Expanding STEM Outreach Resources for the Young Crossrail Programme

Developing a STEM outreach programme for key stage four students

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Abstract

The goal of this project was to develop the *Build your own city* programme for Crossrail, for utilisation in the Young Crossrail STEM outreach programme. We designed and developed this programme by interviewing Crossrail staff, STEM educators, and ambassadors to determine the most appropriate programme criteria. Stakeholders identified the need for a programme to inform and inspire students about STEM careers. Ambassadors will deliver the programme using six handbooks and two presentations to guide participants.

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Many individuals and organisations helped to make this project possible. We would first and foremost like to give a special thanks to Crossrail Ltd.'s Young Crossrail department and the Institution of Structural Engineers, and specifically our project sponsors, Lauren Hillier and Nick von Behr, for making this project possible and providing us with support, resources, advice, insight, and direction throughout the entirety of our project. We would also like to thank the several Crossrail ambassadors and employees who allowed us to interview them to gain insight into their careers and experiences as professionals and ambassadors. We would like to extend special thanks to physics teacher Jo Massey and the Sherborne Girls School in Sherborne, Dorset for allowing us to pilot test a portion of our programme and gather feedback from students and educators.

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Executive summary

The demand for science, technology, engineering, and mathematics (STEM) employees in the United Kingdom has been on a steady increase. However, today, the number of people choosing to pursue careers in STEM is failing to meet the demand of new job openings in STEM fields. Several organisations and companies within the United Kingdom have been trying to reduce this deficit through STEM ambassador programmes. Ambassador programmes work to promote adolescent engagement in STEM education through collaborative, hands-on learning activities. These programmes utilise ambassadors: volunteers who work to facilitate the activities that attempt to engage students.

The Strategic Rail Authority (SRA) and Transport for London (TfL) invested £15.4 billion in launching Crossrail Ltd. as a company in 2002 to create a railway connecting central London between the east and west. In addition to creating the new railway line, Crossrail has worked extensively on community outreach. The company developed the Young Crossrail programme in 2009 to promote student interest in STEM, utilising ambassadors from a wide range of both STEM and non-engineering backgrounds. As Crossrail will end construction in 2018, the company seeks to construct a ‘learning legacy’ to educate future construction companies on the lessons learned throughout their project. Included in this learning legacy are the programmes that Young Crossrail ambassadors have facilitated. In prior years, WPI students have developed low-budget programmes for key stage three (ages 12-14) and high-budget programmes for key stage four (ages 14-16) students, but not low-budget programmes for key stage four students.

Our team worked with liaisons from Young Crossrail and the Institution of Structural Engineers (IStructE) to formulate a programme that could engage key stage four students with little cost to participating institutions. The *Build your own city* programme addresses the need for

engagement in this age group by involving students, aged 14-16, in STEM through a low-budget, multi-phased challenge that tasks teams to work collaboratively to solve a simplified version of the real-world problem of the housing crisis that London currently faces. Crossrail’s new Underground line, which will be named the Elizabeth line, will bring an estimated 1.3 million more people within 45 minutes of the city. Our programme works to frame the problem of housing and population growth and facilitate student engagement while also exposing the students to a real-world problem that they may face if they choose to pursue a career in a STEM field.

After designing our programme, we pilot tested an abbreviated version of it with a group of 13 and 14-year-old students at the Sherburne Girls School to gather feedback. In addition to pilot testing the programme, we also presented the programme to a group of STEM educators to gather feedback on it. The pilot test and educator feedback helped us to identify areas of our programme where we did not clearly convey instructions, as well as help us to identify time constraints for the programme’s different phases. We utilised the feedback we received from students and educators to adjust and improve our programme’s instructions to be more clear and concise and then presented the edited version to the STEM ambassadors we previously interviewed. After receiving their feedback and making minor edits to instructions, we submitted our finished programme to our liaisons at Young Crossrail and IStructE for implementation in their STEM outreach programmes.

Project objectives and methods

To develop our programme, we conducted interviews with our project sponsor liaison sponsors to identify the type of programme they wanted our team to create. We utilised their feedback to create a set of research questions that addressed their programme criteria. We then interviewed stakeholders, including STEM ambassadors, STEM professionals, our liaisons, and non-STEM employees working on the Crossrail project. We also performed literature reviews to answer our research questions and begin the preliminary programme design. After creating a preliminary programme curriculum and supplementary materials, we facilitated an abbreviated programme pilot test at a UK secondary school and gathered participant feedback on the programme. We then revised our programme and gathered stakeholder input to finalise our programme and its accompanying materials. We submitted our finalised product and recommendations for implementation and revision to our liaisons for their use with key stage four students.

Programme structure

We developed the *Build your own city* programme to provide a low budget and open-ended team challenge that incorporated structural engineering and was geared towards key stage four students in the Young Crossrail programme. The six-hour challenge is composed of three major phases, each consisting of multiple modules. STEM ambassadors will work as programme facilitators by introducing the challenge to students and assisting them throughout the programme's duration. Throughout our research process, we identified that students learn best when applying learned skills to real-world contexts. We accordingly chose to parallel our challenge with the housing crisis in London, caused by the lack of affordable housing in the greater London area.

Teams of three students, each assisted by a STEM ambassador, will work collaboratively to design, present, and construct a model of a housing complex to house 200 people. The students will play one of three roles in their teams; they will work as the team's architect to design a floorplan for the housing complex, the team's project manager to create a project budget, or the team's structural engineer to create a materials schedule. In the design phase, team members will work collaboratively to design their complex on paper and identify necessary materials and associated costs to construct it. In the bid phase, teams will present their blueprints to their ambassador, who will constructively critique their design before its approval. Finally, in the build phase, teams will construct a small-scale model of their design via low-cost craft materials that we have identified and associated with the real-world materials that the students used in the design phase.

After the hands-on challenge concludes, the ambassadors will encourage teams to evaluate their finished product and methods to reflect on how their challenge relates to real-world structural engineering challenges through discussion with their ambassador. The ambassador will also highlight academic and vocational steps that interested students can take to pursue a STEM career.

Supplemental Materials

In addition to creating our programme, we also developed a set of guides which future ambassadors and participants can use to run the programme. We created a learning legacy package that includes ambassador presentations, ambassador guides, and student briefs and guides, as well as supplemental resources that facilitators and participants can utilise to cater the programme to their individual needs. The ambassador presentation includes a PowerPoint presentation for ambassadors to present to student participants in order to introduce the students to the programme and how it relates to engineering. The ambassador guides provide ambassadors with detailed explanations of the programme, challenges teams may face, and their roles as facilitators. Moreover, the guides include supplemental resources that the ambassadors can use to facilitate the programme more effectively. The resources include materials that inform ambassadors about gender inclusivity and review the technical skills ambassadors must have or obtain in order to facilitate the programme effectively. The student briefs and guides provide participants with the materials they need to fulfil their roles as architects, project managers, or structural engineers throughout their challenge process. Finally, the additional resources include potential modifications facilitators can implement depending on their budgets, such as using CAD software in their design phase, and/or 3D printing in the build phase, as well as programme evaluations that participants and ambassadors can use to critique and improve the programme based on their experiences.

