‘Build Your Own Digital Railway’ Programme

An Interactive Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfilment of the requirements for the
Degree of Bachelor of Science

By
Elizabeth Fitch
Joshua Friscia
Jordan Kovar
Sean McCarthy
Stephanie Rivard

Date: 2 May 2015

Report Submitted to:
Sponsor Liaisons: Sally Speed & Lauren Hillier
Sponsoring Organization: Crossrail

Professors: Dominic Golding and Patricia Stapleton
Worcester Polytechnic Institute

Abstract

The goal of this project was to develop the Build Your Own Digital Railway Programme for Crossrail, for delivery in schools. This program was designed and developed by interviewing Crossrail staff, STEM education experts, teachers, and ambassadors to determine the most appropriate program criteria. It is delivered using five handbooks to guide teachers, mentors, and students. The program is mapped to two Cambridge Nationals qualifications, along with an additional vocational qualification that extends the program from ten to twelve weeks. Students will choose to follow the Engineering or Creative Strand to obtain the respective qualification while collaborating to build their own digital railway, a transit system designed to help users through their daily routine.

Acknowledgements

This project was made possible through the support of many individuals and organizations. We would first and foremost like to give a special thanks to Crossrail Ltd., its Young Crossrail department, and specifically our project sponsors, Sally Speed and Lauren Hillier, for making this project available to us and providing us with support, insight, guidance, resources, and contacts. Additional thanks goes to the Young Crossrail Ambassadors who allowed us to interview them to gain insights into their experience mentoring students. We would like to extend thanks to Sonia Zahiroddiny of HS2, Kevin McGeever of Network Rail, and Tahir Ahmad of Crossrail for helping us navigate the expansive topic of BIM, as well as Allison Pearce of OCR for helping us choose qualifications that corresponded to our learning outcomes. Our thanks also goes out to Rebecca Roberts of Swanlea School and Anita Money of Maria Fidelis for giving us additional perspective as to how STEM education is implemented in a classroom environment.

The faculty and staff of Worcester Polytechnic Institute were vital to the success of this project. Thanks must go to Sue Sontgerath and Professors Chrys Demetry and Martha Cyr for giving us an early direction in our STEM education research. Finally, we would like to express our deepest thanks to our project advisors, Professors Dominic Golding and Patricia Stapleton, for their unwavering support, encouragement, and feedback throughout every stage of this project.

Executive Summary

Background

There is an increasing deficit of STEM (Science, Technology, Engineering, and Math) proficient workers in the United Kingdom, as the demand for them is increasing while the number of students pursuing STEM careers and degrees has not kept pace. Various organizations are aware of this issue, and they have been making efforts to help bridge the gap and get more students involved in engineering to create a pipeline of STEM graduates who will go on to work in engineering professions. Crossrail, currently the largest public works project in the UK, has developed the Young Crossrail Programme and teamed up with six partner schools along the Crossrail route to increase awareness about this construction project and get students interested in engineering.

The Young Crossrail Programme has resources and activities for Key Stage 3, but lacks resources for Key Stages 4 and 5. The Build Your Own Digital Railway Programme has been developed for Young Crossrail as a way of engaging older students with STEM and allowing them to complete associated vocational qualifications while working on the project. The program will also teach students valuable engineering, collaboration, business, and employability skills.

Project Objectives

To develop our program, we conducted several interviews that helped us determine the design criteria for the program and its implementation. These interviews were conducted with Crossrail staff, STEM education experts, teachers, and ambassadors. These interviews set the framework for the program, allowing us to set the goals and program objectives. After developing a preliminary program curriculum, we consulted our stakeholders and finalized the program and any supplemental documentation. These last minute consultations led to a finished project ready to be delivered in schools at the Key Stage 4 and 5 level.

Program Structure

We developed the Build Your Own Digital Railway Programme to allow for delivery of an open-ended, hands-on project, while emphasizing the importance of collaboration and data management. The 10-week program is broken down into seven modules. Modules 1-5 were designed to deliver the Cambridge Nationals qualifications in Engineering Design and Creative iMedia. Modules 0 and 00 bookend the delivery guide, so the 10-week program can extend to twelve weeks for students interested in receiving an additional qualification in Employability Skills. The program begins with a project brief for the teachers, mentors, and students, which outlines the requirements and goals of the Digital Railway project. Teachers will deliver the project while adhering to and assessing the learning outcomes for each module during the ten to twelve weeks. During the program, it is our hope that each team of four students can be assigned a mentor to act as a resource guide and professional assistant for the project's delivery. We have determined that an active and responsive mentor who is committed to his/her job and the team's success will provide a healthy mentor-mentee relationship. Teams will come together for a final presentation day to present their findings and projects, along with an assessment of their collaboration skills.

Handbooks

The program will be delivered using five handbooks: the Teacher Delivery Handbook, Teacher STEM Resource Guide, Construction Guide, Mentor Handbook, and Student Resource Guide. Each of the handbooks will help in some form to guide the implementation of the program within a school. The Teacher Delivery Handbook has been designed to allow for adaptation of similar curriculums that teachers have already mapped out. The handbook is a guide for the delivery of five modules, each mapped to our learning outcomes and five BIM phases, and two optional modules for students attempting to receive a qualification in Employability Skills Level 2. Recommend activities have been designed for each module to inspire students as teams design and build their digital railway. Teachers will also be offered the Construction Guide, which provides different methods of construction through the use of software or physical materials. The Guide will help teachers decide what options will be available for students during the execution of the project and related activities.

To provide teachers with a better understanding of engineering and how to talk about it with students, e.g. comfortably fielding STEM-related questions, we have developed the Teacher STEM Resource Guide. Along with brief advice about teaching STEM, the Guide offers a peek into the life as an engineer, types of engineering and routes to engineering for students. Mentors will follow the teacher's curriculum plan along with our Mentor Handbook to successfully guide their team through the design and development of the team's digital railway. Students from the Creative and Engineering strands will team up and receive a project a briefing along with the Student Resource Guide. This handbook has been designed to offer students insight into the problems that engineers face during their projects and how those issues have been handled. These design choices seen in the form of case studies, videos, and helpful websites will help students start to develop ideas for the final design of their digital railways. These resource guides have been designed to allow room for future modifications based on the relevance of the case studies and resources at the time the program is implemented.

Major Conclusions and Recommendations

Based on our discussions with stakeholders and observations, we concluded that developing an open-ended program is ideal since it does not limit student creativity and teachers can easily adapt the program to fit their curriculum. In addition, having a longer project spanning 10-12 weeks allows students to continuously build on what they learn throughout the program and apply it to their end result. Also, we concluded that letting teachers present the materials and having ambassadors as mentors to act as a resource would be the best setup for the program; teachers are more knowledgeable about their curriculum and ambassadors have limited time and are not all necessarily trained to deliver or present materials.

The Digital Railway Programme was originally designed for Young Crossrail and its partner schools, but may develop into a much more widely used program as Transport for London (TfL) will be taking on Young Crossrail's outreach commitments. Several recommended actions should take place in order to ensure the success and future of the Digital Railway Programme. These include: doing a pilot test of the program, creating a project website and information hub, additional program spin-offs, teacher and ambassador orientations, and having students showcase their projects and major events.

Authorship

Section	Primary Author(s)	Secondary Author(s)	Primary Editor(s)
Chapter 1	All		All
Chapter 2 Intro	Lizzy		All
2.1 Crossrail	Lizzy		All
2.1.1 Community Outreach	Lizzy		All
2.1.2 Young Crossrail	Lizzy		All
2.1.3 Similar Outreach Programs	Lizzy		All
2.2 STEM Education	Josh & Steph		All
2.2.1 STEM Education in the UK	Josh & Steph		All
2.2.2 UK Qualifications	Sean		All
2.3 Methods and Approaches for Teaching STEM	Jordan		All
2.4 Mentoring Programs	Lizzy	Jordan	All
2.4.1 Examples of Mentoring Programs	Lizzy, Jordan & Sean		All
2.5 Application of STEM in Young Crossrail	Josh & Sean		All
Chapter 3 Intro	Josh		All
3.1 Objective 1 Intro	Jordan		All
3.1.1 Stakeholder interviews	Lizzy		All
3.1.2 Ambassador Interviews	Lizzy		All
3.1.3 Teacher Interviews	Lizzy		All
3.1.4 Student/Ambassador Observation	Lizzy & Steph	Jordan	All
3.2 Objective 2 Intro	Jordan		All
3.2.1 Program Conception	Steph		All
3.2.2 Supplemental Documents	Lizzy		All
3.3 Objective 3 Intro	Jordan		All
3.4 Summary	Josh		All
Chapter 4 Intro	Lizzy	Steph	All
4.1 Program Structure	Jordan & Steph		All

4.2 Learning Outcomes	Jordan & Steph		All
4.3 Supporting documents	Lizzy		All
5.1 Teacher Experience	Sean		All
5.2 Ambassador Experience	Sean		All
5.3 Student Experience	Sean		All
5.4 Construction Guide	Josh		All
5.5 Lesson Plans	Sean		All
5.5.1 Module 0: Employability Pre-Session	Jordan		All
5.5.2 Module 1: Concept/Brief	Jordan		All
5.5.3 Module 2: Design	Jordan		All
5.5.4 Module 3: Construction	Jordan		All
5.5.5 Module 4: Handoff/Commission	Jordan		All
5.5.6 Module 5: Operate and Maintain	Jordan		All
5.5.7 Module 00: Employability Post-Session	Jordan		All
6.1 Project Recap	Josh		All
6.2 Future Changes and Recommendations	Josh		All
6.2.1 Pilot Program with Schools	Josh		All
6.2.2 Information Hub Website	Josh		All
6.2.3 Project Hand-off Program	Josh		All
6.2.4 Project Showcase Events	Josh		All
6.2.5 Teacher Briefing and Orientation Sessions	Josh		All
6.2.6 Ambassador Team Mentors	Josh		All
6.3 Closing Words	Jordan		Sean

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

An analysis on jobs and growth in the UK by the Royal Academy of Engineering predicted a demand for 830,000 additional Science Engineering and Technology (SET) professionals and technicians between 2012 and 2020. With an estimated supply of only 90,000 SET graduates annually, there will be a deficit of over 10,000 workers a year in SET professions (Royal Academy of Engineering, 2012). Currently, the UK government and private organizations are attempting to establish Science, Technology, Engineering, and Mathematics (STEM) education as a stable foundation for possible career paths for British young adults. Although there is a desire to promote STEM education, schools often do not have the groundwork and infrastructure to effectively instruct and create student interest in the various STEM related careers.

As the largest public works project in the UK, Crossrail is cognizant of the need to train more students in STEM and also of its obligation to give back to the communities affected by the construction. Among several outreach programs developed by Crossrail, the Young Crossrail Programme is designed to promote student interest in pursuing STEM courses in school. The program focuses on six schools along the Crossrail route and stimulates interest in STEM topics by engaging students with hands-on activities. By promoting STEM and the related career fields, the Young Crossrail Programme hopes to create an educational pipeline of future workers with the technical skills to fill the demand for STEM proficient employees. To do so, Crossrail plans to introduce relevant STEM programming and resources for Key Stage 4 (14-15 year old) and Key Stage 5 (16-19 year old) students.

The goal of this Interactive Qualifying Project (IQP) was to develop an educational program for Key Stage 4 and Key Stage 5 students, which focuses on exploring different engineering subjects related to the engineering and technology utilized in the Crossrail project. In order to create an education program, we conducted interviews with a variety of stakeholders, including Young Crossrail ambassadors, teachers, and other experts, to identify the best methods and approaches towards STEM education and the current needs of the Young Crossrail Programme. We observed students and ambassadors interacting in the classroom to identify current practices and opportunities for improvement, such as presentation styles and delivery methods. We also observed students reactions to activities to gauge student interest and engagement levels. After we gathered our initial findings we developed and refined a program for the teachers to utilize in the classroom. This included a teacher handbook, teacher STEM education guide, mentor guide, and student resource sheet. The program is split into an engineering and creative strand to fulfill a qualification in either Engineering Design or Creative iMedia at the second level. Students from each strand will work together to create a Digital Railway in which passengers can carry out parts of their daily routine, and they will be able to attain a qualification in Employability Skills. This project was at first executed as an extension of a project completed last year, which developed educational resources for Key Stage 3 (11-14 year old) students in the Young Crossrail Programme. It has developed into a much larger stand-alone project which will serve as a legacy program when the Crossrail project is completed and management and oversight shifts to Transport for London (TfL). TfL will additionally be continuing many of Young Crossrail's outreach commitments upon Crossrail's completion.

Chapter 2: Background

London has experienced substantial growth in population and employment opportunities in recent years, and this growth is projected to continue for the foreseeable future. Currently, over eight million people reside in London and it is estimated that by 2050, the population of the London metropolitan area will top eleven million people (Greater London Authority, 2013). Employment opportunities are expanding quickly, especially within the financial and business districts of London. It is estimated that by 2031 the total number of jobs will approach 5.45 million in comparison to 4.68 million jobs in 2007 (World Population Review, 2014). With the large influx of people and jobs, London's Underground rail network, a popular and widely used mode of transportation affectionately known as the Tube, is becoming increasingly overcrowded. Approximately 1.265 billion passengers utilize the Tube annually (Transport for London, (a), n.d.). The number of commuters using the Tube will continue to grow as more people are attracted by London's residential and employment opportunities (Greater London Authority, n.d).

In order to alleviate overcrowding and congestion on the current London transport system, the Department of Transport and TfL have partnered to sponsor Europe's largest construction project, Crossrail. Crossrail is a new rail line designed to meet London's current and future transportation needs (Crossrail Limited, 2011). Due to the significant impact Crossrail will have in London, Crossrail has taken on various community outreach programs, including the Young Crossrail Programme. This particular program focuses on educating young students on STEM topics and encouraging them to pursue STEM-related careers. The major goal of this project is the development of an educational program for Key Stage 4 (13-15 years old) and Key Stage 5 (16-19 years old) participants in STEM. This chapter includes an overview of Crossrail and the Young Crossrail Programme, as well as an analysis of other educational community outreach programs. In addition, this section explores the history and evolution of STEM education, STEM education in the UK, and effective teaching methods for teaching STEM subjects.

2.1 Crossrail

The idea of a cross-city railway in London was first proposed in the late 1800s, but did not become a serious proposition until almost a century later. In 1974, the Greater London Council and Department for Environment conducted the London Rail Study that discussed the need for a cross-city railway and coined the term “Crossrail” (Crossrail Limited, (a), n.d.). As the London economy and population continued to grow, transportation experts concluded that Crossrail would need to develop separately. In order for London and the surrounding areas to receive the most benefit from Crossrail, this new line would be more than an addition to the tube and a good portion of its journey would be above ground. More than three decades passed until the Crossrail Hybrid Bill received Royal Assent and the Crossrail Act of 2008 was passed, which set the route for the railway. After 35 years of planning, Crossrail finally began construction on May 15, 2009 at Canary Wharf on the east side of London (Crossrail Limited, (a), n.d.). Crossrail is still under construction, but is scheduled to be complete in 2018.

Crossrail presently employs more than 10,000 workers at 46 construction sites tasked with building the 100 km railway route. The main goals of Crossrail are to:

- Increase public transport capacity within London to further support population and employment growth;
- Provide London residents and working people with fast, affordable, and accessible means of transport; and,
- Decrease safety risks and environmental impacts associated with underground transport (Crossrail, 2011)

Today, eight large tunnel boring machines (TBMs) are being utilized to construct (Figure 1) the 42 km of new underground railway lines (marked in Figure 2.1 as pink lines). The last tunnel is scheduled for completion in 2015. As of April 2015, eight sections of tunnels are complete, and only two remain unfinished (Crossrail Limited, (b), n.d.). In addition to the boring of tunnels, the Crossrail project involves the construction of 88.5 km of above ground railway routes (blue lines) and ten new stations at Paddington, Bond Street, Tottenham Court Road, Farringdon, Liverpool Street, Whitechapel, Canary Wharf, Custom House, Woolwich, and Abbey Wood (pink circles). Thirty existing stations will be extensively renovated (blue circles and tick marks). Once completed, Crossrail will increase the travel capacity of London public transport system by 10% and span 100 km, linking the East and West banks of London (Crossrail Limited, 2014 November).

