Build Your Own Digital Railway

Teacher Resource Sheet

WHAT IS STEM

The National Science Foundation first coined the STEM acronym, which stands for Science, Technology, Engineering, and Mathematics, in the 1990s. STEM encompasses many subjects and it is important because it has helped transform and advance many aspects of our lives. STEM education focuses on integrating the STEM subjects into one curriculum to emphasize its real world application. Recent initiatives in STEM education target young students in order to improve proficiency in STEM subjects and inspire them to pursue careers in engineering and other related fields. In response, an outpouring of prominent business leaders, politicians, and academics have been actively encouraging and promoting the teaching and funding of STEM activities in schools over the past decade.

STEM EDUCATION IN THE UK

According to a review of the UK's policies on science and innovation, "There has been a 20-year decline in the number of pupils taking A-level physics" (Sainsbury, 2007). This demonstrates a need for creating a pipeline of skilled graduates in STEM fields since their demand will only increase with the growth of related science and technology careers. The Royal Academy of Engineering's report Jobs and Growth details how the demand for people to fill Science, Engineering, and Technology (SET) occupations currently exceeds supply, which is only likely to intensify with an increase in economic growth (Harrison, 2012). Presently, there is a need for more than 100,000 STEM graduates a year but only 90,000 individuals are graduating with STEM-related degrees (Harrison, 2012). This leaves an annual deficit of over 10,000 STEM proficient workers. This trend is highly worrisome because engineering alone accounts for 21% of the UK's GDP (Browne 2012).

The Parliamentary Office of Science and Technology has long acknowledged the lack of STEM skilled workers in the United Kingdom, and notes that 42% of employers in the UK claim there is a shortage of STEM proficient employees (Parliamentary Office of Science and Technology, 2013). In a report published in 2013, the UK government planned several reforms designed to improve on the situation, most notably including a review of the national curriculum that would increase the focus on English, math, and science. Following an inquiry at the House of Lords in 2012, current recommendations include making mathematical study compulsory past age 16.

The National STEM Centre has taken a major role in implementing these changes, with a focus on evaluation of practices and improvement of STEM education (National STEM Centre, 2011). From as early as Key Stage 1, students are expected to spend a third of their class time studying science and mathematics. Both are required until the end of a student's secondary education (Key Stages 3 & 4), at which point they may choose three subjects in which to continue (Elliott, 1997; UK Department of Education, 2014). Despite the early focus on STEM learning, engineering is still an unpopular choice for students in higher education. It is important for students to participate in STEM outreach programs so they are educated on STEM and the career paths they can pursue if they study STEM. It is also important for educators to understand STEM and all that it entails.

WHAT IS ENGINEERING

Engineering is combining creative and practical skills to design, create, test, and improve products and processes. There are many avenues of engineering and almost every product you come into contact with throughout the day involves some sort of engineering.

TYPES OF ENGINEERING

Engineering plays a major role in many different industries and it is not just for one type of person. There are over 200 types of engineering that students can pursue, each with its own characteristics and career outcomes. Below is a table describing some of the most popular types of engineering:

Types of Engineering	
Aerospace	Responsible for the research, design, and production of aircraft, spacecraft, aerospace equipment, satellites, and missiles.
Agricultural	Look for solutions to problems involving the use of plants, animals, and the natural environment.
Automotive	Design, build, maintain, and operate self- propelled land and sea vehicles.
Biomedical	Combines mechanical engineering with human anatomy to develop technologies related to health care such as prosthetic devices, and medical diagnostic machines.
Chemical	Combines chemistry, mathematics, and physics to the design and operation of equipment and methods for the manufacturing of chemical products.
Civil	Design, management, and construction of buildings and infrastructures such as: highways, railways, transit systems, airports, and bridges.
Electrical	Generation, production, transmission, distribution, and application of electrical components.
Environmental	Develop solutions to problems affecting the welfare of humans and nature such as pollution, water quality, and hazardous waste control.
Industrial/ Manufacturing	Utilize knowledge of equipment, produces, and materials, human resource, and production to improve efficiency, productivity, and effectiveness.
Mechanical	Utilize knowledge of mathematics, material science, and physics to design, manufacture, and maintain mechanical equipment.
Petroleum	Exploration, development, and processing of oil and gas.
Software	Design, develop, and maintain software systems and products.
*definitions from: http://www.aboriginalaccess.ca/adults/types-of-engineering and http://www.nacme.org/types-of-engineering	

WHY STUDY ENGINEERING

There are many benefits to studying engineering. It is a very rewarding career that allows people to blend their knowledge of STEM subjects with creativity and innovation.