Major Conclusions and Recommendations

Based on all stakeholder feedback, we designed the *Build your own city* challenge to be open-ended, time-flexible, and low-cost to allow for the most widespread implementation. The programme puts students in simplified STEM professional roles and allows them to create and innovate in a challenge that mirrors a real-world problem that they would likely face if they chose a STEM career. If successful, the programme should allow students to leave the programme inspired about STEM careers and with the information they need to pursue a career in STEM.

We tested our programme preliminarily, but we recommend the future programme developers to test the programme fully before they distribute it for implementation. We have highlighted a list of recommendations for Young Crossrail and/or IStructE to carry out in regards to our programme, helping to ensure that the programme is continually improved and easily implemented. These recommendations will help to ensure the quality of the programme's materials and implementation. Collaboration between Young Crossrail and IStructE is important to ensure a smooth transition when the Young Crossrail programme comes to an end and delivers its learning legacy for another similar project to learn. Our recommendations include piloting a full version of the programme, continuing to develop programmes for younger age groups, using technology and modelling software to supplement the programme, encouraging ambassadors to buy into a longer timeframe, and including art and philosophy in future programme development.

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Chapter 1: Introduction

The Royal Academy of Engineering (RAEng) projected that, between the years 2012 and 2020, there will be a demand for 830,000 additional science, technology, engineering (SET) professionals and 450,000 SET technicians, which requires at least 100,000 science, technology, engineering, and math (STEM) graduates per year. RAEng predicts that only 90,000 students will graduate with STEM degrees each year during this nine-year period (Harrison, 2012). STEM has become paramount to the United Kingdom's (UK) economic prosperity since the Office for National Statistics officially declared a recession in the final quarter of 2008 and the Crossrail project, a massive effort to construct a new east-west rail line through London, has been instrumental to the UK's resilient economy, specifically through stimulating STEM industries (BBC, 2009). In addition to an increase in infrastructure, the UK produced 7% of the world's scientific research papers and 8% of scientific citations between the years of 2004 and 2008; these are the third and second highest in the world (The Royal Society, 2011). Despite the UK's share of scientific knowledge and demand for STEM employees in construction and infrastructure, 42% of STEM employers in the UK stated that they had difficulty filling open positions in their organisation with qualified staff in 2008 (Nath & Border, 2013).

Many STEM companies participate in STEM programmes to stimulate the supply of qualified applicants in science and technology careers at a young age. These programmes utilise volunteers to provide students with the resources to learn about the expanding fields of study in STEM and prepares them for careers in STEM. While many programmes exist that work to educate young people and stimulate their interest in STEM careers, limited exposure to already limited resources may leave many students uninformed about the opportunities that a STEM education can provide.

Crossrail aims to develop STEM resources for UK students and provide a structured curriculum to promote interest in STEM, particularly in structural engineering. The Young Crossrail programme, which operates under the larger umbrella of Crossrail, Ltd., works with nine key schools along Crossrail's construction route. Young Crossrail provides resources through ambassador programmes, which utilise volunteers and professionals in the field to inspire and inform students about STEM. Young Crossrail's volunteers, called ambassadors, implement hands-on activities, attend career fairs, give presentations, and host group projects where students have the opportunity to construct objects that they learned about in class and attempt to target real-world critical problems. The programmes promote participants' teamwork and project management skills. Young Crossrail's programme will be ending in 2016 and its director, Lauren Hillier, aims to create resources that educators will utilise beyond the lifespan of its project. Ms Hillier works to provide educational resources via guest speakers, facility tours, and interactive projects and activities to pique the interests of young people in STEM careers. However, the director has few low-cost programmes to meet the growing popularity and outreach of the Young Crossrail programme. Recently, Ms Hillier's partnership with WPI has allowed her to oversee the development of low-cost programmes for key stage three students but has yet to broaden Young Crossrail's programmes to activities geared towards other age groups (L. Hillier, personal communication, 23 March 2016).

The goal of our project was to address the lack of a structured curriculum in science, technology, engineering, and mathematics (STEM) geared towards key stage four (ages 14-16) students, in the Young Crossrail programme. We worked with liaisons from Young Crossrail and IStructE to develop a solution to engage adolescents in a STEM programme that ambassadors, teachers, and volunteers can implement with little cost to participating institutions. By utilising prior research in STEM education and information obtained from interviews with professionals, we designed a low-cost and age-appropriate challenge based on simplified engineering problems and developed guides to supplement the designed challenge. These guides made for challenge facilitators, assisted in smooth implementation. Our team used ambassador feedback to assess and improve our challenges. We also worked with Crossrail to make the programme and its supplementary materials readily available online to both students and facilitators.

Chapter 2: Background

In this chapter, we explore science, technology, engineering, and mathematics (STEM) education from its genesis in the United States during the 1960s to the directed programming that many ambassador programmes, like Young Crossrail and STEMNet, have developed and implemented across the UK in the past decade in order to inform and inspire youths about careers in STEM. We will also highlight some design considerations and recommendations from programmes with years of previous experience in developing and implementing educational resources for targeted STEM outreach programmes.

2.1. STEM

Recent STEM initiatives target young students with the purpose of improving proficiency in STEM-related subjects and encouraging more students to pursue careers in either engineering or other STEM-related careers (STEMnet, 2016). The United States was one of the first countries to put an emphasis on STEM, pushing the western world to the forefront of these STEM initiatives ever since. In the 1960s, the space race triggered widespread changes to the national science curriculum of the United States (Sanders, 2008). When the USSR launched Sputnik, the president of the United States believed that there was a serious lack of qualified candidates for higher level engineering jobs. President Eisenhower encouraged the public, specifically parent-teacher associations, to re-evaluate their schools' science curricula, noting that the Soviets had a much more rigorous curriculum (Eisenhower, 1957).

The National Science Foundation coined the title "SMET" to describe science, mathematics, engineering, and technology in 1990. Later that year, a programme officer offered that "STEM" would both look and sound better as a descriptive acronym (Sanders, 2008). The acronym STEM succinctly defines itself: either learning and/or work in disciplines relevant to science, technology, engineering, and mathematics. Though the term STEM describes the above for much of the world, some variability exists pertaining to what fields it includes; some international education policies additionally include health, agriculture, and psychology in their STEM curricula. However, the fundamental disciplines indicated by the acronym are universal

(Freeman, Marginson, & Tytler, 2015). STEM education, a subset of STEM as a whole, refers specifically to the interaction of students and STEM educators: anyone that is responsible for the teaching of science, technology, engineering, and mathematics (Williams, 2011).

United States President Obama spoke in 2008 and communicated the need for “makers,” rather than just consumers, particularly in the young and impressionable generations (Dougherty, 2013). A congressional report on STEM education in 2008 stated that a majority of secondary school students in the United States do not meet proficiency standards in math and science and that those students lack qualified instructors to reach these proficiencies (Kuenzi, 2008).