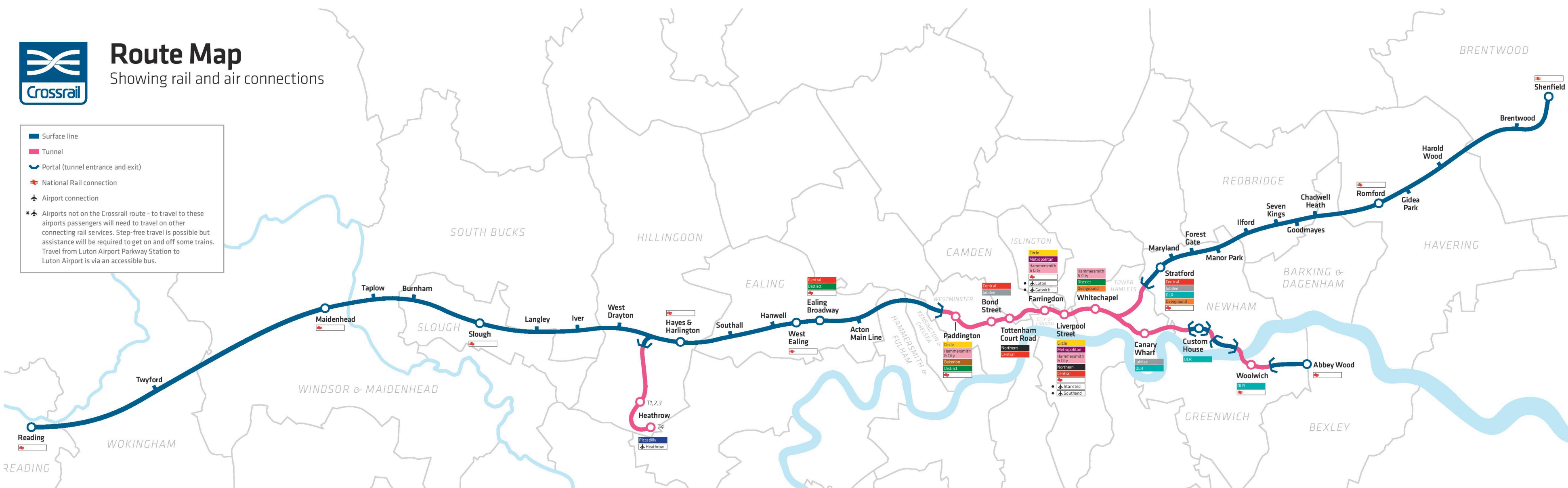


Figure 1: This will be the Crossrail route once construction is completed (Crossrail Regional Map , n.d.)

The Crossrail endeavor is exceedingly complex. To manage this complexity, Crossrail is using an innovative approach called Building Information Modeling (BIM). The purpose of BIM is to improve productivity and reduce waste, which are two common grievances in a large scale construction project (The British Standards Institution, 2013). BIM is the full integration of all aspects of a construction project using complex three-dimensional modeling and shared databases. Project participants can effectively collaborate through a shared virtual prototype of the actual project.

2.1.1 Community Outreach

Due to the large scope and nature of the Crossrail construction, many different communities will be impacted by the project in various ways. For this reason, Crossrail has developed several initiatives to give back and involve the local communities and people of London who are impacted by the project. Three of these outreach initiatives are the Crossrail Apprenticeship Programme, the Community Investment Programme, and Young Crossrail. The Crossrail Apprenticeship Programme seeks to give young people the opportunity to explore and learn a trade within the Crossrail project ranging from construction, quality assurance, and business management (Crossrail Limited, (c), n.d.). The Community Investment Programme focuses on improving the local communities along the Crossrail routes. Crossrail contractors work within their designated communities on various public service projects, such as volunteering at local schools or soup kitchens (Crossrail Limited, (d), n.d). Young Crossrail focuses on six targeted schools within a one-mile radius of the Crossrail route. Its goals are to educate children and young adults about the different types of engineering involved in the project and to inspire them to consider engineering as a future career path.

2.1.2 Young Crossrail

Young Crossrail works with six local schools to raise awareness about the Crossrail project by exposing students to different hands-on engineering activities. This program also attempts to break down common misconceptions about engineering as well as explore engineering's practical application to everyday problems in public transport. One of Young Crossrail's goals is to promote STEM education to the youth of London, so it may inspire the next generation of engineers. This program works hand-in-hand with engineers, teachers, and "Young Crossrail Ambassadors" to facilitate fun and engaging activities related to the Crossrail project. Young Crossrail ambassadors are Crossrail employees who volunteer to work with the program. Every month an email is sent to the ambassadors with dates of potential volunteer events they can help facilitate.

Over the past year, Young Crossrail has reached more than 10,000 students in the London area. The six schools that participate in the Young Crossrail Programme are (Figure 2): Westminster Academy, Maria Fidelis Catholic School, Elizabeth Garrett Anderson School, Rokeby School, Swanlea School, and the Royal Greenwich University Technical College (Crossrail Limited, (e), n.d.).

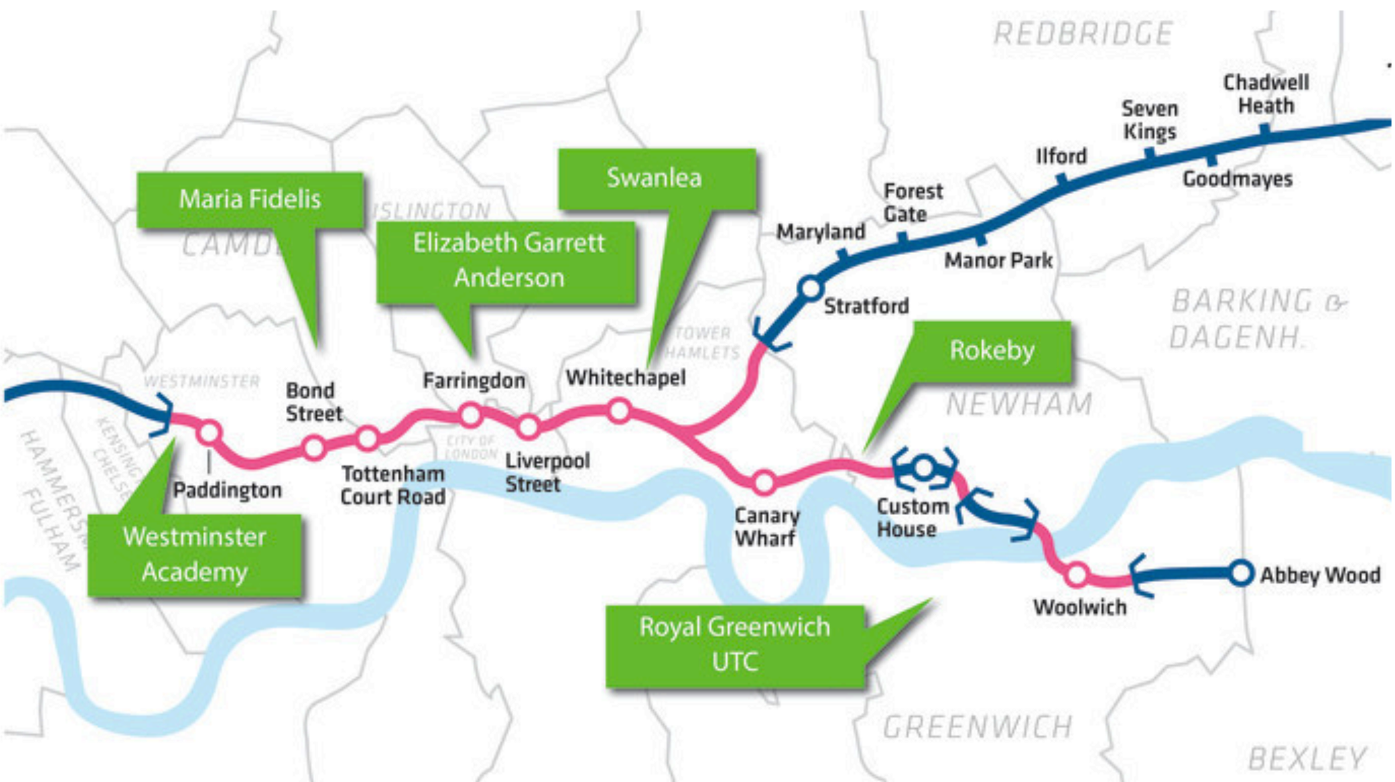


Figure 2: This map shows the six Young Crossrail partner schools along the Crossrail route (Crossrail Partner School Map, n.d.)

2.1.3 Similar Outreach Programs

There are many benefits to utilizing community outreach programs, and many major construction projects have incorporated community outreach into their work. Benefits include: building strong relationships between the local communities and the project teams, creating an open atmosphere where public members can discuss issues or concerns with project managers, building trust among community members and project workers, and increasing public knowledge of the project to allow community members to have a further understanding of the project and all it entails.

Other construction or transport projects like Crossrail, such as the Metropolitan Council of Minnesota and the Philadelphia Water Department, have taken on similar community outreach projects. The Metropolitan Council of Minnesota has taken steps to give back to the local communities surrounding the transit route from downtown Minneapolis to Eden Prairie. Similar to Crossrail's Community Investment Programme, the Southwest LRT Community Works Project works with the Metropolitan Council to aid the local communities by further developing nearby neighborhoods to make them more livable and visually appealing, promoting new business and economic opportunities, and creating ways to access bike paths and walkways (Metropolitan Council, n.d.). The Philadelphia Water Department also utilizes a community outreach program to provide educational opportunities and is similar to the Young Crossrail Programme. The Philadelphia Water Department's educational program, The Fairmount Water Works, offers schools different lesson plans about water quality and the land impacts of water. The program also goes into classrooms to hold different activities and offers summer programs for Philadelphia children (Southwest LRT Community Works program, n.d.).

Programs by Young Crossrail, Southwest LRT Community Works Project, and Philadelphia Water Department have placed a high emphasis on STEM because of declining proficiency and student participation in STEM subjects. This issue has become a concern for the United Kingdom as well as other developed nations. In Australia, for example, student participation in science and math has been consistently declining and overall student performance has dropped (Freeman, 2015). To combat this, the Australian government has created new math and science curricula involving inquiry-based learning and increased funding to improve teaching quality for all students. Canada also has focused efforts on promoting STEM, mainly for indigenous and minority students, in order to raise retention rates and performance of those minority groups in math and science (Freeman, 2015). Other countries such as New Zealand, France, Russia, and the United States, where the STEM education movement originated, have also adopted a range of approaches to promote STEM education and address their own individual issues surrounding educational deficiencies in STEM subjects (Freeman, 2015).

2.2 STEM Education

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. The push for quality STEM education began largely as an American movement, as the United States found it was falling behind in math and science education when the USSR launched the Sputnik satellite in 1957 (Rose, 2004). The National Science Foundation first coined the STEM acronym in the 1990s, and by 2005, when the United States had fallen further behind countries like India and China in global economics and innovation, the modern STEM movement was born (Sanders, 2009).

A growing need for more graduates entering the workforce with STEM skills and experience prompted reviews of the educational curriculum. In the United States, a Congressional Research Service Report on STEM Education stated, “A large majority of secondary school students fail to reach proficiency in math and science, and many are taught by teachers lacking adequate subject matter knowledge” (Kuenzi, 2008). 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. For example, Dean Kamen, the inventor of the Segway, co-founded FIRST Robotics and numerous other outreach programs to get students excited about science and technology (FIRST, 2014). President Obama has also made STEM a key component of the 2015 US fiscal plan, devoting hundreds of millions of dollars to help train teachers, provide grants for schools, and improve STEM learning as a whole (U.S. Department of Education, n.d).

2.2.1 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" (Lord Sainsbury of Turville, 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 gross domestic product (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[1]. Both are required until the end of a student's secondary

---

[1] Students in the United Kingdom, levels of education are broken into "Key Stages" for measuring student progress, with five Key Stages each spanning two to four years (United Kingdom Department of Education, 2015). Students begin their education between 4 and 5 years old (the beginning of Key Stage 1) and end their compulsory education when they are 16 years old (the end of Key Stage 4). At Key Stage 5, students who continue their education begin to specialize within either the sciences or humanities, continuing in their secondary school or moving into a tertiary college (Elliott, 1997).

education (Key Stages 3 & 4), at which point the student 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. According to an article from the *European Journal of Engineering Education*, in 2008 only 5.2% of students pursued engineering in higher education (Barnard, Hassan, Bagilhole, & Dainty, 2012). In particular, the authors also noted that only a little over 2% of all female students in higher education were pursuing engineering. This research may hold some clues as to what factors lead a student to study engineering. Barnard et al. went on to state that the majority of female students who chose to study engineering had an engineer within their families. If female students who have a connection to an engineer are more likely to study engineering in higher education, exposure to engineering may correlate with a positive opinion of engineering as a profession. In addition, the Parliamentary Office of Science and Technology found that, while 14 to 16-year-old students are required to study math and science, they receive "little specific coverage of technology or engineering" (Parliamentary Office of Science and Technology, 2013). If there is a correlation between exposure to engineering and its pursuit in higher education, the lack of consistent and engaging exposure to engineering topics during adolescent key stages could be the reason why so few students pursue engineering in their education.

Furthermore, there is a significant need for students in the UK to get better career advice in order to understand the opportunities available to them in science and technology fields. A survey given to businesses in the UK found that 80% of them believed that the career advice given to students was inadequate for enabling those students to make informed decisions about future career options (Confederation of British Industry and Pearson, 2014). As a result, efforts to increase student awareness of career opportunities in math and science have been spearheaded by The Science Council, a UK organization formed under royal charter. The project, Careers from Science, has developed into a website called Future Morph, which contains resources for students of all ages and teachers on STEM opportunities (The Science Council, n.d.).

The initiative for more quality STEM education in the UK is supported by a number of programs that encourage students to engage in STEM. One such program is STEMNET, the Science, Technology, Engineering, and Mathematics Network. STEMNET works with a network of 27,000 ambassadors who volunteer their time to deliver STEM programs to students across the United Kingdom, in a similar manner to Young Crossrail (STEMNET, n.d.). Ambassadors are typically employed in the STEM fields and represent a wide range of cultures and ethnicities to better engage with their audience (STEMNET, n.d.).

Another STEM outreach program worth noting is STEMworks, a non-profit organization out of Gloucester that offers various activities and workshops to primary and secondary students. STEMworks collaborates with various companies to host STEM-focused information days, competitions, and workshops to engage students in STEM and give them an introduction to local businesses in STEM fields that may hire them in the future (STEMworks, 2011).

2.2.2 UK Qualifications

The UK is clearly making strides to increase STEM education. Students in Key Stage 4 are required to take part in General Certificate of Secondary Education (GCSE) examinations. University Technical Colleges (UTC) offer GCSE (academic) and equivalent vocational qualifications, and are attempting to offer students more options and flexibility in STEM subjects. In a study done in 2011, *Respected - Technical qualifications selected for use in University Technical Colleges*, Professor Matthew Harrison reported on STEM-related academic and vocational qualifications approved for teaching. Unlike UTCs, most schools at the compulsory level require a detailed and structured curriculum set for students. Schools in the UK develop a curriculum that aligns with the national curriculum issued by the Government for the 2014 academic year. For Key Stage 4, the curriculum requires schools to teach courses within the core subjects (English, Maths, and Science), the foundation subjects (Information and Communication Technology, Physical Education, and Citizenship), and at least one other subject (Arts, Design and Technology, Humanities, and Modern Foreign Languages) (British Government, n.d.). The core subjects are taught through the delivery of academic qualifications. Professor Harrison's report on academic and vocational qualifications integrated into the UTC curriculum offers a look into how unique professional qualifications can be achieved over a two-year period. This emphasis on professional and vocational qualifications drives UTC education, offering individual programs for students interested in independent study.

Examination Boards set the requirements for GCSE syllabi and vocational qualifications. For example, the awarding body--Oxford, Cambridge and RSA Examinations (OCR)--offers the Cambridge Nationals and Cambridge Technicals qualifications. These are vocationally-related qualifications that offer more options to students interested in STEM fields. UTCs are able to implement these types of qualifications into their programs because of the lack of restrictions on their curriculum. For example, in June of 2014, UTC Reading students were recognized for their achievement in becoming Autodesk Certified Users in AutoCAD. Joanne Harper, the principal of UTC Reading said, “These students have decided themselves to take advantage of the training offered by our industry partners and to utilise their time outside of lessons” (University Technical Colleges, 2014). A program that could be completed inside or outside of the classroom may pull in similar students who are looking to take advantage of all their school has to offer.

Developing a program that parallels or is inspired by a specific vocational qualification within a STEM-related subject requires an understanding of the how STEM educational methods and approaches have progressed thus far. With an understanding of how to present STEM fields to a classroom effectively, based on either academic or vocational qualifications, the program can be properly structured. This structure will help teachers and mentors present the program’s materials as well as build the requirements to complete the program. Developing a project that can guide the delivery of a one or more STEM-related qualifications may act a vehicle for driving student interest, while offering students incentives.

2.3 Methods and Approaches for Teaching STEM

A major contributing factor to the STEM labor shortage is that STEM is composed of fields that students traditionally perceive as being difficult or boring (PCAST, 2010). As a consequence of that perception, students may become disinterested and disengaged during STEM-based activities if a teacher or instructor uses a non-interactive, predominantly lecture based teaching approach (Knight & Wood, 2005). In contrast, active learning encompasses all activities that require the active involvement of students and provides a more hands-on approach to teaching STEM than a purely-lecture based approach. The discussion of active learning techniques is quite broad and, in STEM education, is typically divided into three subtopics: problem-based learning (PBL), process-oriented guided inquiry learning (POGIL), and peer-led team learning (PLTL) (Eberlein, Kampmeier, Minderhout, Moog, Platt, Varma-Nelsen, & White, 2008).

