that a relatively small amount of technical knowledge can allow pupils to do a lot (to tackle a wide range of problems in a range of ways). By contrast the more traditional approaches to electronics teaching required pupils to learn a great deal



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11 'Progression' model.

(From Bowen, R. (2002). 'Design and Technology in the primary school'. In G. Owen-Jackson (Ed.). "Aspects of Teaching Secondary Design and Technology Perspectives on Practice". (pp. 9-26). London: Routledge Falmer/ The Open University.)

of knowledge that they could do relatively little with.

What do you think the balance should be between teaching pupils a lot of information they may one day need and teaching them how to find out what they need to know when they need to know it? How might you assess pupils' abilities in the second of these approaches?

When should we teach technical knowledge?

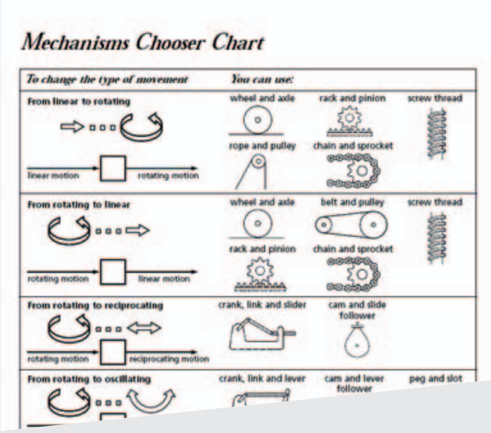
Rob Bowen (2002) suggests that design & technology in the primary school develops from mostly focused tasks, controlled by the teacher and designed to teach specific knowledge and skills, in the early years to more open design and make tasks, in which pupils have greater control over their activities and learning, as they move to year six. This suggests that by Key Stage 3 pupils have been well-prepared for openness in the design tasks they tackle. Sadly the experience of most pupils as they move from KS3 to KS4 mirrors their primary experience; they start with focused tasks controlled by the teacher and gradually move towards more open tasks.

In secondary schools a number of approaches have evolved; these include teaching technical knowledge:

- Prior to the design and make activity, pupils learn a body of knowledge then apply it to an activity;
- During the design and make activity, where knowledge is inserted at appropriate points during pupils' activity;
- As and when pupils need to know; Neil Gershenfeld (2005) has called this *'Just in Time'* learning and contrasts it to the approach in the first bullet above which he calls *'Just in Case'* learning.

What do you think the advantages and disadvantages of the three approaches noted above might be for teachers and for pupils? Make a note of your responses.

These approaches are strongly linked to how other aspects of the design & technology task are organised. In particular the openness of the design task is a critical feature; if a task is tightly defined, with most technical decisions made by the teacher, it is easier to predict the required knowledge and teach it prior to the activity. If pupils are to be given the opportunity to engage with a task in a designerly way, making their own decisions about technical aspects, then it is much more likely that relevant technical knowledge will need to be provided as a task develops.



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12 Part of one of the Nuffield Design & Technology Project 'chooser charts'.

(With kind permission of Nuffield Design & Technology Project.)

Using scientific and mathematical knowledge

The decision about when to teach aspects of technical knowledge might also be linked to when pupils learn about particular topics in science or mathematics. Design & technology has a special relationship with scientific and mathematical knowledge as this often helps designers to understand how things work, or how well they work or to calculate performances or expected results. Recognition of this led David Barlex and James Pitt to suggest in the "**Interaction Report**" that we should exploit this relationship to improve pupils' use of science and mathematics related concepts in their design & technology work (see Barlex and Pitt, 2000). Unfortunately this has proved to be less than straightforward. Two routes through which connections could be developed are (i) systematic links between the science/mathematics and design & technology curricula and (ii) by asking pupils to develop their own conceptual links (and ideally both strategies would be pursued together).

Sadly it turns out that, in the context of the current structure of the English National Curriculum, there is a range of fairly intractable structural difficulties that teachers face in working together across subject boundaries. "**The Interaction Report**" explored these difficulties thoroughly and offered recommendations for development in this area, but there seems to be little incentive for most schools to devote energy to such work. The report "**Becoming an Engineering College**" (Barlex, 2005) showed that schools which are required to make explicit connections between science, mathematics and design & technology, find making such links difficult. Expecting pupils to make their own cross-subject links is likely to be equally problematic if the claims about situated learning noted above are correct.