The Parliamentary Office of Science and Technology (POST) recognises a shortage of STEM skills in the United Kingdom that manifests itself through a lack of qualified candidates for STEM careers. The UK has 5.8 million people employed in STEM-related occupations, making up nearly 20% of the UK’s total workforce (Nath & Border, 2013). Despite this large share of employees in the field, when asked about hiring in 2008, 42% of STEM employers in the UK stated that they had difficulty filling open positions in their organisation with qualified staff (Nath & Border, 2013).

The overabundance of job openings in STEM concerned the UK Government. Politicians believed the jobs would not be filled by qualified candidates in a timeframe that would facilitate economic growth, which led to their defining and deploying of STEM education efforts in the UK (Williams, 2011). The POST reported a lack of specific coverage of technology or engineering in formal education, despite required maths and science mandates (Nath & Border, 2013). The POST highlighted two specific gaps in STEM skills: inadequate mathematical grounding, and poor information and computing technology (ICT) curricula. In 2013, Parliament reviewed the national curriculum and decided that the nation would increase the focus on English, maths, and science. The 2012 House of Lords recommended that maths should be compulsory in post-16 education, to which the Department for Education (DfE) agreed (Nath & Border, 2013). To address the poor ICT curriculum in the UK, the 2014 national curriculum substituted a computing curriculum for ICT, clearly defining three aspects: computer science, information technology, and digital literacy (Berry, 2013). The DfE hoped that these two reforms would help to solve the STEM gap in UK education.

Not only do national statistics show a need for a boost in STEM curriculum, but also recognise a growing gender gap in those studying and practising in STEM fields. In the year 2014, national statistics showed that about 41% of female undergraduates study in STEM fields, as compared to 53% of male undergraduates. Likewise, only 34% of female and 47% of male postgraduates studied in STEM fields. In non-medical engineering fields, women make up only 26% of undergraduates and 32% of postgraduates in the UK (HESA, 2014) with women filling only 9% of non-medical STEM careers in the UK (CaSE, 2014). UK statistics from 2005 outline a gender gap in STEM occupations ranging from only a 5% female representation in the professional engineering workforce to a large minority of 46.4% representation in science research professionals (Wynarczyk & Renner, 2006).

Informal programmes support the initiative for changes to STEM education in the UK, inspiring students, including women, to engage in STEM. The POST highlights the goals of informal STEM education, which range from improving and changing student's preconceptions of science to allowing students to understand how science works through improved scientific knowledge. STEMnet is an exemplary informal STEM initiative that adheres to these goals. In 2010, the DfE funded 1,469 after-school STEM clubs that are within STEMnet's purview totalling £9.1 million in the four years leading up to 2010 alone (Parliamentary Office of Science & Technology, 2011).

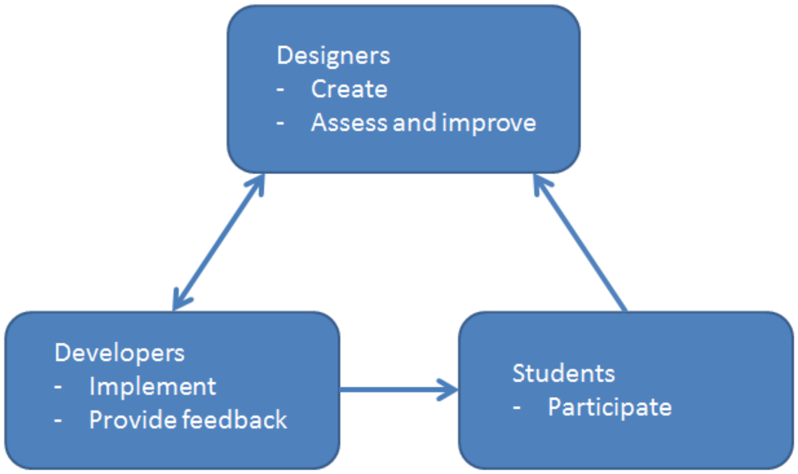
2.2. STEM programming

In 2009, the UK National Audit Office compared both government funded and private initiatives to engage adolescents in STEM (NAO, 2010). The NAO's examination identified several key factors that are important to promoting student success and retention in STEM career paths. The NAO identified that student career guidance and stimulating interest in the subject matter had the most profound effects on student success in STEM (NAO, 2010). The UK central government approved a £3 million grant to increase STEM programming, primarily through the use of STEM ambassadors to meet the need for professional interaction and engaging programming (Mann & Oldknow, 2012).

STEM ambassadors are volunteers who work to promote student interest in STEM careers through a wide variety of programmes. Usually experts or educators in a particular field of STEM, ambassadors facilitate programmes to inform students about STEM fields and career opportunities after college and university (Mann & Oldknow, 2012). Ambassadors generally volunteer for STEM outreach organisations, who train the ambassadors before the ambassadors facilitate the organisation's programmes.

STEM programmes work to promote interest in a certain subject and most STEM programmes function as STEM outreach programmes. The primary goals of STEM outreach programmes are to stimulate student interest in a subject matter. While STEM outreach programmes utilise some academic approaches, they work to pique student interest in the material rather than function as an academic resource. Programmes can span from single, hour-long activities to month-long projects. Programmes differ in subject matter but generally follow the same design scheme. The programmes generally consist of three main groups of people: designers, developers, and students (Handel et al., 2014). Designers work to create structured programmes that focus on a specific area of study. That area can range from a broad topic, such as structural engineering, to a specific case study, such as developing a specific train station for a borough (Handel et al., 2014). In addition to the programme itself, designers often create supplementary materials that developers can use to implement the programmes. After a designer has created a programme and supplementary materials, developers employ and improve it (Handel et al., 2014). Developers, known as ambassadors in UK STEM programmes, are programme facilitators. Ambassadors lead the pre-structured programmes to inform students and pique their interest in pertinent materials (Handel et al., 2014). After the programme has concluded, ambassadors often gather participant feedback and work with the designer to improve the programme for future implementation. Figure 1 highlights the relationship between designers, developers, and students.

Figure 1: Designer, developer, and student relationship



Designers create resources for developers to present to students. Developers and students provide feedback to designers, who use this feedback to improve the programme for future implementation.

Some STEM programmes struggle to transfer information among the three main groups, which can impede programme improvements (Handel et al., 2014). Moreover, poorly constructed programmes can struggle with information transfer on several levels. For example, an ambassador may find a programme's implementation difficult if her instructions are poor (Handel et al., 2014). Poorly constructed programmes lead to disengaged students and a lack of strong feedback for designers from both ambassadors and students.

In order to ensure strong, well-articulated feedback, designers must provide strong guidance and clear direction of programme goals and implementation to ambassadors. Investigation of other STEM ambassador programmes provides a better understanding of their methodologies, directions, and conclusions about effective programming. STEM ambassador programmes vary in their approaches, but generally try to accomplish the same goal: promoting student interest in STEM careers. The STEM programmes we studied incorporate hands-on or "active" learning strategies and engaging projects, allowing students to develop a sense of learning through interaction rather than through lectures (Freeman, 2014). In this section, we review several STEM programmes of different backgrounds to identify which aspects they employ to engage students in STEM.