A PBL approach presents students with a problem that they then have to solve. Students will have to pick up skills or come to certain realizations in order to arrive at a viable solution. In one study at the high school level, a design-based science curriculum—a type of PBL where new scientific knowledge and problem solving skills are constructed in the context of design—was shown to result in a statistically significant increase of knowledge transfer as measured by pre-study and post-study tests (Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005). Another study, which focused on high school level chemistry and engineering that took a PBL approach, presented a project that challenged students to design a heating or cooling system that relied on chemical energy. The students who completed the project were significantly more likely to agree with the statement "I wish to become an engineer" (Apedoe, Reynolds, Ellefson, & Schunn, 2008). Although the PBL approach might require some thought to develop, it is more effective in teaching STEM than non-active learning approaches because it does a better job at engaging students, which in turn has a positive effect on learning outcomes.

POGIL is a learning approach that tries to recreate the original discovery of an idea. Classes are structured with very few lectures, and students are broken up into small groups, given data and guiding questions, and then have to draw their own conclusions. The POGIL approach was originally developed for use in chemistry, but the guiding principles are applicable to all STEM fields (Farrell, Moog, & Spencer, 1999). The results of POGIL in chemistry and chemistry-related courses have been overwhelmingly positive and are well-documented (Bailey, Minderhout, & Loertscher, 2012; Geiger, 2010; Brown, 2010; Barthlow & Watson, 2014). For example, at Boise State University, POGIL was implemented in a biomechanics course to explore the success of POGIL outside of chemistry. While the sample size was limited to the 64 students enrolled in the biomechanics course, the students received higher scores on average on the quizzes, tests, and course as a whole than those who were in a more traditional classroom (Simpson & Shadle, 2013).

PLTL is another learning approach that has one former student in the course leads a workshop where the students work together in teams. An example of PLTL would be a peer-led recitation for a course. The University of Texas at El Paso conducted a ten-year, PLTL implementation in five freshmen and sophomore chemistry, physics, and mathematics courses. Students were less intimidated by the peer leader and more likely to ask questions and actively participate (Darnell, Becvar, Flores, Knaust, Lopez, & Tinajero, 2012). Another study that looked at the same program, but focused only on the chemistry courses, found that the number of students who passed the course with peer leaders increased by 15% and the number of chemistry majors went up by over 300% in the ten year span of the program (Becvar, Saupe, Noveron, &

Narayan, n.d.). Hence, active learning techniques have been shown to be an effective approach to teaching STEM and can be successfully implemented in academic programs.

In considering changes to STEM education, it is important to determine what outcomes and criteria should be used to identify successful STEM education programs. A common criticism of the educational curriculum today is that it is too focused on "teaching to the test", which is to say that short-term, test-taking skills are emphasized more than long-term, learning and comprehension (Overman, n.d.). There are indications that this criticism has some merit and that a correlation between high STEM test scores and workforce readiness is weak or nonexistent (Chen & Luoh, 2010). Test scores are probably the most quantitative benchmarks of student achievement and are important in STEM evaluation. Nevertheless, they do not reflect a student's overall educational achievement and often distract from the actual goal of learning, as evidenced by the previous 2010 study. The National Research Council suggests that the ideal STEM education program capitalizes on students' early interests and experiences, identifies and builds upon the things that they already know, engages the students in STEM practices, and provides them with new experiences to further cultivate their interests (Committee on Highly Successful Schools or Programs in K-12 STEM Education, National Research Council, 2011). The overarching goal of STEM education is to get students to pursue STEM-related careers. Consequently, educators should emphasize student interest over short-term test scores.

2.4 Mentoring Programs

Mentoring programs are a long established educational model, which has proven to be successful when encouraging students to pursue science related careers (Anderson, Jett, Tenenbaum, Yourick, 2014). Especially within the past decade, there has been a great increase in popularity and widespread participation in youth mentoring programs (Cooper, DuBois, Holloway, Valentine, 2002). Mentoring programs are based around the idea that students are able to work individually or in small groups with a mentor who is able to oversee and guide them through various tasks or projects. In order to create an effective academic program, Young Crossrail can utilize a mentor/mentee program to engage and encourage participants to pursue STEM-related careers.

There are many benefits to mentoring programs; however, the most pertinent include: emotional and behavioral functioning, academic achievement, and employment or career development (Cooper, DuBois, Holloway, Valentine, 2002). One study performed at English secondary schools recorded that students reported an increased sense of motivation because of the presence of older mentors (Warrington, Younger, 2009). Additionally, students reported that they experienced increased feelings of aspirations because their mentors challenged them to achieve more. Students felt that their GCSE scores were positively impacted by their mentors and had subsequently changed their career aspirations to jobs that they never before felt they could never aspire to become (Warrington, Younger, 2009). In another study performed at Walter Reed Army Institute of Research, students who participated in a near-peer mentoring program indicated that they felt they were able to connect with their mentors more so than with their teachers. Because of their relationships, students were able to fully understand more about the STEM subjects than they had previously learned. Similarly to the secondary school study, at the end of the program students commented how this program gave them the confidence to pursue educational and career paths that they had not previously considered (Anderson, Jett, Tenenbaum, Yourick, 2014)

Internships and co-op opportunities are another example of STEM mentoring programs. In an internship or co-op, students have the opportunity to temporarily work at a company, thereby gaining valuable skills, work experience, business contacts, and sometimes pay, in the process. They are among the more successful ways in which students can be encouraged to continue to study STEM. A survey from the University of Washington's Center for the Advancement of Engineering found that engineering students who completed an internship or co-op were more inclined to go into engineering careers after graduation (Sheppard, Gilmartin, Chen, Donaldson, Lichtenstein, Eris, Lande, & Toye, 2010). As a result, industry can prove to be an invaluable ally in the mission to increase the number of individuals going into STEM professions.

2.4.1 Examples of Mentoring Program

In 1996, MIT began offering freshman pre-orientation programs (FROPs) for incoming freshmen as a way to increase interest in and exposure to various fields of study. Three programs were created that emphasized mechanical engineering, civil and environmental engineering, and electrical engineering and computer science. As a result, the three sponsoring departments saw an increase in student enrollment and interest (Thompson & Consi, 2007). Another study focused on two outreach groups targeting students aged 14-19 years old–both male and female–of diverse racial, geographic, and academic backgrounds. Outreach included hands-on activities in topics such as robotics, water resources, and rocketry. According to a survey given after the programs had concluded, while the outreach groups had no impact on attitudes towards college in general, they led to positive increases in students' attitudes and perceptions of engineering (Nadelson & Callahan, 2011).

Within London there are also many opportunities for students to get involved with mentoring programs. The Transport for London (TfL) Youth Travel Ambassador Programme is an initiative that allows students to work with TfL mentors for six weeks. For the length of the program, groups of students are assigned to a mentor with whom they meet once a week for an hour. During these sessions, students work to create their own travel campaigns to encourage active and independent travel, casualty reduction, community and personal safety, and skills and employment. Students are also expected to meet regularly outside of their formal sessions with their mentors. Participants leave the program feeling accomplished as well as reporting an increased awareness in their communities, as well as an increase in communication, presentation, and teamwork skills (Transport for London, (b), n.d).

Similarly, the Engineering Development Trust (EDT) is a national provider of activities that promote STEM and STEM-related subjects. It provides activities for youth ages 11-21 years old to guide and "[enhance] their technical, personal and employability skills through industry-led projects, industrial placements and specialized courses" (EDT, (a), n.d). The EDT has led the development of the following learning schemes: First Edition, Go4Set, Open Industry, Industrial Cadets, Engineering Education Scheme (EES), Headstart, and The Year In Industry. Go4Set and EES offer activities for students in Key Stage 4 and 5, and connects them with companies to broaden the students' professional backgrounds. For example, EES links teams of four Year 12 students and their teacher with local companies to work on problems that the company may be facing (EDT, (b), n.d). As demonstrated, mentoring programs provide an important supplement to in-class STEM education and offer students an opportunity to learn employable skills outside of a classroom setting.

2.5 Application of STEM in Young Crossrail

Young Crossrail has endorsed many of the STEM education approaches. For example, WPI students were previously involved in a project to develop an effective learning experience for students in Key Stages 1-3 (Handel, Kim, Li, & Trumbley, 2014). From March into early May 2014, WPI students worked in association with the Young Crossrail Programme to promote a fun approach to learning about and pursuing careers in engineering. The team took a look at the big picture of Crossrail and engineering as a whole and then decided to hone in on a few key engineering disciplines: mechanical engineering, electrical engineering, and systems engineering. They developed individual activities associated with each of these engineering disciplines which were then made available to teachers and Young Crossrail ambassadors.The earlier project also determined that STEM education must be pursued while limiting both lectures and any requirements where students must quickly memorize a breadth of information. Additionally, the previous team recognized the positive impact that interactivity in classrooms has on students. These resources they developed based on this knowledge, however, are not currently often implemented in classrooms.

With Crossrail planning to finish construction and begin operations by 2018, Young Crossrail is attempting to provide assemblies, presentations, and exercises for the students that follow the construction project's remaining timeline. The main focus of the Crossrail project has now shifted to the fitting out of these tunnels and the renovation and building of stations. Accordingly, both of these types of efforts must be interwoven into the student activities offered by Young Crossrail in the coming months.

Our team was thus tasked with developing a multi-week academic program--for an older age group than the previous team--that incorporates engineering and other aspects of the current phase of the Crossrail project in conjunction with BIM concepts and awarding organization qualifications. BIM is a relatively new thought process and Crossrail is on the leading edge of BIM use in construction projects. BIM incorporates an expanse of technical knowledge and almost all aspects of engineering, construction, and their related careers. When incorporating BIM in our activities we hoped to focus on the collaborative and information management aspects of BIM so that the activities would be easy to understand and not require any particular software expertise. Also, incorporating awarding organization qualifications into our activities makes it easier and more likely for teachers to use the resources in the classroom, since the activities will correspond to what they are already teaching.

Chapter 3: Methodology

The goal of this project was to develop a multi-week academic program for Key Stage 4 (15-16 year old) and Key Stage 5 (16-19 year old) students focused on exploring different engineering topics, as well as important business and collaboration skills, relating to the Crossrail project. In addition, the program needed to include learning outcomes that comply with OCR (See Section 2.2.2) qualifications, from which we selected three: Creative iMedia Level 1/2, Engineering Design Level 1/2, and Employability Skills Level 2. This program will be used in classrooms and presented by teachers and Young Crossrail ambassadors. In order to develop the program appropriately, we established three main objectives.

- **Objective One:** Determine the design criteria for the development and implementation of a new academic program;
- **Objective Two:** Develop a preliminary engineering program curriculum; and
- **Objective Three:** Finalize the engineering program, supplemental documentation, and associated resources.

We determined necessary tasks for each of our objectives and then created a flowchart of our overall methodology process (See Figure 3).

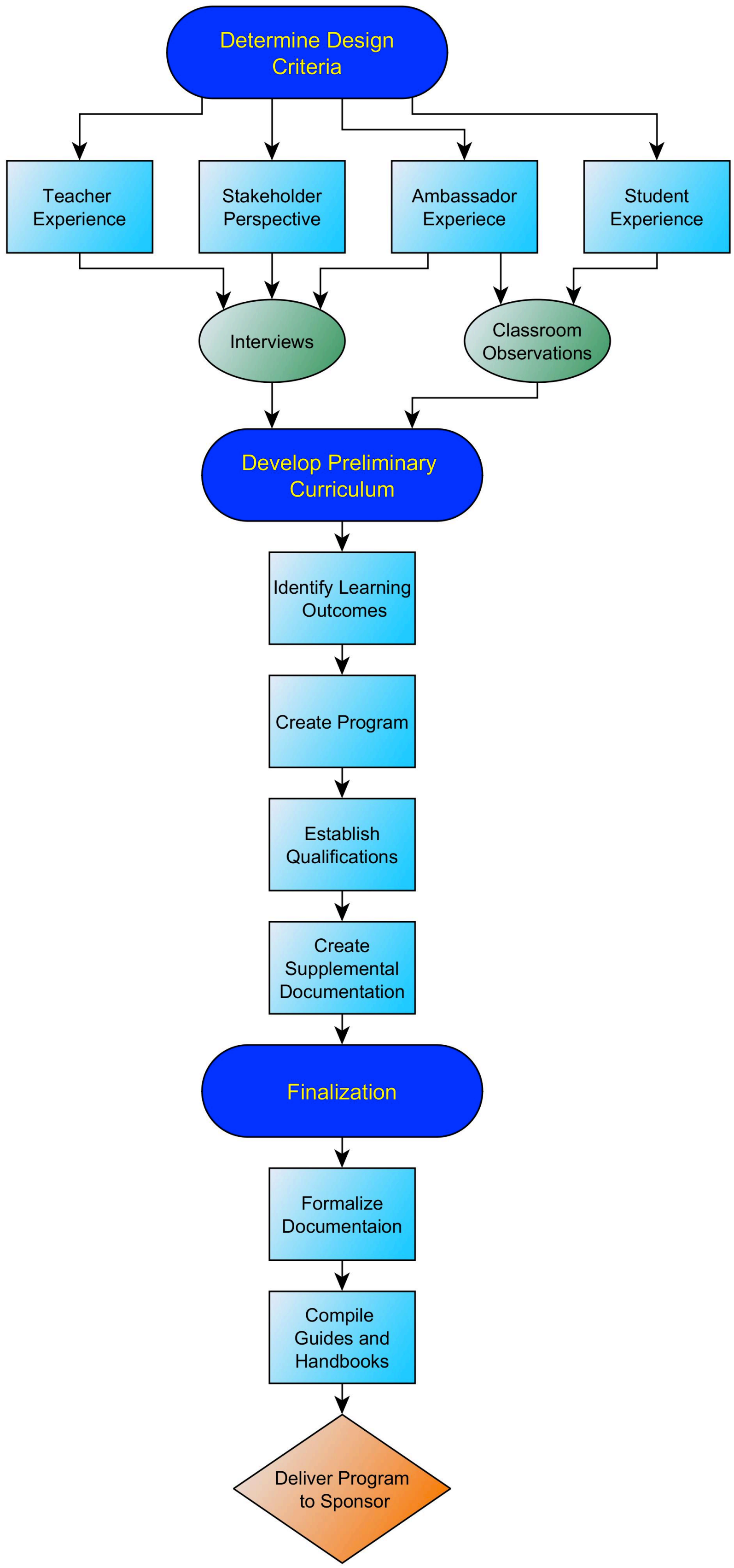


Figure 3: Methodology Flowchart

3.1 Objective 1: Determine Design Criteria

Our initial step in determining design criteria was carrying out research by observing student and ambassador interactions, observing student behavior in a classroom setting, and conducting interviews with key stakeholders in STEM education so we could develop a deeper understanding of STEM education methods and approaches (See Table 1). We also interviewed seven Young Crossrail ambassadors and one teacher, as they have the most exposure and experience with the students in the program and the schools' curriculum. We used the information gathered to assess the current wants and needs of the Young Crossrail staff, ambassadors, students, and teachers. These were used to identify desired learning objectives and outcomes of our program curriculum.

Interviewee	Organization	Date	Subject of Interview
Sue Songtgerath	WPI	18/2/2015	STEM Outreach
Chrys Demetry	WPI	20/2/2015	STEM Outreach
Martha Cyr	WPI	24/2/2015	STEM Outreach
Rebecca Roberts	Swanlea School	20/3/2015	UK STEM
Sebastian Bush	Crossrail	30/3/2015	Ambassador Experience
Yvonne Howard	Crossrail	30/3/2015	Ambassador Experience
Joseph Kanu	Crossrail	30/3/2015	Ambassador Experience
Kerry Bangle	Crossrail	31/3/2015	Ambassador Experience
Sonia Zahiroddiny	HS2	1/4/2015	BIM
Kevin McGeever	Network Rail	1/4/2015	BIM
Adam Usher	Crossrail	2/4/2015	Ambassador Experience
Karenza Tregoning	Crossrail	2/4/2015	Ambassador Experience
Parl Darlington	Crossrail	3/4/2015	Ambassador Experience
Alison Pearce	OCR	7/4/2015	OCR Qualifications

Table 1: Timetable of all interviews

3.1.1 Stakeholder Interviews

Throughout the research phase, which began in the United States and culminated in our first few weeks in London, we interviewed six stakeholders. During our initial research phase in the United States we identified three stakeholders whose experiences and knowledge of STEM education and STEM outreach programs would be valuable to the development of our academic program. Sue Sontgerath is the Coordinator of Pre-College Programs in the Admissions Office and serves as the program director for WPI's Frontiers, Launch, and Camp Reach summer programs. Chrys Demetry is the Director of the Morgan Teaching and Learning Center and is also the co-founder and program director of Camp Reach. Martha Cyr is the director of the STEM Education Center and works with teachers to better integrate STEM into their K-12 curriculums. By conducting interviews with these individuals, we gained valuable insight into effective methods of teaching STEM from people with experience in the field. All stakeholders were passionate about STEM education and dedicated to inspiring young people to enter STEM-based fields and their experiences and knowledge were invaluable to the development of our academic program.