Job Satisfaction

- Engineering is ever changing. Those who enter engineering as a career path will be exposed to many interesting and new opportunities to work on a variety of different projects.

Transferable Skills

- Studying engineering allows students to gain knowledge and experience working in different environments and developing different skills. Students are able to develop communication, teamwork, and critical thinking skills which can be applied to many different life scenarios.

Wide Variety of Career Opportunities

- Studying engineering allows people to have a wide range career opportunities. People who study engineering can easily move between different engineering fields and industries because they have a wide range of skills and capabilities.

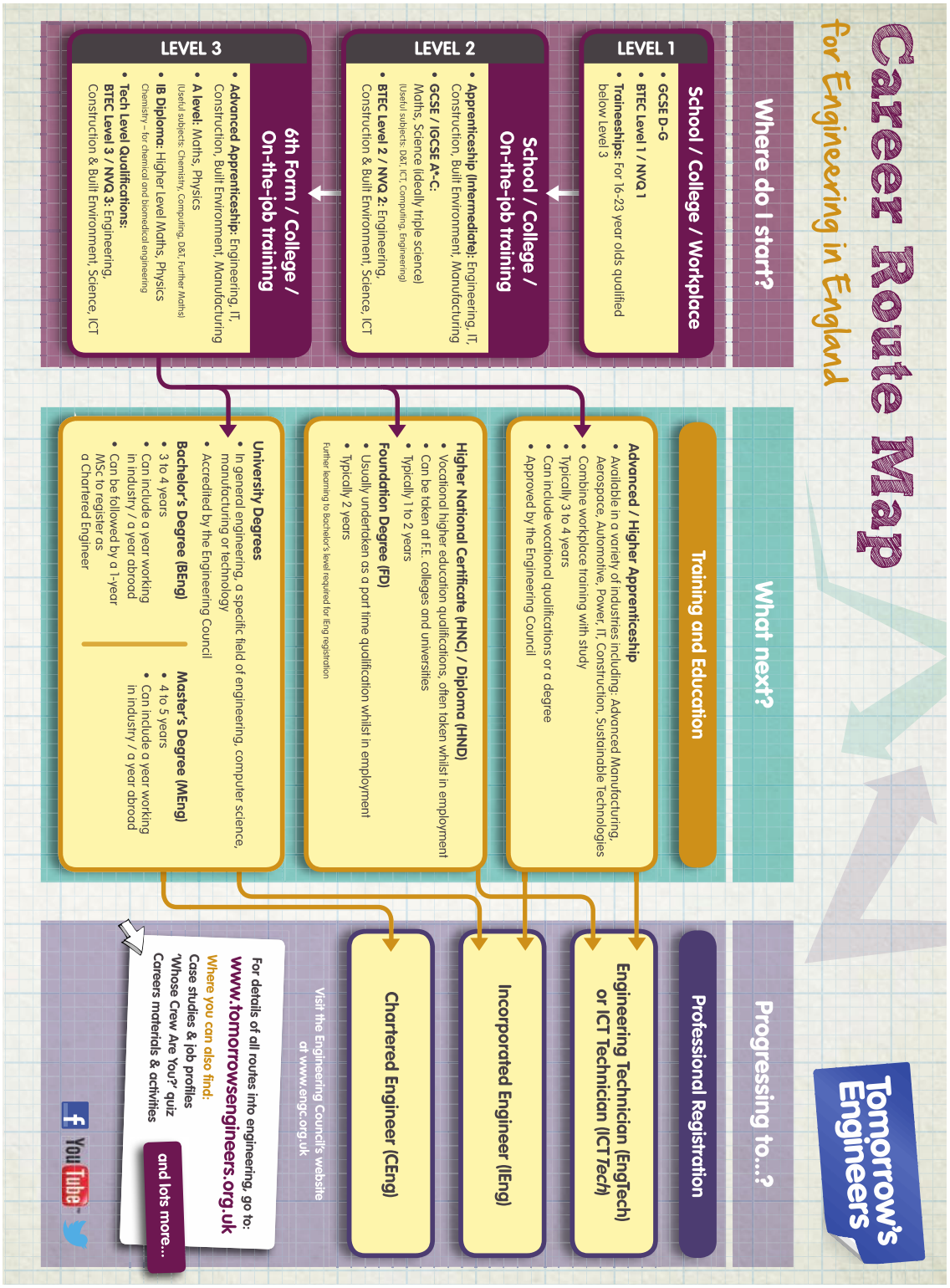
Creative Thinking

- Engineering is a very creative profession. It requires students to find innovative solutions to open ended questions or problems.