We investigated several STEM programmes to identify components of successful programmes. Our criteria for a successful programme included both a programme's ability to engage students and promote participation, as well as inform students about STEM fields, as STEM programmes generally aim to pique student interest in STEM fields while providing careers advice. As our programme's designers, we investigated programmes that focus on programme creation and development in addition to implementation.

STEMnet

STEMnet is a charity subsidised by the UK central government that strives to create extracurricular opportunities to engage young people across the United Kingdom in STEM. The organisation began in 2006 to raise awareness of STEM in schools by facilitating STEM professional engagement with students. In 2010, the central government provided a three million pound grant to promote professional engagement in STEM ambassador programmes, with nearly 80% of the three million pound grant going towards STEMnet's development (Mann & Oldknow, 2012). This grant allowed STEMnet to launch the STEMnet Scheme, a STEM outreach programme that utilises over 30,000 STEMnet ambassadors to engage students in STEM across thousands of schools throughout the United Kingdom (Mann & Oldknow, 2012). Today, STEMnet is renowned as the UK's primary STEM programme network (Welch & Osborne, 2012).

STEMnet's most popular programme is the STEM Ambassadors Programme. The programme provides an extracurricular solution to schools lacking in STEM resources (STEMnet, 2016) and works with schools to establish STEM clubs and day programmes for students. The programme also trains ambassadors to facilitate the clubs and programmes. Clubs can cover a wide array of subjects to cater for the needs of the individual schools and students (Welch & Osborne, 2012) and can allow students to gain exposure to a particular area of STEM in which they may be interested. In addition to establishing independent STEM clubs for students to explore subjects, the STEM Ambassadors Programme hosts periodic STEM competitions in which over 5,500 STEMnet facilitated clubs in the United Kingdom showcase the projects they develop (STEMnet London, 2016). STEMnet encourages students to explore STEM fields, rewarding student achievements through STEM resources and materials that the clubs can utilise for future projects. In 2016, Teddington School, a school in the London Borough of Richmond, won the Best Overall Submission award at the STEM Club Week competition for a moon mapping robotic script the students wrote with the help of their local club's STEM ambassador, receiving over £300 in robotics kits from STEMnet as a prize to help the club in future projects (STEMnet London, 2016).

STEMnet's extensive database of activities, academic resources, and educational references allow it to provide targeted resources for the specific programmes it facilitates. In addition to programme resources, the organisation offers ambassador guides and training resources that all STEMnet ambassadors utilise (STEMnet London, 2016). Moreover, many other STEM outreach organisations, including Young Crossrail, use STEMnet's ambassador training programme as their primary tool for ambassador induction and education (L. Hillier, personal communication, 23 March 2016).

Project Lead the Way

A previous WPI team interviewed Dr Martha Cyr, the director of the Massachusetts hub for Project Lead the Way (PLTW) through WPI (Handel et al., 2014). PLTW is an educational programme that is analogous to ambassador programmes in the UK and works on developing STEM fields with the help of activities done in current US middle and high schools by teachers. The programmes last from six weeks to one year.

The educators go to a two-week long summer training session to prepare to teach students throughout the next year. To help the educators maintain teacher networks, the programme utilises master teachers and provides educators access to an online blog for communication and questions (Handel et al., 2014). Master teachers are dedicated teachers with experience in PLTW and make themselves available to help and answer questions for newer participants.

Professor Cyr shared her experience and explained the difficulties of working with professional engineers and educators. She observed that both educators and engineers generally struggle when changing their work ethics (Handel et al., 2014). Educators are naturally more accustomed to traditional classroom work and struggle with project work while engineers exhibit opposite tendencies. These differences can create difficulties when educators and professional engineers collaborate (Handel et al., 2014). Sometimes educators struggle to adapt to and become comfortable in new environments. Meanwhile, professional engineers struggle to explain and teach information that they themselves comprehend. Cyr concluded that some engineers usually believe students comprehend material as easily as they do, but do not articulate the message they want to convey carefully.

Cyr also noted that developers involved in STEM programmes struggle to repeat processes they have learned after training sessions (Handel et al., 2014). PLTW works to provide solutions by videotaping educators performing programmes and using those tapes to show developers a clear activity model. By providing developers with clear and concise methodologies, designers can ensure that developers effectively implement their programmes (Handel et al., 2014).

Project Lead the Way offers insight into how professionals in STEM fields may approach STEM programmes. While professionals may be well versed in their field of study, they may not always be able to share their knowledge effectively with participants in their programmes. By developing strong supplementary resources that include approaches that developers can take to engage students effectively as both professionals and facilitators, Project Lead the Way works to ensure that students benefit from programmes.

Discover! Programme

Discover! is an all-female weekly STEM ambassador programme created at Cardiff University by the campaign for Women into Science Engineering and Construction (WISE) to engage age 12-13 (key stage three) girls in STEM. Each week, a female STEM ambassador who is a professional in a particular STEM field will work with girls participating in the programme to inform them about her field of study through object-based learning approaches (Watermeyer, 2012). The developers of the Discover! programme believe that students learn best through "direct encounter with the phenomena rather than thinking about the encounter" (Watermeyer, 2012), and thus, the professionals model their challenges after real-world STEM tasks. The programme focuses solely on engaging women to promote female inclusiveness in STEM careers after college and targets age 12 and 13 girls who already show some interest in STEM fields. The programme does not function as a STEM outreach programme trying to pique student interest, but rather as an educational programme that provides more in-depth explanations of STEM careers while utilising materials that students cover in a traditional classroom setting (Watermeyer, 2012). The students participating in this STEM educational programme have already expressed interest in STEM as a career path, and now are trying to learn more about different career opportunities.

The Discover! programme effectively engages students in later key stages. At both key stages three and four, STEM programmes must act as means to inform students about potential future STEM careers rather than simply pique student interest (Watermeyer, 2012). Discover! effectively accomplishes these means through its utilisation of case studies as mentors to give students direction should they choose to pursue careers in STEM. In addition, the programme strives to expose students to real-world phenomena as its learning tool. Challenges based on real-world examples give students a more authentic experience of challenges they may face in their professional careers. Finally, Discover! promotes gender inclusiveness through the use of female mentors and ambassadors, and the WISE campaign as an organisation offers a wide array of free scholastic and extracurricular resources for schools and STEM ambassador programmes to help promote gender inclusiveness (WISE, 2016).

Active learning in STEM programmes

Extracurricular STEM programming is a relatively new area of programming that targets adolescent involvement and has no overarching or prescriptive methods. Programmes can run from as short as an hour to as long as several months, allowing students to engage in STEM fields in several ways. While the programming is diverse, the strong STEM programmes we investigated share active learning approaches. According to a 2015 study by the National Academy of Sciences, active learning approaches enhance student comprehension by over half a letter grade compared to traditional lecture methods (Freeman et al., 2015). In addition, academic failure rates are more than 55% more likely to occur in students exhibiting knowledge acquired from lecture learning than active learning (Freeman et al., 2015). Programmes with active learning approaches promote students' comprehensive understanding of the material through hands-on challenges. Moreover, the collaborative atmosphere of active learning environments empowers students to vocalise their thoughts and develop communication skills (Freeman et al., 2015). By employing active learning methods through ambassador programming, students are more likely to succeed in their fields of study, which strongly correlates with increased interest and happiness in future careers (Weaver, 2006).