We interviewed the remaining three stakeholders during the first half of the project at Crossrail. Sonia Zahiroddiny and Kevin McGeever both worked with BIM. Ms. Zahiroddiny worked in the Information Modelling & Management Capability Programme (IMMCP) Delivery Team at Transport for London and served as a "BIM Expert" in the Design Engineer and Construct GCSE. Mr. McGeever was a project director at Network Rail and had experience implementing BIM ideas into his work overseeing station designs. Both stakeholders were interested in the idea of educating young people about BIM concepts in order to help create the next generation of BIM workers. Ms. Zahiroddiny and Mr. McGeever provided great insight into how major infrastructure projects within London are currently utilizing BIM, as well as ways we could present this to students without being too "tech heavy." We also had an interview with Alison Pearce, the ICT Senior Specialist for OCR. She had a breadth of knowledge and experience working with the OCR qualifications and knew how to develop academic programs, activities, and workshops to help students achieve each qualification. Ms. Pearce was able to look over our learning outcomes and identify different qualifications to tailor our academic program to.

3.1.2 Ambassador Interviews

Young Crossrail ambassadors are Crossrail employees who volunteer to represent Crossrail at different educational outreach events. During our first couple of weeks in London, we interviewed several Young Crossrail ambassadors in order to gain a better understanding of the Young Crossrail Programme and to discuss their experiences with the students. The goal of each interview was to determine current presentation styles, evaluate student engagement in activities, and to receive feedback on possible areas of improvement that we could take into consideration while developing our new academic program.

Overall, we interviewed seven Young Crossrail ambassadors. By asking our project sponsor, Lauren Hiller, to identify Young Crossrail's most involved ambassadors, we were able to ensure that the interview candidates were knowledgeable about the Young Crossrail Programme and had first-hand experience working with London students. The interviews were semi-structured (Appendix A), and from them we received useful feedback that we were able to use when developing the academic program. Common themes that were mentioned in the interviews were:

Identifying ways to engage girls who might shy away from software or more technical topics;
Keeping the presentations short (approximately 10-20 min) to avoid student disengagement;
Remembering to cover the "so-what" factor when working with older students; and
Being mindful of ambassadors time/schedules. Potentially pairing ambassadors together to get the most professional exposure for students.

3.1.3 Teacher Interview

In our stakeholder interview with Sue Sontgerath, she mentioned that teachers are often bypassed when STEM programs are held. She suggested that we interview different teachers, so we could better understand their curriculum in order to tailor our activities to what the students are learning. We were also able to interview Rebecca Roberts, a science teacher from the Swanlea School. This was a semi-structured interview (Appendix B) which allowed us to tailor our conversations to her experiences from the classroom. She taught many of the A-Level science classes and had experience incorporating STEM activities into her curriculum. She was very excited about the potential for a new Crossrail affiliated academic program and was able to give feedback on how this type of program would be able to fit into a school's curriculum. We had planned to have another teacher interview at Elizabeth Garrett Anderson School, but due to a scheduling error, the meeting had to be cancelled at the last minute. It proved difficult to find teachers for us to interview because during the period of time in which we wished to conduct these interviews, the teacher were extremely busy reviewing material with students for the upcoming GCSE and A-Level examinations.

3.1.4 Student/Ambassador Observations

We had the opportunity to observe four different classes, as well as four Young Crossrail events, during the first half of the project. Maria Fidelis Catholic School hosted us for an observation day where we observed a Year 10 Science class, a Year 10 Design and Technology class, a Year 13 Linear Algebra class, and a Year 13 Chemistry class. When observing the classes, we positioned ourselves at good vantage points in the classroom to understand how students reacted to the subjects being taught and to gauge the students' attentiveness and engagement with the teacher. We also observed the teachers' delivery styles and how they interacted with the students.

We observed and worked with the students during four Young Crossrail events. During the Young Crossrail Tunneling Underground Construction Academy (TUCA) visit and House of Parliament Debate, we observed the students and how they interacted with each other and the Crossrail professionals. During our TUCA visit, we observed three students on the last day of their Crossrail internship. We were able to hear their perspectives on engineering and how working with Crossrail has affected what they wanted to pursue as a future career path. We also observed a debate between students from Young Crossrail partner schools at the House of Commons. Hearing students debate topics such as "apprenticeship is a better route to careers than University" and "gender quotas should be introduced in engineering" gave us insight on their attitudes towards technical careers and gender representation in engineering.

During the last two Young Crossrail events we attended, we not only observed students, but we also had the chance to work with them during activities. At the London City Airport Industry Day, each of us partnered with a group of five to seven students and served as an engineering expert for the day. The students completed a design-based challenge where they had to brand the Royal Docks as a center for innovation. This event gave us some valuable insight into the creative thought process of students when those students try to solve design-based challenges. During the Maria Fidelis Theme Day we helped groups of students complete an engineering design challenge with ambassadors from the multinational construction company Laing O'Rourke. This provided further insight into the students' creative thought process, in addition to demonstrating how they collaborated together and resolved conflicts that arose. We also experienced firsthand some of the difficulties that ambassadors can come across when interacting with students once the students' attention is lost. From these observations we could see how the students interact with ambassadors and how they respond when given an engineering activity.

3.2 Objective 2: Develop Educational Resources

The information that we gathered from objective one was used to create an engaging, age-appropriate, and open-ended project that teams of students would be able to complete in 10-12 weeks. We first established a set of learning outcomes for the program and then developed activities that would help students learn the important concepts that were required to work on their projects. Next, we brainstormed some possible ideas for the program. To ensure that the program incorporated the desired concepts, we took the learning outcomes and divided up the program so that each session was specifically tailored to a single set of learning outcomes. We also created the necessary supporting documents (student resources, worksheets, activity instructions, etc…) with the help of ambassador and teacher feedback to facilitate the delivery of the activities and the entire program.

3.2.1 Program Conception

Our program development began with our first meeting with our sponsors, where we were encouraged to move from developing individual activities for single class periods to developing a 10-12-week program that aligned with a vocational qualification. We were also encouraged to explore how engineering is structured in Crossrail, and were put in contact with Tahir Ahmad, a BIM technical expert for Crossrail.

Mr. Ahmad explained to us that BIM is a relatively new thought process that is increasingly being used in major construction projects like Crossrail. It focuses not only on the technical aspect of managing projects, but also on the business and collaboration side. Since BIM incorporates almost all aspects and careers associated with construction and engineering, we decided it would be a great way to engage students with a variety of career interests instead of just limiting the project to just a handful of engineering disciplines. We chose to consolidate the seven phases (See Figure 4) of BIM into five major ones to focus on: Concept/Brief, Design, Construction, Handover/Commission, and Operate and Maintain. We combined the Concept and Brief phases into one phase as both are essentially about initial planning. We also combined the Definition and Build & Commission phases into the Construction phase. Establishing these five major phases simplified the BIM process for us and made it easier for them to serve as the structure of our entire program.

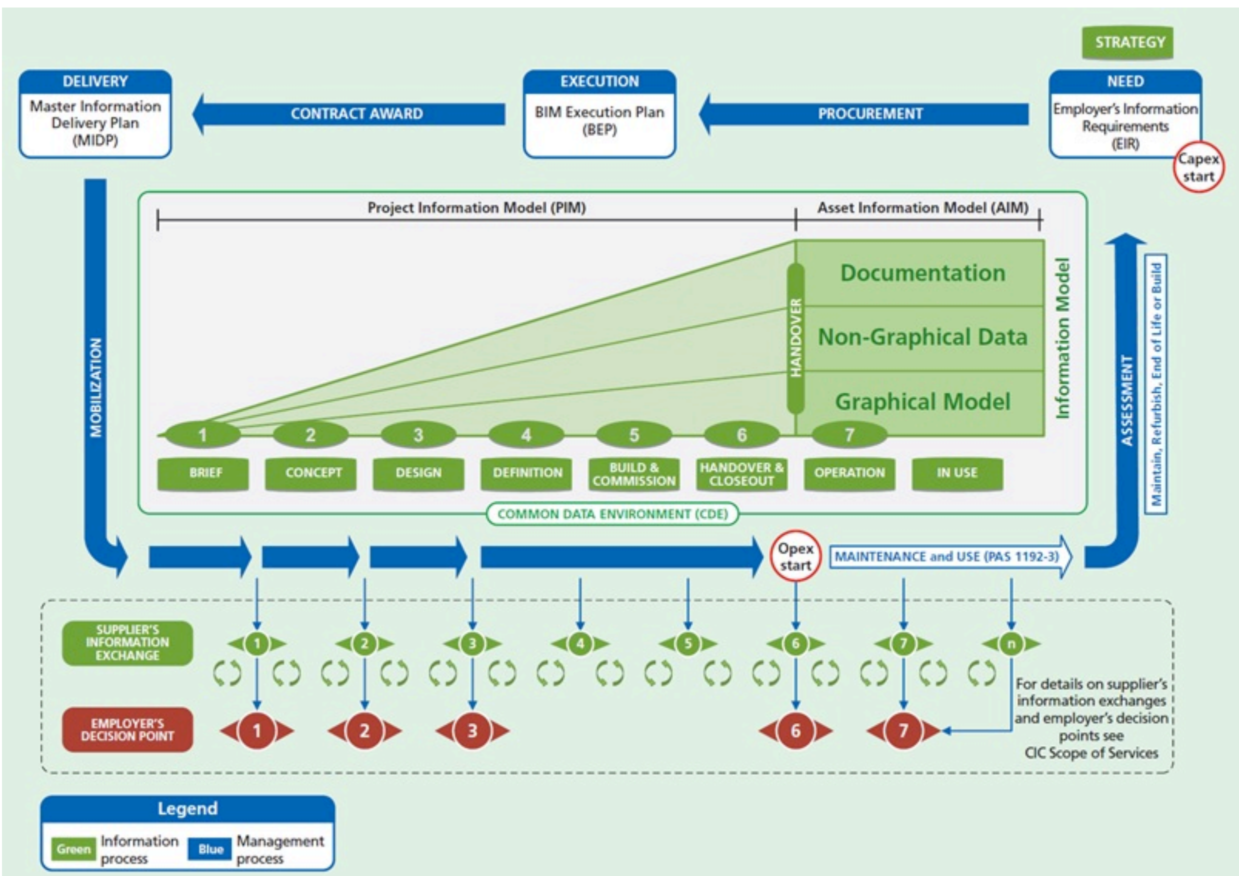


Figure 4: Information delivery cycle of BIM (The British Standards Institution, 2013)

Based on the advice of our sponsors, interviews with key stakeholders, discussions with Crossrail employees, and various ambassador interviews, we identified three initial design criteria:

- The program should have an open-ended design focus, with BIM as an underlying theme, to span the course of ten to twelve weeks.
- The program should adhere to a set of learning outcomes that closely relate to one or more vocational qualifications.
- The program work should be representative of work done within STEM-related careers.

With our design criteria established, we brainstormed a set of learning outcomes to serve as the skeleton of our program (Appendix C). We based these outcomes on aspects of the five BIM phases that we had selected and categorized them into five different modules, one for each BIM phase. Working under the assumption that the students would spend an hour a week on in-class sessions for this project, we decided that each module could span between 1-3 sessions depending on the number of outcomes and complexity of that module. Students could spend additional time working outside of class or the whole program could be done as an extracurricular activity depending on the schools and teachers using the program.

After establishing our learning outcomes and separating them into modules, we next decided on what tasks the students would complete for the program. After an interview with Young Crossrail Ambassador Kerry Bangle, who talked about modern railways in Korea where passengers can order groceries during their commute, we were inspired to theme our project around the "railway of tomorrow." The program has students design their own digital railway, wherein passengers could carry out parts of their daily routines, like doing their shopping or getting ready in the morning. Our aim was to keep the program design brief as open-ended as possible, but provide Crossrail case studies as context to inspire the students to explore how they could improve on London's newest rail. Students would be put into groups of four or five to complete this project, with team dynamics and individual roles being important to the structure of the program.

With our program theme roughly established, we moved our focus to tailoring our program to a Cambridge Nationals qualification. We initially believed that we would be tailoring the program towards the ICT qualification, which centers on data management. However, after reviewing our learning outcomes with Alison Pearce, the ICT curriculum coordinator at OCR, we were encouraged to tailor our program to three different qualifications simultaneously: Engineering Design, Creative iMedia, and Employability Skills. She suggested that we have two students in each group of four follow a “creative strand”, wherein they would be completing the Creative iMedia qualification and taking on more visual media roles in the project, and two students following an “engineering strand”, wherein they would be completing the Engineering Design qualification and taking on more engineering-oriented roles in the project. Both halves of each group would be working toward the Employability Skills qualification starting with a team building activity before the start of the program, and concluding with the final presentations and a debrief at the end of the program. A flowchart outlining how each qualification ties into our learning outcomes is shown below (Figure 5). The two different strands are colored red and purple for the engineering and creative strands respectively. The qualifications that correspond to each strand are listed in the rectangular boxes and shaded with the appropriate color. Qualification boxes that overlap both strands are colored both purple and red.

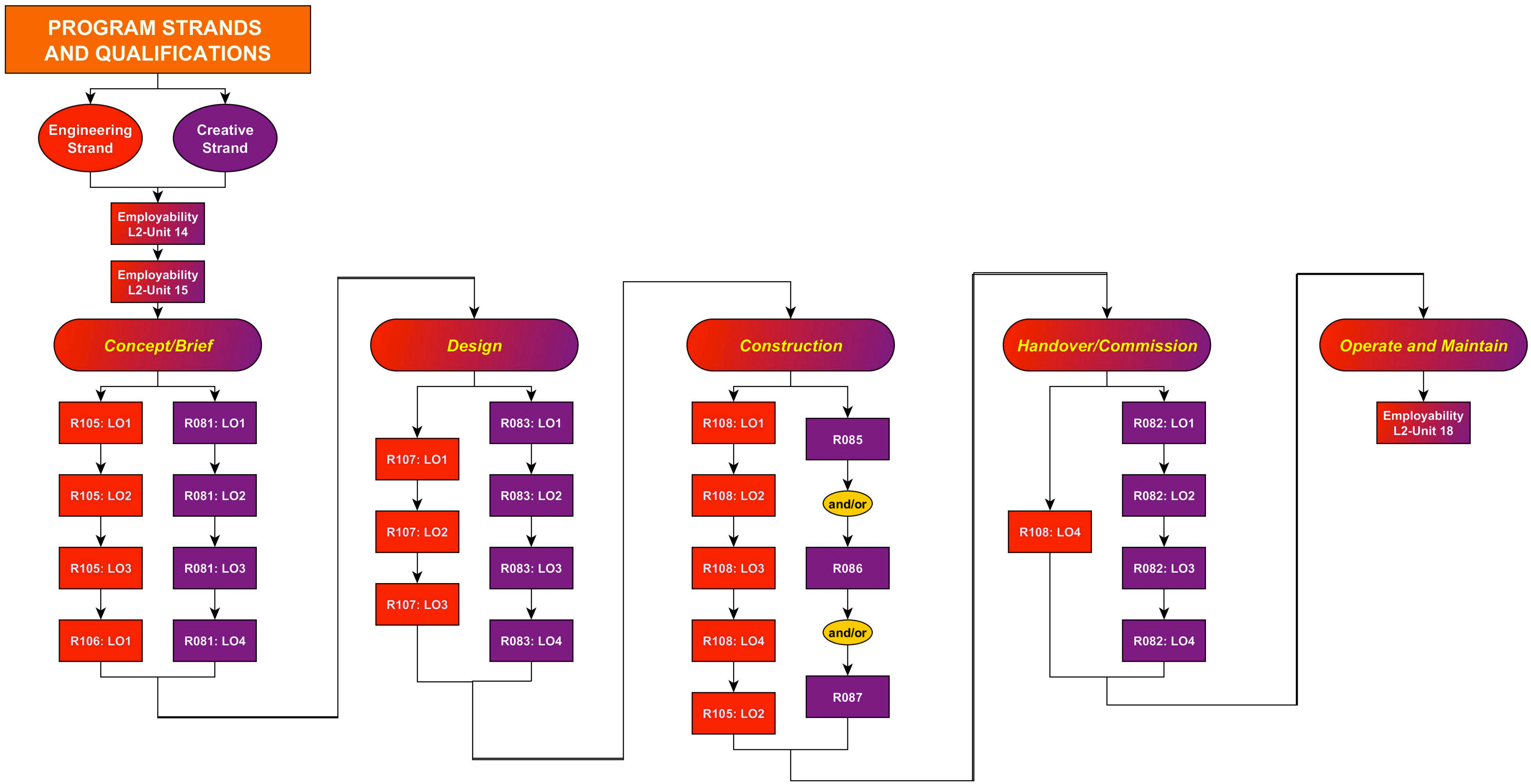


Figure 5: This is a flowchart of the program strands and qualifications.