Potential to Benefit Society

- Everything engineers do benefits society in some way, shape, or form. Although not all engineers can see the benefits they bring to society, they do contribute to bettering the lives of people.

ROUTES TO ENGINEERING



TEACHING STEM

'Changing the Conversation' is a social movement towards benefitting the engineering industry. Some of the problems include a misconception of engineering the career opportunities available, the field's lack diversity, specifically the percentage of women within the industry, and how engineers communicate with professionals (and students) outside of the industry. While teaching about the above information and similar STEM-related concepts, consider the following notes and statistics from *Engineering UK 2015*: *The state of engineering* authored by Dr Anil Kumar, Neil Randerson, and Elliot Johnson:

- "Almost one if five (17%) of all STEM teachers think that a career in engineering is undesirable for their students" (p48).
- "engineering came highest on a list careers that teachers professed to being unfamiliar with: 39% of teachers stated that they had no personal understanding of engineering as a profession" (p49).
- "STEM engagement activities should incorporate several key elements which include… continuing professional development for STEM teachers" (p49).
- "Uninspiring teachers was one reason pupils gave to inspectors to explain why they did not wish to continue studying science" (p49).
- "one in five children said they did not feel informed about what jobs are available" (p50).
- "The Social Mobility and Child Poverty Commission reported that '55% of employers think not enough young people leave school with work experience...children are more likely to struggle to get access to high quality opportunities'" (p51).
- "encouraging women into the STEM sector is vital in order to fulfill business needs" (p53).
- "the World Economic Forum [states] that… 'a nation's competitiveness depends, among other things, on whether and how it educates and utilizes its female talent" (p53).

The Engineering UK Report annually updates the status of engineering, reviewing the year's most important engineering and STEM-related studies, a multitude of challenges the UK must overcome to move forward and realise its full potential. The original report can be found here: http://www.engineeringuk.com/EngineeringUK2015/EngUK_Report_2015_Interactive.pdf

Useful Websites

Below you will find a list of useful websites for presenting STEM to students.

Tomorrow's Engineers is a one stop shop for information and resources about the careers available in engineering. It also contains resources for students and young people, including engineering case studies, and downloadable resource packs for teachers.
http://www.tomorrowsengineers.org.uk/

Young Engineers is a national network of schools and individual students that offers engineering oriented resources and activities as well as opportunities to attend engineering focused events and compete in engineering challenges.
http://www.youngeng.org/

Royal Academy of Engineering is the UK's national academy for engineering. Developed with teachers, the Academy has produced a suite of engineering based resources for teachers and STEM Ambassadors.
https://www.raeng.org.uk/education/eenp/engineering_resources/default.htm

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STEMNET works with schools and colleges to help educators inspire students in STEM. They help educators access a range of STEM Enhancement and Enrichment (E&E) opportunities, including STEM Clubs and links with STEM Ambassadors.
http://www.stemnet.org.uk

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Disclaimer: All links are recent as of April 2015. Outdated links may become broken, incorrect, or irrelevant.

Build Your Own Digital Railway

Mode of Construction Recommendations

Listed below are several suggestions for how student teams can go about building the models for their digital railway. You may wish to have every group use the same mode of construction, depending on time and resources available, or you may wish to allow groups the freedom to choose their own.

Each mode of construction has a different learning curve, level of model complexity that can be produced, usage requirements, and expected cost range.

The table below gives a general overview on the different options:

Construction Choice Overview				
Mode of Construction	**Learning Curve**	**Complexity**	**Cost Range**	**Requirements**
Engineering BIM Software	HIGH	HIGHEST	Most software is free or discounted to educators and students	Computers that can handle running engineering software. See specifications on manufacturers' websites.
Sandbox Video Games	MEDIUM	MODERATE-HIGH	Free to upwards of £17.95 per students	Computers that can run games with low to moderate graphics requirements. Possible separate computer to run as world server.
Building Kits	LOW	LOW	£18.49 per student team to £569.99 per team	Building kit materials.
Craft Construction	VERY LOW	MODERATE	£0 if using recycled materials; otherwise, costs are relatively low	Craft tools (i.e. s scissors, hot glue, tape, rulers, etc.)