2.3. Young Crossrail

The Strategic Rail Authority (SRA) completed the London East-West Study in 2000 and determined that the city needed an additional railway to connect central London from the east and the west (SRA, 2000). SRA and Transport for London (TfL) contributed £154 million to launch Crossrail Ltd. as a company in 2002 (Crossrail, 2002). The construction on the Crossrail project started in May of 2009 and is expected to end in 2018 (Crossrail, 2016).

In order to facilitate community outreach, Crossrail Ltd. developed the Young Crossrail programme in 2009 to promote student interest in STEM along its anticipated route. Volunteers from a wide range of construction and engineering backgrounds work as Young Crossrail ambassadors to contribute to the Young Crossrail programme and its community of participants. The programme works mainly with nine schools that are close to the Crossrail route and its ambassadors have put over 1200 hours of work towards improving STEM outreach (Todd, 2016). The ambassadors visit schools local to the Crossrail route and share their real-life experiences in engineering and construction disciplines. The ambassadors strive to encourage young students, especially girls, to engage in STEM education. Young Crossrail also worked with 13,000 students, parents, and teachers in 70 different schools in addition to the nine partner schools throughout the years 2014 and 2015 (Crossrail, 2016). Young Crossrail identifies clear objectives for its programmes to ensure that ambassadors are prepared to guide students through learning experiences. Young Crossrail's policies provide ambassadors with sets of the facilitation objectives including giving feedback, ensuring everybody's participation, and giving supervision from professionals (Crossrail Limited, 2016).

As a programme, Young Crossrail strives to broaden its physical reach by developing better STEM programmes for more young students, especially for young women. The Rail Minister of London, Claire Perry, spoke in January of 2016 at the House of Commons (Crossrail, 2016a). At this event, titled "Women Delivering Crossrail," Perry talked about Crossrail's efforts and ambitions to increase the involvement of women in the construction industry. The Rail Minister highlighted the lack of women engineers in this area, noting that only 11% of employees in UK construction industries are women and only 6% of the engineers in this industry are women. On the other hand, Perry indicated that Crossrail has taken a lead in this area and today almost 33% of the employees at Crossrail are women (M2 Presswire, 2016). She also stated that Young Crossrail had already reached out to 36,000 school students, teachers, and parents and that strong collaboration between Young Crossrail and the non-profit organisation Women into Construction made the Young Crossrail activities more accessible and comfortable for women (M2 Presswire, 2016).

Young Crossrail concentrates efforts not only on increasing interest in STEM but also on developing career opportunities in STEM and construction industries. In 2014, Young Crossrail had several engineering competitions and the awards were significant career opportunities. The competitions were for women aged 16-19 and the task set for the participants was to find the best ways to increase the number of women in engineering and the construction industry. The participants brainstormed ideas that would engage more women in STEM, out of which Young Crossrail chose the best thirty ideas. Crossrail awarded those thirty students with the opportunity to attend the winner's day, where those students had a Crossrail site tour and met with leading women engineers in the construction and STEM fields. After the winner's day, Young Crossrail chose the five students with the best ideas and awarded them with a Crossrail engineer mentor for a year. Crossrail Central Section director Ailie MacAdam indicated that the main goal of the competition was to give young women access to successful careers in a skilled workforce (Eleftheriou, 2014).

WPI and Young Crossrail

In this section, we discuss the previous projects completed by Worcester Polytechnic Institute (WPI) students at Young Crossrail. We explain the learning outcomes from previous projects and how they inform our research and design.

2014 Young Crossrail Interactive Qualifying Project

In 2014, a team of WPI students developed an IQP with Young Crossrail to create STEM resources for key stage three (ages 11-14) students. The team designed several challenge-based activities to stimulate students' interests through four simplified STEM tasks. The IQP team designed the activities for groups of three to five students using low-cost materials commonly found in middle school classrooms, such as pens and paper (Handel et al., 2014).

The IQP team developed a programme package that included ambassador presentations, ambassador guidelines, and student activity sheets. Ambassador presentations help ambassadors to present the main activities of the programmes to students while guidelines provide ambassadors with the information they need to run the programmes' activities. Student activity sheets function as reference guides that students can utilise throughout their programmes to keep them on task (Handel et al., 2014).

After the trial programmes were completed, the team started to work on activity development. They gathered together and brainstormed to analyse the information that they researched and to define the criteria of successful ambassador programmes from their reviews of previously existing Young Crossrail programmes. They grouped these criteria into two categories: student criteria and ambassador criteria (Handel et al., 2014). Student criteria included factors that affected students' experiences in the programme and examined adaptability, variety, and student engagement. Adaptability refers to the extent to which a programme accommodated the range of student academic ability levels. Variety refers to a range of ethnic diversity, genders, learning styles, and interests which the team tried to incorporate in the programme. Engagement measures how much the students enjoyed the programme (Handel et al., 2014).

While the team developed four activities, Young Crossrail has only implemented two of them. The other two challenges required significantly more effort and time on behalf of ambassadors to learn and comprehend the supplemental information before implementing the challenges. This previous project demonstrates that effective programmes must engage students but must also be designed such that ambassadors can perform them independently. While the goal of the designers of STEM ambassador programme is to design a programme that engages students in STEM, they usually are not the ones who will facilitate the programme, but ambassadors are. They must develop activities that ambassadors can perform independently without designer intervention. To achieve independent implementation, designers need to devise the supplementary material to be both robust in information and easy to comprehend.

The 2014 IQP team also created an evaluation and improvement scheme that relied on feedback ambassadors would collect after the programme. This scheme promotes the programme’s long-term sustainability through consistent feedback after implementation, which can lead to design improvements.

2015 Young Crossrail Interactive Qualifying Project

In 2015, an IQP team worked with Young Crossrail to develop the Digital Railway Project: an open-ended ten to twelve-week educational programme for key stage four and key stage five students (Fitch, Friscia, Kovar, McCarthy, & Rivard, 2015). The IQP team divided the programme into engineering and creative components to connect structural engineering topics and technologies. In administering the team’s programme, ambassadors divided participating students into teams of four and asked the teams to plan, design, construct, and present concepts of their ideal future railways. Students worked collaboratively using a wide array of multidimensional modelling software, and the project team provided comparative analyses of the pros and cons of each software utilised (Fitch et al., 2015). In addition to formulating a curriculum, the students developed several resource manuals for their modelling software, as well as exercises that students and ambassadors could perform. In their design approach, Fitch et al. (2015) adhered to the Cambridge Nationals qualifications in Engineering Design and Creative iMedia. They also chose to pursue General Certificate of Secondary Education (GCSE) and Oxford, Cambridge and RSA Examinations (OCR) standards, which helped in their programme's subsequent accreditation.