3.2.2 Supplemental Documents

We created supplemental documents to help guide Young Crossrail students, ambassadors, and teachers throughout the program. The Student Resource Guide will be available for students to utilize throughout the program should they need examples or explanations on how to complete each part of the program. The handbook was purposely kept simple to maximize student creativity and minimize constraint. We also created the Mentor Handbook to educate ambassadors on how to be effective mentors and role-models. The Handbook included materials on their roles and responsibilities within the program, effective mentoring styles and approaches, and a program overview. Ambassadors will also be able to utilize the Teacher Delivery Handbook to review activities before they go into the classrooms and to gather the necessary student kits. Finally, we created the Teacher Delivery Handbook to help teachers facilitate the program. Each handbook contained the teacher's roles and responsibilities, a program overview, and an overview of each session's outcomes and objectives. A teacher should thus be able to take the Teacher Delivery Handbook and model their lesson plans around each module outline.

3.3 Objective 3: Finalize Suite of Educational Resources

We reviewed the deliverables with Ms. Hillier and Ms. Speed in order to get their feedback. It was important that Ms. Hillier and Ms. Speed reviewed our work to ensure that it satisfied the requirements initially prescribed by Young Crossrail. We also took this opportunity to explain the various program aspects to ensure they were comfortable putting this program into practice. Any problems with the various aspects of the program were corrected and then reexamined by Ms. Hillier and Ms. Speed until we received their approval. After all issues were resolved, the program was ready for use in the Young Crossrail Programme.

3.4 Summary

Breaking down the resource creation into three main steps (Research and Analysis, Program Development, and Finalization) has given us the opportunity to properly develop an impactful program curriculum for students. We obtained valuable and relevant information from the various key stakeholders, teachers, and ambassadors to determine our design criteria. Using these criteria, we chose to create a 10-12 week-long, open-ended program curriculum that incorporates multiple aspects of design, engineering, and construction associated with Crossrail. By doing this, the program is flexible and could be easily adapted by teachers based on their needs and available resources. The finalization of our curriculum resulted in the creation of a resource for instructors to implement our program and create associated lesson plans around it that tie back into what is currently taught in the classroom.

Chapter 4: Findings

We worked with four main stakeholders to develop this academic program: Young Crossrail staff, ambassadors, teachers, and students. Through our interviews and observations, we found that the stakeholders each emphasized different needs and criteria that could be used to structure our program (Table 2).

Stakeholder	**Emphasized Criteria**
Young Crossrail Staff	• Multi-week project • Corresponds to a qualification • Facilitated by teachers with some ambassador interaction • Related to the Crossrail project
Ambassador	• Flexible time commitments • Resources for student-engineer interaction
Teacher	• Easily incorporated into schools' curriculum • Adaptable to schools' available resources
Student	• Open-ended project to allow for creativity • Encourages collaborative side of BIM and engineering

Table 2: Stakeholder Program Criteria

The main findings can be seen in the table above which outlines the stakeholder requirements/criteria. We used these stakeholders' suggestions to determine the program structure, learning objectives, and supporting documents that this program requires. We spent three weeks defining these requirements/criteria before beginning program development.

4.1 Program Structure

From our interviews, observations, and interactions with our project sponsors we developed the following criteria for our academic program:

- 10-12-week program, with students and teachers meeting for one hour every week
- Project maps to one or more vocational qualifications
- Incorporates Crossrail concepts and corporate values

- Open-ended problem that engages students and encourages creativity and collaboration
- Encourages students (especially girls) to pursue engineering careers
- Adaptable to different schools' curriculum
- Teachers serve as the main program facilitator
- Ambassadors serve as mentors

During our interactions with Young Crossrail, our project sponsors emphasized that they wanted a long-term project that students could complete in conjunction with fulfilling a qualification (see Section 2.2.2 for more information regarding qualifications). By incorporating qualifications into the program, schools would have more incentive to run the program because students would be able to gain an award or certificate within a qualification which in turn could positively impact schools ratings. After creating our program learning outcomes, with the help of OCR Curriculum leader in ICT Ms. Pearce and Crossrail engineer Ms. Bangle, we were able to create a program that would allow for student teams to create their own *Digital Railway* while still completing units within the Engineering Design and Creative iMedia qualifications. Ms. Bangle introduced us to the idea of digital railways, which we then used to then use as a starting point for our academic program. Each subunit of a qualification has several learning outcomes. Matching the desired learning outcomes from our program to the learning outcomes from a qualification provided a convenient way to make our program adaptable to teachers' lesson plans. Ms. Pearce was able to identify two qualifications—Engineering Design and Creative iMedia— that students could potentially fulfill based on our learning outcomes.

Additionally our sponsors directed us to a program called Go4SET. Go4SET is a 10-week program that matches teams of pupils in England and Scotland with companies. The matched company then provides the student with a project to complete, a company mentor to help them, and a series of workshops to help them understand the problem and think of ways to approach it. After the 10 weeks, the students must then present their solutions to the companies and peers and are interviewed by a panel of STEM expert judges (EDT, 2014). The Go4SET program served as a loose inspiration for how we wanted our program to be put into practice. This is reflected in our program's 10-12-week duration, the team-based format, the role of teachers and ambassadors, and the learning outcomes that accompany each phase of the project.

This would allow students to have supervised time with a teacher, while encouraging teams to meet regularly outside their normal school hours.

Our project sponsors also emphasized that Crossrail concepts and values should be incorporated into the project. To do this, we incorporated Crossrail case studies into the program with the hope that students can draw inspiration from Crossrail and use that information when developing their own digital railways. These included how engineers and construction workers come together to solve a possibly detrimental issue if left unattended. For example, engineers had to design a way to monitor city buildings' movement during the tunnel construction. Students will have access to Crossrail ambassadors who will serve as mentors throughout the 10-12 weeks. Case studies expose students to the Crossrail project so they can gain a better understanding of what the project's current focus. We included the five Crossrail values—Safety, Inspiration, Respect, Collaboration, and Integrity—into each of the five modules to encourage students to live up to the Crossrail ideals (Crossrail Limited (f), n.d.).

Several ambassadors and other stakeholders supported the idea of having our program focus on Building Information Modeling (BIM), specifically on the collaboration side of BIM as opposed to the technical side. Through our conversation with BIM practitioners, we were able to gain a good understanding of BIM concepts and how students would benefit from learning this new concept. By doing more research on BIM, as well as being mindful of the focus on collaboration, we were able to create a program that was designed to encourage students to collaborate together in teams to complete their projects. Students will be able to collaborate with one and other in groups of four to complete their project, but will also have time to divide into groups of two to focus on their qualification-specific tasks within the project.

An important consideration that we tried to address was to have girls more actively engaged in the program. In our interviews with Ms. Sontgerath and Ms. Demetry, both pointed out that girls tend to be more engaged when they are doing things where they can see that they are having a clear positive impact. This contributed to our decision to make collaboration an overarching theme of the program. While this program was not designed to be specifically for girls, it is our hope that we can better engage female students by demonstrating how each person's work directly contributes to the completion of the digital railway.

During our interview with Ms. Roberts, she noted that her biggest concern about the program would be her ability to balance it with the curriculum. After conversations with our project sponsor, we decided that the teachers would be the main facilitators of this program due to the fact that the program incorporated complete qualifications. To make the program easier for teachers to deliver, we left modules relatively unstructured so that teachers could incorporate the different units into their current curricula. In order to make this process as straightforward as possible, we also created the *The Teacher Delivery Handbook*. This handbook provides teachers with the necessary guidance on how to facilitate this program within their classrooms.

After interviewing several ambassadors, however, we recognized we recognized that they have busy schedules and cannot be expected to attend a once-a-week class meeting for 10-12 weeks straight. Consequently, ambassadors will still be involved in the program, but in an auxiliary role where they will serve more as a resource and mentor for students rather than a facilitator. Ambassadors should be willing to attend some meetings with the students; yet, their main role is to be available via email or phone so they can link students to important resources.

4.2 Learning Outcomes

We realized early on that while we wanted clearly defined deliverables, we also wanted to leave the program broad enough so that teachers and students have maximum creative flexibility. Our solution was to place the emphasis on a set of learning outcomes for the students and allow the teacher delivering the program to develop the lesson structure and content to meet the specific learning outcomes. After our interview with Mr. McGeever (personal communication, 4/1/2015) , we decided that the fundamental theme of this program would be collaboration. As discussed above in Section 3.2.1, we developed our learning outcomes to follow the five phases of BIM on which our project is focused—Concept/Brief, Design, Construction, Handover/Commission, Operate and Maintain—and to encourage collaboration at all stages of the program. In addition, our talk with Ms. Pearce led us to three qualifications that aligned with our chosen learning outcomes. We further investigated the qualifications, and found that our current learning outcomes covered much of what was required to complete each qualification. Accordingly, we proceeded to map our learning outcomes to the qualifications (Appendix D) This gave us a map of how the students would complete the Cambridge Nationals and Vocational qualifications' learning outcomes with respect to our program.

While we managed to cover a large portion of each qualification in our program, there were inevitably some units and learning outcomes of the qualifications that we would be unable to capture, in part or at all, in the scope of the program. To address these units and outcomes, we developed several open-ended, activities to correspond with each of our program modules (Appendix E). These suggested activities can be used and modified by teachers to ensure that students are able to receive the full qualifications that our program covers.

We discovered while researching for our literature review that most teachers are unfamiliar with what engineers do (Chartered Institute for Securities and Investments, 2014). Ms. Roberts commented that while she came from an engineering background and tried to expose her students to engineering ideas, most students come into her class not knowing anything about engineering (personal communication, 4/7/2015). By focusing specifically on the learning outcomes instead of the learning methods, we have established a clear connection between engineering-related skills and topics that could be covered in the classroom. Furthermore, the two tracks in the program are representative of the different types of work needed to make a massive construction project like Crossrail happen.

4.3 Supporting Documents

In order for this program to be easy to understand and deliver, we developed supporting documents for the ambassadors, teachers, and students. Our project sponsors, Ms. Speed and Ms. Hillier, requested a handbook for teachers that explained how to deliver the program. Because teachers would be the main facilitators of this program, we created three separate documents: a Teacher Handbook, a Teacher Construction Guide, and an Engineering Overview Guide. Each guide serves as a tool for teachers to successfully deliver this program.

4.3.1 Teacher Handbook

Ms. Speed directed us to review the F1 in Schools Engineering Design project for inspiration during the development of our own teacher handbook. After reviewing this project we created our own teacher handbooks that included a program brief, the seven modules of the project, and suggested activities that could be completed during each module. Teachers can use this handbook as a foundation for how they will approach the *Build Your Own Digital Railway* project.

4.3.2 Construction Guide

In addition to the handbook, we created a teacher construction guide to aid teachers specifically during Module 2 and 3: the design and construction phases. This provides teachers with different methods of construction based off different limiting factors, such as price, availability, and difficulty. Through our interactions with our project sponsors, we realized that the program needed to be transferable between different schools. This construction guide allows teachers to determine what the best method of construction, whether it is with software or physical materials, their students can utilize during the project.

4.3.3 Student Resource Sheet

During our interview with Ms. Pearce, we discussed different types of student resources. She suggested we create a student resource sheet, as opposed to a student workbook. She advised that workbooks typically allow students to go through the motions of a project or activity without doing all the research or thinking because they will follow whatever the workbook instructs (personal communication, 4/7/2015). In order for our students to produce the most creative and innovative solutions to their project, we created a student resource sheet that included key websites and tools they can use throughout their project. This will give students some guidance without directly telling them how to complete the project.

4.3.4 Mentor Handbook

Our project sponsors also indicated that a mentor handbook would be a good resource for the Young Crossrail ambassadors. Although the ambassadors will not be the main facilitator of this project, they will still serve as a resource and mentor for the students. Mentor handbooks will include various resources on how to be an effective mentor and what their role is within the project. Mentor handbooks include a suite of resources that the mentor can share with the students if they are in need of extra research and data.

4.3.5 Engineering Overview Guide

It was also advised to create an engineering overview guide for teachers. This includes sections on what is STEM and what is engineering. This also defines a variety of type of engineering so teachers can inform students of the different professions that stem from engineering. There is also an overview on the different approaches to pursuing STEM and offers advice on how to teach STEM in the classroom. This guide is for teachers who are not familiar with STEM and engineering topics.

Chapter 5: Program Design

This chapter will clarify any generalizations within Chapter 4 and expound upon ambassador/mentor, teacher, and student-interaction with the program.

5.1 Teacher Experience (Teacher Delivery Handbook & Teacher STEM Resource Guide)

We have created a guide for teachers to effectively deliver the Engineering Design and Creative iMedia qualifications. It was designed to offer teachers a plan to teach students how the Engineering and Creative strands can link together during the project's five BIM-related phases defined previously (see Section 3.2.1). It also provides an understanding of how data exists as an asset and can be used in a collaborative setting. The guide has been broken down into multiple sections with a similar format for each section. After the guide's introduction about what skills students will be taught by the end of the project, the guide's objectives are defined. Teachers should refer to these objectives while developing a curriculum based on the guide. Following the introduction is a breakdown of the modules and the learning outcomes for the two Cambridge Nationals qualifications as well as the Employability Skills Vocational qualification. Teachers may have students attend two separate modules for students to acquire the third qualification. These modules will bookend the project and guide students to assess a team's weaknesses and strengths, assess members' skills and attributes, and identify skills that will be needed for the project.

The modules following the breakdown are all formatted in similar fashion to OCR's delivery guide for F1 in Schools (OCR, 2014). Teachers will be provided with a number of recommendations for session development for each module, as well as estimated time needed for the session. The modules are separated into two strands (Engineering Design and Creative iMedia) with the key concepts to be understood by module completion, listed for each strand. This includes tables with the assessment criteria, learning outcomes, and units from the strands' respective qualifications (See Figure 6, numbers 1 & 2).

Teachers must hold to these learning outcomes, so that the students can receive full credit for the units delivered in this guide. To do so, teachers may alter curricula they are already using to accommodate for these learning outcomes, or they could devise a new curriculum to successfully deliver the qualifications. During the curriculum planning, teachers will have a list of recommended practice review activities for the students to take part in (Figure 6, number 3). The activities have been designed to drive student engagement and inspiration for the *Digital Railway* project. Lastly, each module ends with a Crossrail design challenge task for the teams to execute (Figure 6, number 4). These tasks may be built on top of or in congruence with their final *Digital Railway* project. Teachers can use these tasks to create benchmarks or milestones for the student teams to meet.

During the delivery of this project, teachers will also have access to the *Teacher STEM Resource Guide* that offers insight on engineering--specifically the definition of engineering, different types of engineering, and how to appropriately address engineering-related questions. We have created this resource pack to combat common misconceptions that students have about engineering, as well as offer teachers a chance to become more knowledgeable in the field of engineering.

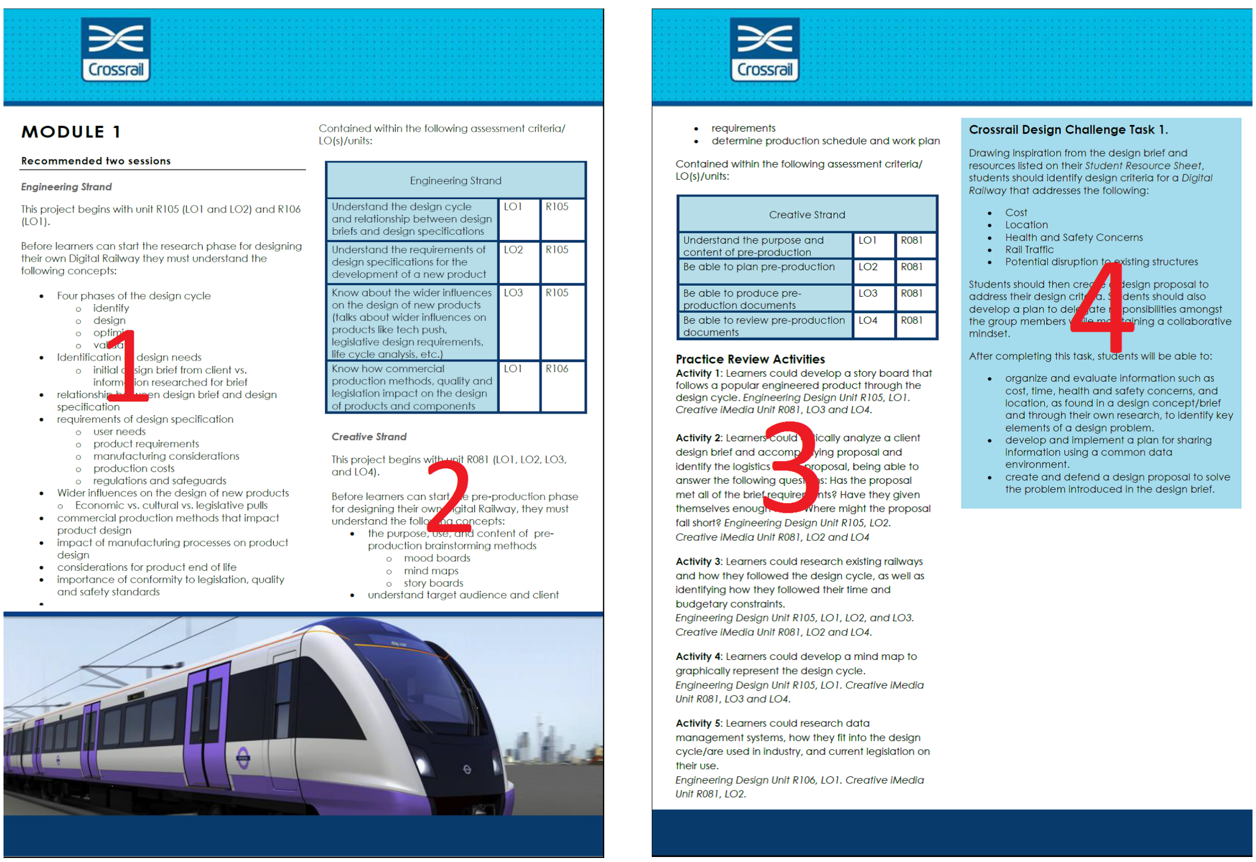


Figure 6. This is a breakdown of the Teacher Delivery Handbook.