Engineering BIM Software

Overview:

BIM software is more than just CAD or 3D modelling. It allows the user to add building information such as: time, cost, manufacturer details, sustainability and maintenance information, etc. to the building model.

The table below shows several different types of software that can be used:

Engineering Software Comparison			
Software†	**Cost**	**Comments**	**Computer Requirements†**
AutoDesk Revit	Free*	BIM software that allows users to create 3D CAD models, annotate them with 2D drafts, and create a building information database	http://knowledge.autodesk.com/support/revit-products/troubleshooting/caas/sfdcarticles/sfdcarticles/System-requirements-for-Autodesk-Revit-products.html
SketchUp Make	Free*	SketchUp is a 3D modelling software. It has an assortment of useful plugins and libraries that help to model structures and incorporate BIM	http://help.sketchup.com/en/article/36208
Graphisoft ArchiCAD	Free**	2D and 3D drafting software with documentation functions for users to create detailed technical documentation	http://www.graphisoft.com/support/system_requirements/AC18/index.html
Bentley MicroStation	Free*	CAD software 2D and 3D design and drafting. Can also generate smart 3D BIM models based on input parameters	ftp://ftp.bentley.com/pub/help/microstation/081109292en/readme.htm

*Companies offer free software licenses to students and educators only
**Free to design and architecture students. Contact Graphisoft to see if you qualify
†Outdated software, computer requirements, and hyperlinks may no longer be relevant. Table is up to date as of April 2015.

Pros:

- Students will learn a marketable skill that they can put on their resume/CV
- Students will have a head start on understanding CAD and engineering software if they end up pursuing a related career or university degree
- Most software is free to students and educators
- Students can create models with the highest level of complexity and detail

Cons:

- High learning curve
- May require ambassador or volunteer help to teach the software
- Usually only one student will be able to work on the model at a time
- Requires computers that are able to run the software

Recommendations:

It is recommended to use AutoDesk Revit if choosing to use engineering software. Revit is one of the most commonly used types of BIM software. Other AutoDesk products, such as AutoCAD, are also used in universities and in engineering careers. Having knowledge in related programs is beneficial if students wish to pursue a degree or career in an engineering related field.

If instructor, ambassadors, or students are more familiar with one of the other programs above, then that software can easily be used instead. Bear in mind that time will have to be set aside for students to learn how to use the software properly. Formal instructional lessons can be delivered by teachers or ambassadors. Students can additionally be assigned to work on software tutorials and practice using it on their own time, if possible. There is a plethora of online resources available that students can take advantage of to learn how to use the software.

Sandbox Video Games

Overview:

Sandbox games allow players to freely roam and interact with a virtual environment. Many sandbox games let players build objects of variable complexity from static block structures to dynamic constructions controlled by intricate circuitry. Players can often work together on a project at the same time if they are connected to the same server which is usually hosted on a separate computer or through a paid hosting site.

Below is a brief overview of different sandbox games available:

Sandbox Games Overview				
Game†	**Cost**	**Comments**	**Computer Requirements†**	**Server Requirements*†**
Minecraft	• £17.95 per license • £8 per month for hosted server • Free self-hosted servers*	Minecraft is one of the most popular sandbox games on the market. You collect and place blocks to build anything you can imagine.	https://help.mojang.com/customer/portal/articles/325948-minecraft-system-requirements	http://minecraft.gamepedia.com/Server/Requirements
MinecraftEDU	• £9.5 - £12 per license • £14 per month for hosted server • £28 for server software*	Educational version of Minecraft. Includes access to commercial edition of Minecraft as well.	*Same as above*	*Same as above*
Blockland	£6.99 per license	Gameplay is similar to a virtual LEGO world	http://www.blockland.us/Help.html	http://www.blockland.us/portforward/index.html
Minetest	Free	Open-source Minecraft clone. Similar gameplay with limitations and not as many features.	http://www.minetest.net/	http://wiki.minetest.net/Setting_up_a_server
Roblox	Free	Multiplayer sandbox world in which users build things out of different sized blocks and share with friends.	https://en.help.roblox.com/hc/en-us/articles/203312800-Technical-Issues-Computer-Hardware-Operating-System-Requirements	*N/A*

*Not required if using server hosting services

†Outdated games, computer requirements, server requirements, and hyperlinks may no longer be relevant. Table is up to date as of April 2015.