While the 2015 IQP developed a strong and accredited curriculum, Lauren Hillier, director of Young Crossrail, believes the programme developed by Fitch et al. (2015) was overdeveloped (L. Hillier, personal communication, 23 March 2016). The wide array of multidimensional modelling software they utilised in their curriculum is too complex for ambassadors to teach to students. Moreover, their programme requires a profound amount of background knowledge of Building Information Modelling (BIM) software packages. BIM is a collaborative process, helped along by digital resources that allow for three dimensional computer modelling of assets. BIM unlocks more efficient methods of designing, creating and maintaining physical properties. The building information and computer model can be used for effective management of properties throughout a project's lifecycle – from concept through to operation. This heavy background, however, limits the number of STEM ambassadors that can facilitate the curriculum. Due to these limitations, Young Crossrail has been unable to implement Fitch et al.'s (2015) programme broadly. Their supplementary manuals and resources, however, do provide detailed explanations of the tasks that students would perform if they participated in the programme, as well as great resources for ambassadors who have learned how to use the programmes effectively. This example highlights the importance of creating programmes that are simple enough for ambassadors to access and implement effectively while still being engaging and challenging to students.

2.4. Design considerations

In this section, we review relevant theoretical and empirical work to identify best practices for the three main considerations in our design: keeping design prompts and challenges open-ended and contextual, remaining cognizant of gender, and using a hands-on learning approach.

2.4.1. Contextual and open-ended design

In 2009, the Royal Academy of Engineering (RAEng) teamed with corporate sponsor BAE Systems to deliver an Engineering Engagement Programme (EEnP) that ran for three full academic years and worked directly with over 300 schools ("Engineering engagement programme," 2016). In the years following this programme, RAEng shared a suite of resources aimed to assist any other organisation or individual with the goal of developing a similar programme. In 2011, RAEng released an EEnP entitled "Guide to developing resources" that has tips for developing the activity and lesson plan templates, includes ways to evaluate the completed programme, and advises on running an ambassador event. We find the most insightful section of this resource is titled, "How do you engage young people?" RAEng recommends keeping any presentations brief, using a variety of different audio/visual aids, incorporating hands-on activities, and using activity prompts that can be contextualised by the pupils to engage young people in the best way possible (The Royal Academy of Engineering, 2011).

Lesh and Zawojewski (2007) also promote a programme approach that ensures appropriate context to real-world engineering tasks. In contrast to regular problem-solving activities, Lesh and Zawojewski (2007) encourage the use of problems that require students to design and build a model that allows students to conceptualise a real-world design process. This approach encourages students to bring their STEM knowledge into an open-ended context, as opposed to applying previously learned STEM skills within a specific context to solve that problem. For example, One might ask how we can design a solution to add office space to a one-story building, leading the pupils to ask a host of questions about the task and to discover more than one way to solve the open-ended question, whereas a closed-ended problem might ask how can we add one story to this specific building using previous knowledge of structural engineering. Lesh and Zawojewski's (2007) method simultaneously allows students to learn STEM skills and also develop more of an understanding of the given situation rather than fully understand the situation and apply a close-ended solution (Lesh & Zawojewski, 2007).

Using Lesh and Zawojewski's (2007) model, English and Mousoulides (2010) developed engineering-based problems for an activity that facilitators implemented in sixth-grade classrooms that focused on redesigning the 35W Bridge, which collapsed in 2007 in Minneapolis, Minnesota. Students participated in these activities and engaged in a cyclic design process. As their groups progressed through the design process depicted, English and Mousoulides (2010) guided students through the following design steps:

1. **Ask -** There is not enough office space for all employees at a company: What is the task? What needs to be solved and in what context?
2. **Imagine** - Think about ways to solve the office space problem: How can we solve this problem?
3. **Plan** - Design a structure or structures that can host all of the employees: How can we model this problem; either on paper or with the given materials?
4. **Create -** Build a structure using the given materials to model your design: How can we follow our plan to create our model?
5. **Improve -** Think on what you did well and what you could have done better: What works in our model? What can be modified and improved?

After engaging in the above steps, students that participated in the activities expressed an initial frustration during the activity due to a lack of teamwork, but also stated that the challenge was exciting when the process of working collectively helped to uncover the real-world application of maths. Teachers that engaged in the implementation of these activities appreciated that the real-world application brought a refreshing ambiguity to the problems that students explored and that the programme required the students to work collaboratively (English & Mousoulides, 2010).

2.4.2. Gender-inclusive design

The UK Resource Centre for Women in Science, Engineering, and Technology (UKRC) provides guidance that is useful in the design of programmes that are gender-inclusive and engaging to young women (London Engineering Project, 2009). The UKRC and RAEng led the London Engineering Project (LEP) to encourage minorities to consider engineering as a career path. The UKRC has found through practice that focusing on the inclusion of young women in STEM ambassador programmes does not have any negative impact on the young men participating, but poor inclusion practices have a disproportionately negative impact on young women's engagement. The following guidelines should be applied to increase the chance that the resulting programme will be as gender-inclusive as possible (London Engineering Project, 2009).

1. Challenges must be appealing to both genders *e.g. women may be more interested in an engineering problem if they feel some personal identification with the problem, and that can be facilitated by providing examples of role models with whom they have something in common.*
2. Challenges must be designed with societal, environmental, or ethical context. Research indicates that women, in general, place greater importance on social relevance in their career choices, preferring jobs in which they can see clear societal impacts of their work (Betz, 2004). *e.g. rather than merely asking pupils to build a circuit with a light bulb, encourage them to design a circuit system using the light bulb to install in the home of a deaf person to alert the homeowner that there is someone at the door.*
3. Challenges must consider the language and images in all resources. Research indicates that women, in general, feel excluded by the practice of using non-inclusive gender pronouns and imagery (Mitchell, 1990). *e.g. do not overuse male pronouns with relation to female pronouns and if there are photos, are there as many women as men in the images?*

2.4.3. Active learning approach

Educators generally define active learning as an educational approach that engages students in the learning process (Prince, 2004). As opposed to traditional lecture-style methods in which educators simply provide students with information, active learning approaches promote student engagement through questions and student activities. The STEM programmes we researched all employ active learning approaches, particularly hands-on approaches, in their programme design. We researched multiple analyses to understand the importance of active learning approaches and their relevance to STEM.

In 2013, a team of analysts from the National Academy of Sciences examined how active learning approaches affect both student performance and retention. The team of analysts performed a meta-analysis of hundreds of independent American undergraduate STEM scholastic reports to determine how different educational approaches to equivalent STEM courses affect both student comprehension and academic performance (Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, & Wenderoth, 2014). The team concluded that students will perform statistically one half letter grade better when their educator employs active learning approaches than students who learn information through traditional lecture-style learning (Freeman et al., 2014). Moreover, students who are statistically in the 50th percentile academically in a class employing active learning approaches would transitively be in the 68th percentile in a lecture-style course (Freeman et al., 2014). Finally, failing students (analysts denoting failure as a scaled “D” or “F” in the course) in courses utilising active learning approaches composed approximately 21.8% of the total class population, while failing students in lecture-style courses composed 33.8% of students in the class (Freeman et al., 2014). Based on these results the team concluded that active learning approaches play a statistically significant role in both STEM student success and retention. Courses that employ active learning approaches statistically pass more students than lecture-based courses, and students statistically receive higher marks, correlating with a stronger understanding of course material (Freeman et al., 2014). By utilising active learning approaches, a higher percentage of students are likely to graduate with a degree in STEM and pursue a STEM career (Freeman et al., 2014).