5.2 Ambassador Experience (*Mentor Handbook*)

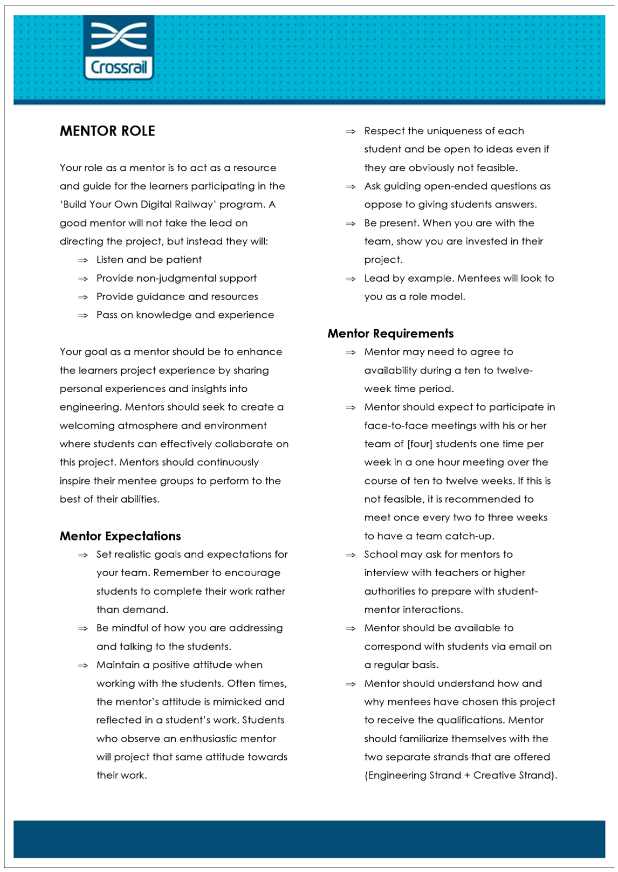
We created the *Mentor Handbook* to define in detail an ambassador's interactions with the program. The handbook was designed based on the *Elements of Effective Practice for Mentoring Checklist* by MENTOR: the National Mentoring Partnership, a United States-based program (MENTOR, 2012). We modified the checklist to reflect the requirements defined by the Young Crossrail staff and other stakeholders (see Table 2). The mentoring handbook consists of the following sections and subsections:

- Introduction
- Program Rules
- Mentor Role
  - Mentor Expectations
  - Mentor Requirements
- Relationship Development and Maintenance
- Mentor Challenges
  - Difficult Questions
  - Managing Behaviors
- Closure
- Support Material

Ambassadors will follow along through this handbook to learn how they can be useful assets to guide the students' and teams' success during the design and development of the project. After a brief on the *Digital Railway* project, the *Mentor Handbook*'s introduction provides insight on the recommended activities and events to take part in during the advancement of these students and their project. This includes weekly team meetings and career discussion. The goal of the *Mentor Handbook* is to present the benefits and outcomes mentors experience from participating in a mentoring program.

The Program Rules section details the project that the students will be attempting to complete, while receiving credit for each qualification. This section was created so that the mentors did not need to read the entire teacher guide to understand the *Digital Railway* project. Because mentors lack the time and knowledge of educating students, it is not necessary for mentors to read the *Teacher Delivery Handbook*, rather mentors are provided with abbreviated information that focuses on their specific role within the program. The handbook next presents in more detail what is expected of the mentor during the program. The Mentor Role section is necessary, so mentors do not fill their schedule before realizing the program's required and recommended time commitment (See Figure 7).

The last sections provides a guide for how a mentor's relationship with his/her mentee(s) will develop over the course of a project. In case the mentor is placed in an awkward situation, we have provided brief guides on responding to difficult questions and managing behavior. An appropriate send-off is also recommended at the project's close, so a mentor can offer any other help as a continual resource for the students. By utilizing the *Mentor Handbook*, mentors should be able to handle a team of four students that are working to design and build their *Digital Railway* concept.


Crossrail

MENTOR ROLE

Your role as a mentor is to act as a resource and guide for the learners participating in the 'Build Your Own Digital Railway' program. A good mentor will not take the lead on directing the project, but instead they will:

⇒ Listen and be patient
⇒ Provide non-judgmental support
⇒ Provide guidance and resources
⇒ Pass on knowledge and experience

Your goal as a mentor should be to enhance the learners project experience by sharing personal experiences and insights into engineering. Mentors should seek to create a welcoming atmosphere and environment where students can effectively collaborate on this project. Mentors should continuously inspire their mentee groups to perform to the best of their abilities.

Mentor Expectations

⇒ Set realistic goals and expectations for your team. Remember to encourage students to complete their work rather than demand.
⇒ Be mindful of how you are addressing and talking to the students.
⇒ Maintain a positive attitude when working with the students. Often times, the mentor's attitude is mimicked and reflected in a student's work. Students who observe an enthusiastic mentor will project that same attitude towards their work.
⇒ Respect the uniqueness of each student and be open to ideas even if they are obviously not feasible.
⇒ Ask guiding open-ended questions as oppose to giving students answers.
⇒ Be present. When you are with the team, show you are invested in their project.
⇒ Lead by example. Mentees will look to you as a role model.

Mentor Requirements

⇒ Mentor may need to agree to availability during a ten to twelve-week time period.
⇒ Mentor should expect to participate in face-to-face meetings with his or her team of [four] students one time per week in a one hour meeting over the course of ten to twelve weeks. If this is not feasible, it is recommended to meet once every two to three weeks to have a team catch-up.
⇒ School may ask for mentors to interview with teachers or higher authorities to prepare with student-mentor interactions.
⇒ Mentor should be available to correspond with students via email on a regular basis.
⇒ Mentor should understand how and why mentees have chosen this project to receive the qualifications. Mentor should familiarize themselves with the two separate strands that are offered (Engineering Strand + Creative Strand).

Figure 7. This is a breakdown of one part of the Mentor Handbook.

5.3 Student Experience (*Student Resource Guide*)

Students that take part in the *Digital Railway* project will have the chance to interact with engineering professionals while designing and constructing models of their transit system that helps travelers complete parts of their daily routine. Students will follow their teacher's project delivery and curriculum based on the guide that we have developed for the teachers. The final program session will include a presentation of a project that emphasizes collaboration and the five BIM phases. Students will not be handed program workbooks or worksheets at the beginning of the program, but will instead receive a resource pack. The *Student Resource Guide* briefs the student on the project and the pack's content. Within the pack is a list of video resources, case studies related to Crossrail and other rail projects, and STEM and transit websites for the students to peruse at their own leisure.

The *Student Resource Guide* is designed to inspire students and teams during the project design and development. Offering these real-world situations and resources for students to analyze will hopefully promote successful design and problem solving techniques. For example, students are directed to *The Fifteen Billion Pound Railway*, a documentary series following some of Crossrail's engineer and construction workers. It focuses on the design choices made when overcoming different challenges. During the project, these engineers came together as a unit to solve the issues, while assessing pertinent information they gathered in light of the situation. Because this pack has been created only as a foundation, there are no concrete solutions for all possible issues that may arise during the design and build of the *Digital Railway*. This means that teams will have to exercise effective collaborative techniques while sharing the information they find in this resource pack and then apply to it the project and activities appropriately.

5.4 Construction Guide

The *Construction Guide* provides teachers with recommendations on what different modes of construction the students can use to build their project model. The *Guide* gives a brief overview on using engineering BIM software, sandbox video games, building kits, and craft construction. Engineering software and sandbox games can be used to build virtual models, whereas building kits and craft construction can be used to create physical models. This range of construction modes allows teachers and students to be flexible with the project and tailor it to their needs based on what resources are available. As you can see in Table 3 below, each construction mode is compared across the categories of: learning curve, level of model complexity, cost range, and other requirements.

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.)

Table 3: Construction Choice Overview

We also created individual overviews for each type of construction mode, which includes a list of pros and cons. Furthermore, specific examples of usable software, sandbox games, construction kits, and crafts are provided in the respective overviews for each construction mode. These examples are compared against each other and offer teachers an understanding on some of the choices available. Table 4 shows some different options available for using engineering software with a brief description and cost comparison for each.

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.			

Table 4: Engineering software comparison

All software and video game examples also contain links to system requirements so that teachers can find out if their school computers can handle running particular programs. Similar tables are used to compare different options for the other modes of construction.

Lastly, recommendations are included in each mode that highlight which of the given examples is generally the best or easiest to use. Teachers are encouraged, however, to figure out which one would work best for them and the students based on their knowledge, expertise, and available resources. Other recommendations, resources, and ideas are included for how best to implement the given construction mode in the classroom.

5.5 Lesson Plans

Each of the modules for the *Build Your Own Digital Railway Programme* were designed to reflect the open-endedness of the design brief. By offering these modules as guidelines for teachers, they may be able to map them to pre-existing curriculums. Below is a summary of each of the module's main goals and objectives.

5.5.1 Module 0: Employability Pre-Session

The zeroth module in the *Teacher Delivery Handbook* covers the optional employability pre-session. Unlike the main modules, the Employability Pre-Session is not split into an Engineering and a Design Strand. Students will learn how to make responsible career and financial decisions. The specific concepts covered include: the relationship between skill set, personal attributes, career, and success in that career; the evaluation of one's own skill set and personal attributes to make informed career choices; skill set development; the purpose of financial documents; budgeting; debt and credit.

5.5.2 Module 1: Concept/Brief

The first module in the *Teacher Delivery Handbook* is about the Concept/Brief stage (colored red in Appendix D). Module 1 mostly touches upon the background research objectives. For the Engineering Strand, concepts covered include the design cycle, identifying design needs, design specifications, outside influences on design, the effects of commercial production method that impact product design, the impact of manufacturing processes on product design, product lifespan considerations, and quality and safety standards. For the Creative Strand, concepts covered include understanding the purpose of pre-production brainstorming methods, target audience and client requirements, and production schedule and work plan. After this, students would develop basic concept for their digital railway.

5.5.3 Module 2: Design

Module 2 focuses on design and design techniques (colored green in Appendix D). For the Engineering Strand, concepts covered include hand drawn design techniques, techniques to produce technical drawings, CAD and its applications, and communicating design proposals. For the Creative Strand, concepts covered include learning how to create 2D and 3D digital characters, knowing when to use them, and interpreting clients requirements for digital characters. After going over all of these concepts, students would then develop with their own design

5.5.4 Module 3: Construction

Construction is covered in Module 3 (colored purple in Appendix D). For the Engineering Strand, concepts covered include consideration when building a prototype, how to identify safety risks and come up with possible precautions, building a prototype using the appropriate tools and methods, and learning how to evaluate the performance of a prototype. For the Creative Strand, concepts covered include pre-production brainstorming methods, target audience and client requirements, and production schedule and work plan.

5.5.5 Module 4: Handover/Commission

Module 4 focuses on the Handover/Commission of the students' digital railway (colored blue in Appendix D). For the Engineering Strand, concepts covered include learning how to evaluate the performance of a prototype as well as one's own performance. For the Creative Strand, concepts covered include the purpose, properties, and creation of digital graphics.

5.5.6 Module 5: Operate and Maintain

The final module covers operation and maintenance (colored orange in Appendix D). For both the Engineering Strand and the Creative Strand, students will create and deliver a presentation on their final result and explain how the railway will be operated and maintained, as well as how users will interact with the railway's features.

5.5.7 Module 00: Employability Post-Session

The Employability Post-Session module is an extension of the optional Employability Pre-Session module. Like the zeroth module, the post-session module is not divided into an Engineering and Creative Strand. The Employability Post-Session will have students reflect on their roles while building their *Digital Railway* and compare those to real world careers. The concepts covered include planning for specific work placement, the importance of professional behavior, and independent completion of tasks during work placement, and assessing one's own performance during work placement.

Chapter 6: Conclusions & Recommendations

6.1 Project Recap and Conclusions

The Digital Railway Project is an open-ended 10-12-week program in which students will work in teams of four to plan, design, construct, and present what their ideal future railway would be like. The program contains five main modules centered around collaboration and business aspects of the five key phases of Building Information Management (BIM): Concept/Brief, Design, Construction, Handover/Commission, and Operation & Maintenance. There are also two additional modules (before and after the program) that focus on employability skills. The program will be delivered by teachers and, as such, it incorporates different OCR qualifications that students can complete. Qualifications are split into an engineering strand that satisfies Engineering Design Units and a creative strand that satisfies Creative iMedia Units. Students choose which strand they want to pursue and then collaborate with team members of the other strand to create deliverables for their project. Ambassadors are volunteers that act as a resource and mentor for students to answer questions at different sessions and provide guidance and expertise.

We concluded that an open-ended program tied to curriculum requirements and learning outcomes is preferred to pre-defined activities because many schools have time, resource, and other constraints that would deter them from implementing a stand-alone activity in the classroom. Leaving the program open-ended allows teachers to tailor the project to fit their needs and the resources that they have available. Tying in curriculum requirements and qualifications also makes it easier for teachers to work the project into their already established curriculum. We decided that a 10-12-week program was ideal because it mirrors already existing projects like GO4SET and F1 in Schools. The 10-12 week project length is not a definitive requirement; it is recommended based on our findings, but can be adapted by teachers to fit their curricula. The recommended program length however, allows enough time for students to fully realize and develop their ideas without rushing through a short-term project. Additionally, students are able to continuously build on the things they learn as the project progresses instead of learning relatively unrelated information from only a few activities. Since we have five main modules in our project, we estimate the program will take on average two sessions, with one session per week, per module. Some modules should only take one session to complete, while others will take more, but having ten weeks to teach all five modules became a reasonable timeframe. The additional two weeks are designated for the two employability modules, each lasting one session and recommended as bookends- one before, one after- to the project.

Our discussions with stakeholders revealed that teachers should be the primary people delivering the program, with ambassadors serving as supporting resources. The program is meant to tie qualifications to what is already being taught in the classroom, in order to build on the teachers' expertise. Ambassadors do not have have the training to teach content to the students. Instead, they are generally better at and more comfortable with answering student questions and sharing their expertise, thus becoming a resource for students. Ambassadors are volunteers with time commitments outside of the Young Crossrail Programme, so they may not be able to make it to every session. Having flexible commitments and pairing up ambassadors for each classroom, in case one is unable to show up on a given date, makes it easier for ambassadors to stay involved as mentors without putting pressure on them to teach and spend additional time preparing materials. There are a few drawbacks to pairing ambassadors. One may wind up putting more work in than the other or otherwise skip most of the sessions since they think that the other ambassador will be there anyways. If ambassadors are not at the same sessions and do not communicate with each other, then they can wind up giving conflicting information to students regarding the project. These issues can, however, be avoided through proper mentor training and having open communication between ambassadors as well as teachers.

Through centering our project around BIM, we have determined that teaching engineering concepts and business collaboration skills to students is more important than focusing on teaching them how to use any particular software. There are two sides to BIM, that we are using as the layout for our project. The first side is the technology aspect which strongly focuses a lot on data and asset creation and management using software and databases. The other side is the business and collaboration aspect which focuses more on communication and working together effectively to complete tasks using this data. As mentioned previously, schools have different resources and constraints, so they might not be able to use engineering software. Focusing on the collaboration side of BIM teaches students valuable skills that are transferable, in addition to making the program accessible to more schools. The flexibility of the program still allows schools to teach engineering software if they wish.

Based on our observations and interviews, we established our program to break into two different strands- engineering and creative- to make the program appeal to a wider range of students. Offering two different options gives students the choice to pursue whichever one interests them. All students learn about engineering, collaboration, business skills, and other concepts, but the strand they choose will determine which side of the project they will work.