Pros:

- Effective way to engage students
- Students may already be familiar with the game or own it
- Multiple students can work at once if connected to a server
- Can create a moderately high level of complexity depending on game used

Cons:

- Computers with appropriate system requirements are required to run the games
- If using a server to allow students to collaborate simultaneously, an additional computer and internet connection may be required. Alternatively, a paid subscription to a hosting service will have to be used.
- Slight initial learning curve, but overall easier than CAD software

Recommendations:

If choosing to use a sandbox game, it is highly recommended to use Minecraft or MinecraftEDU because of the abundance of tutorials, wiki articles, and other instructional information readily available for both games. Other games are free, but some are open source and do not have the same capabilities as Minecraft and MinecraftEDU.

Purchasing MinecraftEDU also allows access to the commercial edition of Minecraft. However, students can only log on to a MinecraftEDU server through MinecraftEDU. A server is not entirely essential, but is recommended as it does allow students to work together at the same time in the same virtual world rather than one person working at a time. Servers can either be hosted by the instructor on a computer or through a hosting service for a small monthly fee. For more information on hosting servers see https://help.mojang.com/customer/portal/articles/429052-how-do-i-play-on-a-multiplayer-server-?b_id=5408[1] for information on Minecraft and http://minecraftedu.com/hosting[1] for information on MinecraftEDU.

Since some students may already have knowledge of Minecraft and own the game, deciding to use the commercial Minecraft or the EDU version is dependent on convenience for educators, student knowledge, and computer availability. If students are particularly interested in using a sandbox game for their project, instructors can encourage teams to test out some of the free games and do their own research before instructors purchase licenses for the paid games.

[1] Outdated links may be irrelevant. Last updated/checked April 2015

Building Kits

Overview:

Building kits contain an assortment of interlocking or connectable pieces that can be combined to create different structures.

Below is a table of a few brands of kits along with price ranges for each:

Kit Comparison		
Building Kit	**Cost Range***	**Comments**
LEGO	£34.99 - £335.99	Kits can range from basic brick sets to LEGO Mindstorms kits.
K'NEX	£18.49 - £90.10	Many kits include a wide assortment of K'NEX pieces. Amount of total pieces is generally linearly proportional to pricing
VEX	£299 - £569.99	VEX is geared more towards creating and programming robots. Kits are very expensive and somewhat limited in what can be built.
*All costs shown are regular prices (no educational discounts applied) including VAT. Contact respective companies for educational pricing and bulk order discounts. Prices are recent as of April 2015		

Pros:

- Kits can easily be reused for multiple years
- Offers a more structured mode of construction for students
- Easier and quicker option if there are time constraints

Cons:

- Model can only have a low to moderate level of complexity since kits are limited by type and amount of pieces
- Kits can be very expensive
- Can limit the creativity of students by being too structured

Recommendations:

It is not highly recommended to use building kits for this project. Despite their ease of use, kits are generally expensive and limit what the students can build. For this reason, kits should really only be used if there are significant time constraints.

The instructor can, however, work these drawbacks into the lesson plan if they give teams a budget and have them buy the kits and pieces they need to complete their project. These tie in with concepts such as cost planning and resource acquisition.

Craft Construction

Overview:

Craft Construction can include anything from cardboard and duct tape to wood and screws to create a physical model.

Pros:

- Allows the most creativity and flexibility.
- Costs can be close to zero if using recycled materials
- Low learning curve, students do not need to know much to begin construction

Cons:

- Requires relevant tools to work with whatever materials are being used.
- Potentially most dangerous if using sharp hand tools, scissors, etc.

Recommendations:

Craft construction is highly recommended if the use of computers is difficult or limited. It offers the most flexibility and can be one of the cheaper options. Instructors can give students a budget and have them research and source their own materials or alternatively provide an assortment of materials in bulk.

If the use of dangerous tools is required, be sure to go over safety rules beforehand. Stressing a "Target Zero" attitude is important to make sure that any accidents are prevented. Health and Safety are critical concepts in construction and engineering and can be tied in to the overall project.

Other

These are only a handful of possible construction modes for this project. Students are encouraged to research other ways to construct their digital railway. Instructors can also have students combine different modes to make both a virtual and physical model of their project. If access to a 3D printer or laser cutter is possible, having students take CAD models they create and then 3D print or laser cut them is a great way to combine virtual and physical elements of design.