To understand the effectiveness of active learning better, Dr Michael Prince investigated several different active learning approaches. Prince investigated collaborative, cooperative, and project-based approaches to identify how both scholastic and interpersonal factors contribute to student success. Prince examined a 90-year meta-analysis of collaborative learning approaches to examine these factors. Scholastically, collaborative learning leads students to achieve statistically 49% to 70% higher academic marks than students who choose to work individually (Prince 2004). Moreover, the meta-analysis measured student self-esteem through perceived student self-image on a scale from one to ten (Prince, 2004). Students who worked on collaborative methods have an average 41% higher level of self-esteem after the project than students who worked individually (Prince 2004). Prince repeated this analysis for both cooperative and project-based learning approaches with similarly conclusive results (Prince 2004). While some approaches may be better suited for certain programmes than others, all active learning approaches hold statistical merit. Prince also concluded that balancing both active learning and lecture learning approaches can greatly benefit students more than utilising solely active learning approaches (Prince, 2004).

2.4.4. Hands-on learning

Hands-on learning gives students clear motivation and focus. A well-known educational expert in the area of social constructivism, Wertsch (1990) reviewed the vast extent of Lev Vygotsky's work and his ideas on hands-on learning. Physical tools, like screwdrivers, and psychological tools, like symbols and signs, both function as essential parts of both performing an activity and comprehending why an activity leads to a particular result. Today, many educational psychologists agree that while understanding that an activity will lead to specific results is important, understanding how the result comes to fruition constitutes a deeper level of learning (Wertsch, 1990).

The author of an article about hands-on learning reviewed several different innovative primary science curriculum projects that utilised hands-on approaches to learning in 2010 (Satterthwait, 2010). Hands-on activities are activities that enforce educational principles through interaction with physical objects to achieve a goal or complete a task (Johnson, Wardlow, &

Franklin, 1997). The projects that Satterthwait (2010) examined differed in their academic merit, background, and subject matter, and were linked by her examination solely because each project utilised a hands-on learning approach. Satterthwait (2010) stated humans learn by comparing what they encounter in the present to their existing knowledge. Moreover, to make sense of encounters and develop a complete understanding, people share information with each other. Through her analysis, Satterthwait (2010) concluded that the hands-on studies promoted a complete comprehension of prescribed material than traditional, hands-off approaches.

The processes of learning are highly complex and psychologists try to categorise the collected data in “explanatory models” that make it easier to put findings in actual systems that generate possibilities for future applications (Spellman & Willingham, 2005). Because of this complexity described by Spellman & Willingham (2005), findings in psychological studies are rarely implemented when bettering education. Teachers may have difficulties understanding the psychological studies and psychologists may have difficulties understanding that class environments vary greatly and do not fall into a narrowly defined classroom form. Although it is hard to synthesise exact guides for quality hands-on activities, we can still glean general lessons from Satterthwait’s (2010) research.

- Programme designers should know the students’ existing knowledge about the topic before teaching and using group activities. This gives a good starting point for teaching and also helps to target weak spots or misunderstandings in students’ knowledge.
- Programme designers should establish an environment where students are involved in the active discussion of their knowledge by offering thought-provoking questions.
- Programme designers should allow students to experiment, manipulate, and test the given materials so they better understand the objects. Let them use their own ideas on how to use these items to achieve the given goal. The interaction with the objects will let them understand any properties or limitations of the given objects and understand the different outcomes of different uses of them.

Chapter 3: Methods

The goal of this Interdisciplinary Qualifying Project (IQP) was to address a lack of structured activities in science, technology, engineering, and mathematics (STEM) within the Young Crossrail programme. We worked with Young Crossrail and IStructE to develop a low-cost STEM programme that consists of a hands-on challenge as well as supplemental introductory and conclusory activities to engage key stage four (ages 15-16) students in structural engineering. The programme included supplementary materials for STEM ambassadors to utilise in the programme's implementation.

During the project, we worked on various tasks that made up three separate objectives:

1. Identify effective approaches for designing and implementing a successful STEM outreach programme.
2. Design a low-cost and age-appropriate outreach programme, with associated implementation guides, based on simplified engineering problems.
3. Assess and improve the programme.

Objective 1: Identifying effective topics and resources

In this section, we outline four specific methods that we used to identify important components of successful STEM ambassador programmes. We interviewed Crossrail professionals with a range of ambassador programme experience and asked about their source of interest in STEM, their experience with successful ambassador programmes, and their contributions to Young Crossrail. We reviewed the resources that IStructE and Crossrail provided pertaining to STEM ambassador programmes, and real-world engineering problems, and case studies that describe engineering for young adults. We also attended ambassador programmes to develop a better understanding of how they function. As the last part of this objective, we combined all of our experiences, resources, and interviews to create a model that outlines the criteria of a successful ambassador programme. The first three methods of this objective served the purpose of gathering information about successful ambassador programmes. The last method of the objective allowed us to frame the model of a successful ambassador programme by combining and analysing all the gathered information, allowing us to transition to our programme design.

Objective 1 - Method 1: Interviewing STEM professionals

Crossrail, Ltd. employs hundreds of professional engineers and non-engineers who have worked on the design, construction, and management of the Crossrail project. For our interviews, we specifically targeted those Crossrail employees and IStructE associate engineers who have had experience either with Young Crossrail or similar STEM ambassador programmes. These employees provided us with data about how to create successful ambassador programmes, frame real-world engineering problems, and address the gender gap in STEM.

We conducted our interviews with the following overarching research questions in mind and asked the interviewees specific questions designed to elicit responses that would address the larger research questions. Although our interviews were informal, we generally progressed through our discussion topics in the order below.

What motivates people to pursue a career in STEM?

We interviewed engineers and non-engineers to answer this question. The interviewees helped to identify which components of the STEM career would be helpful to emulate in a challenge to promote student interest in potential future STEM career paths while also minimising student disengagement (e.g. the component of the construction industry that may interest children might be that each building finished will be used by many people for years to come)

What components make up effective and ineffective STEM ambassador programmes?

We interviewed people who have participated as ambassadors in Young Crossrail and/or some other STEM ambassador programme to answer this question. The interviewees helped to confirm that challenges and activities for our programme were age-appropriate and if they were not, how we could modify them accordingly. We designed the challenges to achieve the maximum engagement of participants (e.g. use hands-on tasks) and to minimise a number of procedures that proved to be ineffective in previous STEM ambassador programmes (e.g. be clear in student prompts). The answers from interviewees were both broad and specific and informed our decisions on how to design a programme to be interesting to students to promote outreach and interest.

How can we use real-world engineering tasks in an effective STEM ambassador programme?