This whole project has taken into account the criteria that we determined from our findings and conclusions. To warrant successful delivery and legacy of the program, we have created a series of recommendations and improvements that can be carried out.

6.2 Future Program Changes and Recommendations

Due to the dedicated time for this project and length of the program we created, we were unable to test it in with schools or solicit feedback from testing for further improvements. Thus, we created a list of recommendations for Young Crossrail to carry out regarding the program we have created. These recommendations will help ensure that the program is implemented seamlessly and further developed to promote its widespread use and continued legacy. Most of these recommendations apply to TfL as well, since they will be taking over many of Young Crossrail's outreach commitments upon Crossrail's completion and handover to TfL. Collaboration between TfL and Young Crossrail would be beneficial in carrying out these recommendations to ensure a smooth transition of the program between organizations.

Our recommendations include: doing a pilot test of the program with schools, creating an information hub website, developing an additional hand-off program, having students showcase their projects at events, hosting teacher orientation sessions, and assigning a mentor or mentors to every student team.

6.2.1 Pilot Program with Schools

Since there may be unforeseen problems during implementation of the program, it should be tested out first before large-scale implementation. Young Crossrail could do a pilot test of the program with some of their partner schools to solicit feedback from teachers, students, and ambassadors. This feedback would be used to evaluate and refine the program. A test period would reveal any potential misunderstandings of the documentation, or reveal other necessary tweaks that the program might need to run more smoothly. If only a few schools take part in the test phase of the program, then there will be fewer people to notify regarding changes and problems should be more easily addressed. We suggest rolling out the entire project in a large-scale implementation after the supplemental documentation has been updated and the program is refined based on the pilot schools' feedback.

6.2.2 Documentation Updating Guide

Creating a guide that goes over how to properly update all of the supplemental documentation would be helpful since many of the handbooks contain hyperlinks and information that could change or become outdated. If qualification requirements or learning objectives change, then some of the learning outcomes in the teacher handbook will need alterations. Several items are cross-referenced in the guides, so there may be confusion if all of the documents are not being simultaneously updated.

This documentation updating guide could map out what pages or sections need to be checked and edited. A checklist for each document would also be helpful in the guide so that it is easier to keep everything up to date and not skip over important alterations.

6.2.3 Information Hub Website

The creation of an information hub that serves as common database for all students would be an extremely useful addition to the program. We suggest that Young Crossrail, in association with TfL, creates a website that contains a variety of resources and supplemental materials for students, including information from videos, case studies, articles, and other resources. The website could also be used as a communication forum for students, teachers, and ambassadors, through formal chat, messaging services, or discussion boards. Communication resources, like a website, could help keep mentors in contact with students in case teams are in search of additional resources or project guidance.

The website could also be used by student teams to track and present the progress on their projects during the delivery of the program. Upon completion, student teams could upload their deliverables to share them with the whole project community. This would help inspire future program participants by letting them see what other students their age were able to accomplish by participating in the program.

Creation of the website would initially take a great deal of resources to get it up and running. Additionally, a dedicated person who manages the website, along with forum moderators, may also be required. With the investment of these resources, the information hub can become the central place for students to gain knowledge and collaborate on the project.

6.2.4 Project Hand-off Program

As a follow up to the information hub website, a new program could be created that involves past team projects. This program would entail past projects being handed off to new student teams who would be tasked with creating innovative solutions to any problems that the past teams may have encountered.

Most project learning outcomes would end up being the same, but they would focus on modifying a project completed previously instead of creating a new one from scratch. The noteworthy part about this project is that it would test how well BIM has been used in both programs. Information created by previous teams should be easily understood by all parties that are going to come in contact with it. New teams should be able to work with that information to solve issues with or improve the previous team's final product. Collaboration will still exist as the most important factor during the project's execution as well.

The creation of this new program could potentially be set up by Crossrail or TfL for development as a future IQP for WPI students. Having an IQP team develop this new program would allow them to build off of the research and materials we have already created.

6.2.5 Project Showcase Events

If this program becomes popular and is able to gain interest from many businesses and schools, it may be beneficial to bring the program to Skills Shows or a similar event where teams can submit and present their final work. This would be an effective way for students, teachers, and schools to gain recognition for their achievements. It would also promote the program to even more schools so that they can implement it in their respective curricula and have students showcase projects at the Skills Show the following year. Ideally, every year there would be an increasing number of students and schools that would use the program and present at the Skills Show.

At the event, Crossrail or TfL could have judges score projects and present awards in different categories to teams. Making the program competitive and giving out awards would further encourage students to put more time in and get more out of the program.

6.2.6 Teacher Briefing and Orientation Sessions

Once there are more teachers and schools using the program, it might be helpful to have a briefing and orientation for all teachers who plan on implementing the program in their classrooms. The orientation could address how to effectively teach the program for the engineering and creative strands as well as explaining to teachers what all of the documentation is for and how best to use it.

Crossrail or TfL could host the briefings and have teachers who have already used the program in their classroom lead the orientation and give their feedback about the value the program and how to implement it efficiently and effectively. Ambassadors who have had experience as mentors for the program could also add their knowledge to the orientation, giving teachers useful advice on how to work with the ambassadors and use them as a resource.

6.2.7 Ambassador Team Mentors

If this program picks up interest from many different schools and starts developing into something much larger, more outside companies and individuals may be interested in participating in various ways. If engineers are already eager to talk to students in schools about their profession, the program can try to bring on as many volunteers as possible. Engineering ambassadors might each be able to represent a team and act as a team mentor. With one designated mentor per team, students would be able to get more individual help and the time commitment for each ambassador would be lessened since they are only helping a single team.

With a high number of mentors and ambassadors, it would be helpful to have orientation and briefing sessions for ambassadors similar to the teacher ones, as mentioned earlier. This would ensure that all ambassadors and mentors are aware of the responsibilities and commitments for volunteering in the program and it would provide information on how best to interact with students.

6.3 Closing Words

In the 14 weeks that we spent on this project, we identified the key criteria in successful STEM education programs and used that knowledge to develop a complete educational program along with all of the supporting materials. Due to the time constraints inherent to the IQP, we did not have the opportunity to put this program to practice. Young Crossrail is planning to implement the *Build Your Own Digital Railway Programme* during the 2015-16 academic year. If successful, this program may be further rolled out into schools and serve as a lasting legacy to the Young Crossrail Programme after Crossrail is handed over to Transport for London.

References

Anderson, S., Jett, M., Tenenbaum, L., Yourick, D. (2014.) An innovative near-peer mentoring model for undergraduate and secondary students: STEM focus. *Innovative Higher Education, 35* (5), 375-385. Retrieved from http://link.springer.com.ezproxy.wpi.edu/article/10.1007%2Fs10755-014-9286-3#

Apedoe, Reynolds, Ellefson, & Schunn. (2008). Bringing engineering design into high school science classrooms: The heating/cooling unit. *Journal of Science Education and Technology, 17*(5), 454-465. Retrieved from http://link.springer.com/10.1007/s10956-008-9114-6http://www.springerlink.com/index/pdf/10.1007/s10956-008-9114-6

Bailey, C. P., Minderhout, V., & Loertscher, J. (2012). Learning transferable skills in large lecture halls: Implementing a POGIL approach in biochemistry. *Biochemistry and Molecular Biology Education,40*(1) Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/bmb.20556/epdf

Barnard, S., Hassan, T., Bagilhole, B., & Dainty, A. (2012). 'They're not girly girls': An exploration of quantitative and qualitative data on engineering and gender in higher education. *European Journal of Engineering Education, 37*(2), 193.

Barthlow, M. J., & Watson, S. B. (2014). The Effectiveness of Process-Oriented Guided Inquiry Learning to Reduce Alternative Conceptions in Secondary Chemistry. *School Science and Mathematics*, *114*(5), 246-255.

Becvar, J. E., Saupe, G. B., Noveron, J., & Narayan, M. Plus Two Peer-Led Team Learning for Large Introductory STEM Classes: Improved Study Skills, Increased Retention, and Higher Graduation Rates.

British Government. (n.d). The national curriculum. Retrieved March 30, 2015, from https://www.gov.uk/national-curriculum/key-stage-3-and-4

The British Standards Institution. (2013) PAS 1192-2:2013 Specification for information management for the capital/delivery phase of construction projects using building information modelling.

Browne, J. (2012, February 28). Viewpoint: UK economic future 'depends on engineers' Retrieved April 9, 2015, from http://www.bbc.com/news/science-environment-17192460

Brown, S. D. (2010). A Process-Oriented Guided Inquiry Approach to Teaching Medicinal Chemistry. *American Journal of Pharmaceutical Education*, *74*(7), 121.

Chartered Institute for Securities and Investments (2014). Parents, Teachers and Young People's Attitudes to Financial Services. Retrieved April 14, 2015, from http://www.cisi.org/bookmark/genericform.aspx?form=29848780&URL=91652952#

Chen, S., & Luoh, M. (2010). Are mathematics and science test scores good indicators of labor-force quality? *Social Indicators Research, 96*(1), 11. Retrieved from http://www.jstor.org/stable/40649321?seq=1#page_scan_tab_contents

Confederation of British Industry and Pearson (2014). *Gateway to growth CBI/Pearson Education and Skills Survey*. 63. Retrieved from http://www.cbi.org.uk/media/2807987/gateway-to-growth.pdf

Cooper, Harris., DuBois, David L., Holloway, Bruce., Valentine, Jeffrey. (2002.) Effectiveness of Mentoring Programs for Youth: A Meta-Analytic Review. American Journal of Community Psychology, 30(2), 157-197. Retrieved from http://dx.doi.org/10.1023/A%3A1014628810714.

Crossrail Limited (a, n.d). Crossrail – from its early beginnings. Retrieved January 19, 2015, from http://www.crossrail.co.uk/route/crossrail-from-its-early-beginnings

Crossrail Limited. (b, n.d). Meet our giant tunnelling machines. Retrieved January 26, 2015, from http://www.crossrail.co.uk/construction/tunnelling/meet-our-giant-tunnelling-machines/

Crossrail Limited (c, n.d.) Moving you forward: the crossrail apprenticeship programme. Retrieved February 4, 2015, from http://www.crossrail.co.uk/careers/apprenticeship-programme/

Crossrail Limited. (d, n.d). Crossrail community investment programme - supporting local communities. Retrieved January 26, 2015, from http://www.crossrail.co.uk/benefits/supporting-local-communities/

Crossrail Limited (e, n.d) Young Crossrail. Retrieved February 4, 2015, from http://www.crossrail.co.uk/careers/young-crossrail/

Crossrail Limited. (f, n.d.) Retrieved April 20, 2015, from http://www.crossrail.co.uk/careers/working-for-crossrail/our-purpose-and-values

Crossrail Limited. (2011, July). Crossrail Business Case Update: Summary Report. Retrieved January 19, 2015, from http://www.crossrail.co.uk/benefits/wider-economic-benefits/

Crossrail Limited. (2014, July 31). Teach first conference. Retrieved February 4, 2015, from http://www.crossrail.co.uk/careers/young-crossrail/latest-news

Crossrail Limited. (2014, November). Crossrail in numbers. Retrieved January 29, 2015, from http://www.crossrail.co.uk/benefits/crossrail-in-numbers

Crossrail Regional Map [Image] (n.d.) Retrieved Janurary 29, 2015, from http://www.crossrail.co.uk/route/maps/regional-map

Crossrail Partner School Map [Image] (n.d.) Retrieved February 15, 2015, from http://www.crossrail.co.uk/careers/young-crossrail/find-out-more-about-our-partner-schools

Committee on Highly Successful Schools or Programs in K-12 STEM Education. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics* Washington, DC: National Academies Press.

Darnell, A., Becvar, J., Flores, B., Knaust, H., Lopez, J., & Tinajero, J. (2012, May). Achieving Student Success Using Peer-Led Team Learning (PLTL). In *Proceedings of the Inaugural Conference*.

Eberlein, Kampmeier, Minderhout, Moog, Platt, Varma-Nelson, & White. (2008). Pedagogies of engagement in science. *Biochemistry and Molecular Biology Education, 36*(4), 262-273. Retrieved from
http://onlinelibrary.wiley.com/doi/10.1002/bmb.20204/abstract

EDT. (a, n.d). About edt. Retrieved March 30, 2015, from http://www.etrust.org.uk/about-edt

EDT. (b, n.d). About EES. Retrieved March 30, 2015, from http://www.etrust.org.uk/node/75

EDT. (2014). Information for Schools. Retrieved April 17, 2015, from
http://www.etrust.org.uk/go4set/information-schools

Elliott, K. R. F. (1997). Science education in the United Kingdom. *Frontiers (Carlisle), 3*(2), 43-50.

Farrell, J. J., Moog, R. S., & Spencer, J. N. (1999). A guided inquiry general chemistry course. *Journal of Chemical Education, 76*(4), 540-544. Retrieved from
http://pubs.acs.org.ezproxy.wpi.edu/doi/pdf/10.1021/ed076p570

FIRST (2014 , January 9). Inventor dean kamen urges members of congress to close innovation deficit. Retrieved February 4, 2015 from
http://www.usfirst.org/aboutus/inventor-dean-kamen-urges-members-of-congress-to-close-innovation-deficit

Fortus, D., Krajcik, J., Dershimer, R. C., Marx, R. W., & Mamlok-Naaman, R. (2005). Design-based science and real-world problem-solving. *International Journal of Science Education, 27*(7), 855-879. Retrieved from
http://www.tandfonline.com/doi/pdf/10.1080/09500690500038165

Freeman, B., Marginson, S., & Tytler, R. (2015). *Age of STEM: Educational policy and practice across the world in science, technology, engineering, and mathematics.* New York: Routledge.
http://worldpopulationreview.com/world-cities/london-population/

Geiger, M. (2010). Implementing POGIL in allied health chemistry courses: Insights from process education. *International Journal of Process Education, 2*(1), 19-34. Retrieved from
http://www.processeducation.org/ijpe/2010/pogilh.pdf

Greater London Authority. (n.d). The mayor's London plan. Retrieved January 19, 2015, from http://www.london.gov.uk/shaping-london/london-plan/facts/

Greater London Authority. (2013). Population And Employment Projections to Support the London Infrastructure Plan 2050. Retrieved April 8, 2015, from https://www.london.gov.uk/sites/default/files/Population%20and%20employment%20projections%20to%20support%20the%20London%20Infrastructure%20Plan%202050.pdf

Handel, R., Kim, K. Y., Li, E., & Trumbley, A. (2014). *Developing Educational Resources for Young Crossrail*.

Harrison, M. (2012). Jobs and growth: the importance of engineering skills to the UK economy. Retrieved February 15, 2015, from http://www.raeng.org.uk/publications/reports/jobs-and-growth

Harrison, M. (2011). Respected - Technical qualifications selected for use in University Technical Colleges. Retrieved March 30, 2015, from http://www.edge.co.uk/media/73505/respected_hires_29.9.11.pdf

Knight, J. K., & Wood, W. B. (2005) Teaching More by Lecturing Less. Cell Biology Education, 4(4), 298-310.

Kuenzi, J. J. (2008). Science, Technology, Engineering, and Mathematics (STEM) Education Background, Federal Policy, and Legislative Action. *Congressional Research Service*. (http://fas.org/sgp/crs/misc/RL33434.pdf)

Lord Sainsbury of Turville. (2007). The race to the top: a review of government's science and innovation policies. Retrieved February 15, 2015, from http://www.rsc.org/images/sainsbury_review051007_tcm18-103118.pdf

MENTOR. (2012). Elements of Effective Practice for Mentoring. Retrieved April 16, 2015, from http://www.mentoring.org/downloads/mentoring_1222.pdf

Metropolitan Council. (n.d) Public involvement. Retrieved February 15, 2015, from, http://metrocouncil.org/Transportation/Projects/Current-Projects/Southwest-LRT/Public-Involvement.aspx

Nadelson, L., & Callahan, J. (2011). A Comparison of Two Engineering Outreach Programs for Adolescents. *Journal of STEM Education: Innovation and Outreach*. *12*(1-2), 25-36.

National STEM Centre. (2011). Evaluating STEM initiatives. National STEM Centre. Retrieved from www.nationalstemcentre.org.uk

OCR. (2014). Cambridge Nationals in Engineering: A Project Approach to Delivery - F1 in Schools. Retrieved April 8, 2015, from http://www.ocr.org.uk/Images/174434-units-r105-r108-f1-in-schools-project-approach.pdf

Overman, S. (n.d.). Fighting the Stress of Teaching to the Test. Retrieved March 30, 2015, from http://www.nea.org/tools/fighting-stress-teaching-to-Test.html

Parliamentary Office of Science and Technology. (2013). Stem education for 14 to 19 year olds. Retrieved from http://www.parliament.uk/business/publications/research/briefing-papers/POST-PN-430/stem-education-for-1419-year-olds

PCAST (President's Council of Advisors on Science and Technology). (2010). Prepare and inspire: K-12 education in STEM (science, technology, engineering and math) for America's future.