In any case, studies of the ways that engineers and technologists make use of scientific knowledge carried out by David Layton (1993) suggest that it has to be re-conceptualised into a form that is relevant to the technological task at hand before it can be used. Re-conceptualisation of scientific concepts in a form that pupils can easily access to support work in design & technology has been popularised through the Nuffield Design & Technology Project materials (1995) in the form of 'chooser charts' and these have proved to be remarkably accessible to both teachers and their pupils.

Carousels

We should not leave the questions of 'how' and 'when' to teach technical knowledge without acknowledging the difficulties brought about by Key Stage 3 curriculum arrangements such as the 'carousel' or 'circus'. The circus limits the time available in each area and this, in turn, limits the opportunities

for autonomous 'finding out' new knowledge by pupils (Steeg & Davies, 2005). One way of addressing this, perhaps, would be finding out what other colleagues are teaching and thinking about how you could build on this. This certainly applies if your six week scheme of work includes the teaching of, for example, writing a design specification. If you teach this to year 7 in September it may well be valuable new knowledge; if you teach it in May then they are likely to have already covered it elsewhere, leaving you more time to focus on the development of relevant technical knowledge. Find out, also, what is being taught in science and geography; there may well be areas that you can develop and build on. This does, we know, take time but if it allows you to spend lesson time on more appropriate and relevant learning then it must be time well-spent.

Alternatively, discuss with colleagues what the focus of each scheme of work will be. It may be that you 'give up' one of your schemes of work to focus on the development of design skills but, in turn, gain a scheme of work that focuses on the development of technical knowledge.

Rotational courses are a pragmatic response to the National Curriculum requirements in England, but they should be designed to work for the benefit of pupils, not to ease curriculum planning!

Implications for design & technology education

So what are the implications of all this for design & technology in schools; how does technical knowledge and understanding inform designing and making?

Robert McCormick (2002, p. 96) claims that research has shown that *'problem-solving skill is dependent upon considerable domain knowledge'*, indicating that pupils will need to have, or acquire, technical knowledge in the specific area in order to be able to successfully design and make. One consequence of this is that we, as teachers, need to think about what level of technical knowledge will be appropriate. For example, do pupils need to know about gelatinisation of starch molecules in order to be able to create a good sauce-based product or how polymer molecules respond to heat in order to be able to use the line-bending machine? Could too little, or too much, technical knowledge constrain pupils' design thinking?

In addition, good design and make tasks will be sufficiently 'open' that pupils are required to make decisions of their own, for example in relation to the mechanism to use or the fabric construction method. In these cases it is likely that pupils will require technical knowledge that was not predicted. As a teacher, then, you should be helping pupils to be able to identify when they need new technical knowledge and developing their ability to learn independently; introducing them to areas of knowledge that are likely to be useful but then creating spaces, through the use of 'open' tasks, for the pupils to find out and construct their own knowledge. And the amount of knowledge 'out there' is vast, and growing; in what ways might we restrict what pupils learn by making decisions about what we teach?

But, we argue, technical knowledge is not needed by pupils just in order for them to design and make. Technical knowledge and understanding gives pupils an insight into how things might work, it helps them to understand how the world around them operates. Pupils who learn about the fantastic strength and toughness of spiders' web silk may be amazed and look afresh at spiders' webs. In the same way we remember one session with pupils on 'smart and modern materials' that introduced them to motion control gel, a lubricant used to give 'cheap and dirty' mechanisms a smooth and expensive feel. The pupils were amazed to see the way in which the gel allowed a travelling alarm clock case to 'glide' open and we began to discuss other ways in which this gel might be used. As a result of this experience these pupils now have a little more insight into the workings of the technological world they live in. This opening up of minds is, surely, part of the remit of design & technology education.

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WJEC: www.wjec.co.uk

iMac design resources:
- Digital Design Museum; iMac 1998: http://www.designmuseum.org/digital/jonathan-ive-on-apple/imac-1998
- Jonathan Ive describes the rules behind the design of the iMac: http://www.fastcompany.com/magazine/29/buy.html
- The man behind iMac: http://edition.cnn.com/TECH/computing/9809/22/imacman.idg/

Handling collections and case studies:
- Design Museum: http://www.designmuseum.org/education/secondary
- The Design Council: http://www.designcouncil.info/educationresources/schools.html
- Dyson: http://www.international.dyson.com/education/
- Nuffield D&T: http://www.secondarydandt.org
- BAE Systems: http://baesystemseducationprogramme.com/systemsengineering/
- Practical Action: http://practicalaction.org/?id=resources_online