Rose, C. (2004). The Cold War's Effects on U.S. Education. *American Decades Primary Sources, 6*, 128-135.

Royal Academy of Engineering. (2012). Jobs and growth: the importance of engineering skills to the UK economy. Retrieved from http://www.raeng.org.uk/publications/reports/jobs-and-growth Sanders, M. (2009).

Stem, stem education, stemmania. *The Technology Teacher*, *68*(4), 20-26. Retrieved from http://esdstem.pbworks.com/f/TTT+STEM+Article_1.pdf

The Science Council. (n.d.) Careers from science. Retrieved February 15, 2015, from http://www.sciencecouncil.org/careers-from-science

Sheppard, S., Gilmartin, S., Chen, H. L., Donaldson, K., Lichtenstein, G., Eris, O., ... & Toye, G. (2010). Exploring the Engineering Student Experience: Findings from the Academic Pathways of People Learning Engineering Survey (APPLES). TR-10-01. *Center for the Advancement of Engineering Education (NJ1)*.

Simpson, S. R., & Shadle, S. E. (2013). Implementing process oriented guided inquiry learning (POGIL) in undergraduate biomechanics: Lessons learned by a novice. *Journal of STEM Education, 14*(1) Retrieved from http://scholarworks.boisestate.edu/cgi/viewcontent.cgi?article=1113&context=kinesiology_facpubs

Southwest LRT Community Works program. (n.d.) About the project. Retrieved February 15, 2015, from http://www.swlrtcommunityworks.org/beyond-rails/planning-information/about-project

STEMNET. (n.d.). About us. Retrieved February 15, 2015, from http://www.stemnet.org.uk/about-us/

STEMworks. (2011). About us. Retrieved February 15,2015, from http://www.stemworks.co.uk/about-us

Thompson, M., & Consi, T. R. (2007). Engineering Outreach through College Pre-Orientation Programs: MIT Discover Engineering. *Journal of STEM Education: Innovations and Research*, 8.

Transport for London. (a, n.d) Facts & figures. Retrieved February 3, 2015, form https://www.tfl.gov.uk/corporate/about-tfl/what-we-do/london-underground/facts-and-figures

Transport for London. (b, n.d) Youth Transport Ambassadors. Retrieved March 30, 2015, from http://www.tfl.gov.uk/info-for/schools-and-young-people/teaching-resources/youth-travel-ambassadors?intcmp=14802

U.S. Department of Education (n.d). Science, technology, engineering, and math: education for global leadership. Retrieved February 4, 2015, from http://www.ed.gov/stem

United Kingdom Department of Education. (2014). National curriculum in England: secondary curriculum.. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/381754/SECONDARY_national_curriculum.pdf

United Kingdom Department of Education. (2015). The national curriculum - GOV.UK. Retrieved from https://www.gov.uk/national-curriculum/overview

University Technical Colleges. (2014). Students gain more professional qualifications at UTC Reading. Retrieved March 30, 2015, from http://www.utcolleges.org/news/students-gain-more-professional-qualifications-at-utc-reading/

Warrington, Molly., Younger,Mike. (2009.) Mentoring and target-setting in a secondary school in England: an evaluation of aims and benefits. *Oxford Review of Education, 35*(2), 169-185.

World Population Review. (2014, October 19). London population. Retrieved January 19, 2015, from http://worldpopulationreview.com/world-cities/london-population/

WorldSkills UK. (n.d.). About us. Retrieved April 25, 2015, from http://www.theskillsshow.com/about-us/

Appendix A: Ambassador Interview Questions

Ambassador Interviews

Good Morning/Afternoon/evening I'm_______. I am a student at Worcester Polytechnic Institute working with Young Crossrail. I'm here completing an academic project: to understand your experience with STEM education and your involvement with Young Crossrail. Your inputs will help us enhance our project's end result. What you say will translate into the design of a multi-week academic program for Young Crossrail. Your responses are invaluable and we respect and appreciate the time given to us, this wouldn't take more than a half hour. If you have any questions or doubts, do not hesitate to ask me at any time. This interview is strictly for academic purposes and your name or identifiable information will not be recorded. Shall we begin?

1. What are some of the major challenges you have found, if any, with presenting activities to Key Stage 4 and Key Stage 5 students? Are they less inclined to fully participate in activities? What do you think we can do to avoid these issues?

2. Are there any sort of activities that tend to resonate especially well with students? How about any sort activities that are received poorly?

3. What sort of activities do you like presenting? How about the sort of activities that you dislike presenting? Is this due to personal preference or are the activities just not that interesting or engaging?

4. What is the worst experience you have had as an ambassador when presenting an activity to students in the past? Is there anything we could do to mitigate the chances of something similar happening to another ambassador?

5. Do you think it would be feasible to have Young Crossrail ambassadors commit to a ten week long academic program meeting once a week with a group of students?

6. Are there any other observations, comments, or suggestion which you would like to make which you believe would be helpful for us when designing the activities or their documentation?

Appendix B: Teacher Interview Questions

Teacher Interviews

Good Morning/Afternoon/evening I'm_______. I am a student at Worcester Polytechnic Institute working with Young Crossrail. I'm here completing an academic project: to understand your experience with STEM education and your involvement with Young Crossrail. Your inputs will help us enhance our project's end result. What you say will translate into the design of a multi-week academic program for Young Crossrail. Your responses are invaluable and we respect and appreciate the time given to us, this wouldn't take more than a half hour. If you have any questions or doubts, do not hesitate to ask me at any time. Shall we begin?

1. What sort of STEM subjects do you cover in class? Do you discuss engineering at all?

2. What STEM concepts in particular do you find students have a difficult time grasping or being fully engaged in? What concepts do students find fun or engaging?

3. Can you describe your instruction style? Do you tend to hold classes in a lecture format or do you like to do demonstrations? Are there any particular demonstrations or activities that you like to do? How does this vary by topic?

4. Are there any concepts that we could potentially incorporate into an activity that would be helpful to your teaching efforts?

5. Are there any you areas you feel are lacking in the current school curriculum? Is there anything that can be supplemented with a project or activity?

6. Do you think that the curriculum is flexible enough utilize a multi-week academic program involving STEM concepts? This program incorporates a unit from an examination board's qualification guidelines.

7. Are there any other observations, comments, or suggestions you could make to help us design a STEM-themed activity or the accompanying documentation?

Appendix C: Programme Learning Outcomes

Overall Learning Outcomes

- Students will be able to recognize and apply effective collaborative techniques to all stages of project development.

Concept/Brief (2 sessions)

- Students will be able to organize and evaluate information such as cost, time, health and safety concerns, and location, as found in a design concept/brief and through their own research, to identify key elements of a design problem.

- Students will be able to develop and implement a plan for sharing data and file management using a common data environment.

- Students will be able to create and defend a design proposal to solve the problem introduced in the design brief.

Design (2 sessions)

- Students will be able to create a conceptual/prototype 3D model of a structure/building/system to incorporate multi-level information.

- Students will be able to visualize a 3D model as a 4D multifaceted database.

- Students will be able to identify which type of engineer would be working on each "layer" of the model.

Construction (3 sessions)

- Students will be able to translate their conceptual model into a set of building plans to construct their final model.

- Students will be able to critically analyze the logistics (structural stability, cost of materials, construction processes, etc.) of the build plan.

- Students will be able to tabulate "costs" of materials used in their model to make budgetary decisions.

Handover/Commission (2 sessions)

- Students will be able to provide a detailed cost report for their constructed model.

- Students will be able to describe and defend any design changes made during construction.

- Students will assemble a detailed report on their design processes, from conceptualization to final construction.

Operate and Maintain (1 session, final presentation)

- Students will be able to show peers how to operate and maintain their final product.

Appendix D: Learning Outcomes Mapped to Qualifications

	Learning Outcome	Engineering Design Units and Outcomes	Creative iMedia Units and Outcomes
Overall	Students will be able to recognize and apply effective collaborative techniques to all stages of project development.	N/A	N/A
Concept/ Brief	Students will be able to organize and evaluate information such as cost, time, health and safety concerns, and location, as found in a design concept/brief and through their own research, to identify key elements of a design problem.	R105, LO1	R081, LO1 R081, LO2 R081, LO3 R081, LO4
	Students will be able to develop and implement a plan for sharing data and file management using a common data environment	R105, LO3 R106, LO1	R081, LO1 R081, LO2
	Students will be able to create and defend a design proposal to solve the problem introduced in the design brief.	R105, LO2	R081, LO3 R081, LO4
Design	Students will be able to create a conceptual/prototype 3D model of a structure/building/system to incorporate multi-level information.	R107, LO1 R107, LO2 R107, LO3 R107, LO4	R083, LO1 R083, LO2 R083, LO3
	Students will be able to visualize a 3D model as a 4D multifaceted database.	N/A	R083, LO3

	Students will be able to identify which type of engineer would be working on each "layer" of the model.	N/A	R083, LO4
Construction	Students will be able to translate their conceptual model into a set of building plans to construct their final model.	R108, LO1 R108, LO2 R108, LO3	R085, LO1 R085, LO2 R085, LO3 R085, LO4 R086, LO1 R086, LO2 R086, LO3 R086, LO4 R087, LO1 R087, LO2 R087, LO3 R087, LO4 *Only one of the 3 units is required, but all 4 learning outcomes of the applicable unit must be completed.
	Students will be able to critically analyze the logistics (structural stability, cost of materials, construction processes, etc.) of the build plan.	R108, LO4	
	Students will be able to tabulate "costs" of materials used in their model to make budgetary decisions.	R105, LO2	
Handover/ Commission	Students will be able to provide a detailed cost report for their constructed model.	R108, LO4	R082, LO1 R082, LO2 R082, LO3 R082, LO4
	Students will be able to describe and defend any design changes made during construction.	R108, LO4	R082, LO4
	Students will assemble a detailed	N/A	R082, LO4

	report on their design processes, from conceptualization to final construction.		
Operate and Maintain	Students will be able to show peers how to operate and maintain their final product.	N/A	N/A

Appendix E: Suggested Activities

Module 0: Pre-Program Session

Activity 1: Learners could research a person successful in their career and write a brief description on the skills and personality traits that make them successful.
Employability Skills Unit 14, LO1

Activity 2: Learners could take an online skills assessment test (ex. https://www.iseek.org/careers/skillsAssessment) and reflect on their results. They could then browse through recommended careers for their skills. The results of this test could also be used to break up students into groups with a range of skills and identify which students will complete the Creative strand and which will complete the Engineering strand.
Employability Skills Unit 14, LO2

Activity 3: Learners could select a career that is related to their skillset and/or program strand and identify what specific skills are necessary for that career. Learners could then identify what skills they already possess and which need to be developed, and form a plan for their development.
Employability Skills Unit 14, LO3 and LO4

Activity 4: Learners could examine a bank statement and/or a wage slip. Learners could then identify and define the following information: National Insurance Number, Sort Code, Annual Percentage Rate, Income Tax Code, and Gross/Net pay.
Employability Skills Unit 15, LO1

Activity 5: Learners could develop a budget based on the design brief on their student resource sheet that includes money management and payment methods, contingency plans, and how they'll get themselves out of debt if they overspend. This activity may be completed during module 1 and revisited over the course of the program.
Employability Skills Unit 15, LO2 and LO3

Activity 6: Learners could assess the credit rating for a fictional person using a free credit rating website. They could then identify whether the person has good, bad, or average credit and suggest ways to improve the credit rating.
Employability Skills Unit 15, LO4

Module 1: Concept/Brief

Activity 1: Learners could develop a storyboard that follows a popular engineered product through the design cycle.
Engineering Design Unit R105, LO1. Creative iMedia Unit R081, LO3 and LO4.

Activity 2: Learners could critically analyze a client design brief and accompanying proposal and identify the logistics of the proposal, being able to answer the following questions: Has the proposal met all of the brief requirements? Have they given themselves enough time? Where might the proposal fall short? *Engineering Design Unit R105, LO2. Creative iMedia Unit R081, LO2 and LO4*

Activity 3: Learners could research existing railways and how they followed the design cycle, as well as identifying how they followed their time and budgetary constraints.
Engineering Design Unit R105, LO1, LO2, and LO3. Creative iMedia Unit R081, LO2 and LO4.

Activity 4: Learners could develop a mind map to graphically represent the design cycle.
Engineering Design Unit R105, LO1. Creative iMedia Unit R081, LO3 and LO4.

Activity 5: Learners could research data management systems and how they fit into the design cycle/are used in industry, and current legislation on their use.
Engineering Design Unit R106, LO1. Creative iMedia Unit R081, LO2.

Module 2: Design

Activity 1: Learners could disassemble a simple engineered product, identify the methods of manufacture, and (using CAD or hand drafting techniques) produce a set of design drawings for the product.
Engineering Design Unit R106, LO3; Unit R107, LO1, LO2, LO3. Creative iMedia Unit R083, LO1, LO2 and LO4.

Activity 2: Learners could develop a set of design drawings from a simple design proposal.
Engineering Design Unit R107, LO1, LO2, and LO3. Creative iMedia Unit R083, LO2, LO3.

Activity 3: Learners could interpret a set of commercial design drawings, identifying the client, tolerancing, materials, etc.
Engineering Design Unit R107, LO1, LO2, LO3; Unit R105, LO2. Creative iMedia Unit R083, LO1 and LO4.

Activity 4: Learners could analyze a "customer" description of an engineered part and create a 3D representation (CAD or physical) of the part.
Engineering Design Unit R107, LO2 and LO3. Creative iMedia Unit R083, LO2 and LO3.

Activity 5: Learners could analyze a set of engineering drawings and identify missing information (dimensions, part description, customer, material, etc.)
Engineering Design Unit R105, LO2; Unit R107, LO1. Creative iMedia Unit R083, LO1 and LO4.

Module 3: Construction

Engineering Strand:

Activity 1: Learners could create a presentation on safe prototyping practices.
Engineering Design unit R108, LO2.
Activity 2: Learners could develop a step-by-step plan of how they would create a prototype from a given design drawing.
Engineering Design Unit R108, LO1 and LO3.

Activity 3: Learners could create a prototype evaluation sheet for evaluating features, function, materials, aesthetics, ergonomics, construction processes, and alternative manufacture techniques. This evaluation sheet can later be used to evaluate their constructed project model.
Engineering Design Unit R108, LO4.

Creative Strand:

Unit R085:
Activity 1: Learners could create a presentation on different mediums for web access and how they access the internet.
Creative iMedia Unit R085, LO1

Activity 2: Learners could create a layout for a website based on a client brief.
Creative iMedia Unit R085, LO2 and LO3.

Activity 3: Learners could critically assess a popular social media website (Facebook, Tumblr, Twitter, etc.) and identify potential areas for improvement.
Creative iMedia Unit R085, LO4.

Unit R086:
Activity 1: Learners could develop a storyboard for an advertisement for their digital railway.
Creative iMedia Unit R086, LO1 and LO2.

Activity 2: Learners could review an animation against its original brief and identify areas for improvement.
Creative iMedia Unit R086, LO4.

Activity 3: Learners could create a simple animation (using Adobe Flash or a similar program) to highlight some aspect of their railway's design.
Creative iMedia Unit R086, LO2 and LO3.

Unit R087:
Activity 1: Learners could create a presentation on different interactive multimedia products, identifying where such products are used, design consideration, required hardware, software, and peripherals, and limitations to such products.
Creative iMedia Unit R087, LO1.

Activity 2: Learners could design an app to highlight the functions of their digital rail.
Creative iMedia Unit R087, LO2, and LO3.
Activity 3: Learners could critically assess a popular social media app (Facebook, Tumblr, Twitter, Instagram, etc.) and identify potential areas for improvement.
Creative iMedia Unit R087, LO4.

Module 4: Handover/Commission

Engineering Strand:

Activity 1: Learners could critically analyze an existing product and identify the products strengths and weaknesses. They could then suggest areas for improvement.
Engineering Design Unit R106, LO2; Unit R108, LO4.

Creative Strand:

Activity 1: Learners could edit the current London Underground map to include their digital railway.
Creative iMedia Unit R082, LO1, LO2, and LO3.

Activity 2: Learners could create a concept graphic of their digital railway in operation.
Creative iMedia Unit R082, LO2 and LO3.

Activity 3: Learners could compare a concept graphic or advertisement to the physical entity it represents.
Creative iMedia Unit R082, LO1 and LO4.

Module 00: Post-Program Session

Activity 1: Learners could reflect on their performance during the program, identify whether they met their personal goals for the project, where their skillset helped or hindered them, what skills they've developed through the program, and whether they were able to work independently within the group.
Employability Skills Unit 18, LO4

Activity 2: Learners could research work placements based on their post-project skills, and identify how their learned and pre-existing skills could benefit them in the work placement.
Employability Skills Unit 18, LO1

Activity 3: Learners could identify the workplace behavior expected for the work placement they researched, identifying necessary communication skills, acceptable dress, PPE requirements, etc.
Employability Skills Unit 18, LO2