We interviewed engineers who have participated as ambassadors in any Young Crossrail programmes and/or any other STEM ambassador programmes to answer this question. By interacting with these engineers we identified what kind of real-world engineering problems might interest young people (e.g. a new Underground line). These interviews gave us details of specific projects that aim to solve real-world engineering problems and gave us an opportunity to choose some essential details from each problem when creating a simplified version of a real-world engineering project for our STEM programme.

How do Young Crossrail and IStructE define success in their ambassador programmes and what makes their programmes different from other ambassador programmes?

We interviewed people who have held ambassador roles in Young Crossrail programmes or any other STEM ambassador programmes to answer this question. We used this information to identify the clear objectives and requirements of Young Crossrail and IStructE ambassador programmes and to make sure we follow these requirements and objectives. The answers to these questions showed us the individual preferences about outreach methods for Young Crossrail and IStructE ambassadors. These preferences guided us when designing the challenges and activities to make sure that our programme fits the norms of Young Crossrail and IStructE ambassador programme principles and protocols and helped us to achieve a common goal.

How can we ensure that our STEM programmes are gender-inclusive?

We interviewed people who have held ambassador roles in Young Crossrail programmes or any other STEM ambassador programmes to answer this question. We utilised these answers to identify potential causes of gender inequality in STEM careers and in STEM ambassador programmes, effective approaches that our programme can utilise to address the issue of gender inequality in STEM ambassador programmes, and misconceptions on methods to address the complexity of gender inequality in STEM ambassador programmes.

Interview Logistics

We decided to make our interviews informal to allow us to add more questions throughout the interview. Informal interviews also allowed us to have more in-depth discussion about specific topics for our project rather than strictly abiding by our pre-structured question set.

Recording and Preamble

Recording the audio of our interviews allowed us to review the interview, check if we missed any details, and analyse the content at any time of our work. Because we recorded the interviews and used information from those interviews in the results of this research, we drafted a preamble to explain to interviewees that we planned to record the audio of the interviews and that our interviews were not fully confidential or anonymous. We informed the interviewees that we planned to use their names and job titles along with their direct quotes to inform our research paper. We also notified the interviewees that the research was completely voluntary and that they could refuse to answer at any time. We then recorded their responses to consent or not consent to the conditions of the interview. This preamble can be found in Appendix A.

Roles

We divided our interview process into three roles and assigned ourselves the roles that would maximise the use of our individual skills and as a result, maximise the quality of how we collected information. Seth took the role of the interview leader; he made introductions, led the interview, and asked the main pre-prepared questions and supplementary questions to engage the participants in the interview. Reed took the role of the recorder; he recorded every part of the interview in writing, took part in discussions, and asked questions that appeared to be missing while he took notes. Vakhtang took the role of the observer; he took short notes to make sure nothing was missed, made sure there were no research questions missed by checking the main topics off from the list, and also thought of new questions to fit the current conversation and accentuate certain points of discussion. In this way, we achieved engagement from interviewees, recorded all information, and made sure to answer all of our research questions.

Post-Interview Analysis

After each interview, we spent some time to analyse the useful information that we gathered in the interview and to evaluate how effectively we ran the interview. We talked about the new answers that we gathered for our research questions and edited our collective answers to reflect these changes. Our intention was to identify what did and did not work well when interviewing, enabling us to improve our interview strategies for later interviews.

Objective 1 - Method 2: Review programme literature

We accessed all the programmes that Young Crossrail has facilitated since its genesis. We looked through these files and identified Crossrail engineering problems to reflect on when designing our challenges. We evaluated Young Crossrail projects that included some feedback and identified potential positive and negative qualities of STEM ambassador programmes. We used these resources to find information that was related to our project, shared that information with each other, and utilised these resources to inform our choices throughout the whole project.

Objective 1 - Method 3: Attend ambassador programmes

We attended ambassador programmes to observe how ambassador programmes run as well as gather information about how students reacted to the programme while observing and interacting with ambassadors and other participants of the programmes. While attending these programmes, we learned which activities are especially fun and engaging for young adults and what makes the others unappealing. We also had conversations with organisers and shared information about our project, which led to them giving us suggestions pertaining to informing people about engineering and running STEM ambassador programmes. There were clear logistics that we needed to consider in our design, like time requirements, and the programmes that we attended showed us how ambassadors handle these logistics within the STEM ambassador programmes. Some questions that students had about engineering informed what we covered in our presentations as well as what questions the ambassadors needed to be prepared to answer.

One ambassador programme that we attended was held by The Institution of Mechanical Engineers (IMechE), the Institution of Engineering and Technology (IET), and the Institution of Civil Engineers (ICE). The event was called Engineering Your Future, which took place on 18 March 2016 at IMechE. We attended the event to observe a STEM ambassador programmes first-hand. The event aimed to illustrate the diverse careers available in engineering, to encourage 15-18-year-old students to study engineering after leaving school or college, and to increase public awareness of the importance of engineering to society and the economy. Four companies took part in the programme, one of them being Crossrail. The event was held for five different groups of students, each rotating through events at 45-minute intervals, seen in Figure 2 below.

Figure 2: Timetable from typical IMechE "Engineer Your Future" event.

09.30 - 10.00	**Registration**
10.00 - 10.20	**Welcome Talk**
10.25 - 11.10	Company Workshop 1
11.15 - 12.00	Company Workshop 2
12.05 - 12.50	Careers Speed Networking
12.55 - 13.35	**Lunch**
13.40 - 14.25	Company Workshop 3
14.30 - 15.15	Company Workshop 4
15.20 - 15.30	**Close**

The activities will be run by organisations such as:

- **Firstco**
- **Transport for London**
- **Crossrail**
- **Bechtel**

(Institution of Mechanical Engineers, 2016)

We decided that it would be most effective if we split our team and each team member joined a different group. This allowed each member to attend every event individually, allowing each group member to compare and contrast his experiences with the programme while identifying differences between different ambassador and participant groups. After the event, we discussed our experiences to understand commonalities or differences amongst them.

Objective 2: Design challenges and materials

Our programme included a hands-on challenge to promote student engagement and emulate engineering problems that participants may face in potential structural engineering careers. The challenge followed the design, bid, build approach, which is a commonly used approach in structural engineering. We address these components in greater detail later in this section, but briefly, the design phase tasks teams of students to create a blueprint of how they will address the problem our programme presents. The bid phase asks the teams to present their blueprints to their ambassador, who will critique and either accept the bid or deny it, according to a set of guidelines we provide. Finally, the build phase instructs the teams to construct their blueprint out of low budget materials and test its structural integrity.

Objective 2 - Method 1: Challenge considerations

To provide participants with exposure to authentic engineering problems, we used real-world examples to design our challenge. After several discussions with ambassador interviewees and current news coverage in London, we identified the housing crisis as the real-world problem that we would use as the basis for our challenge. To create a simplified simulation of the housing crisis challenge, we investigated population statistics and projected growth rates over the next twenty years. We visited national and borough-specific government websites, as well as performed history literature reviews. Doing so allowed us to identify what major factors contributed to population growth and what geographic areas of the city were most affected. We used this information to create a simulated environment for the hands-on challenge and introduce teams to the problem they will work to solve. We incorporated these statistics into several aspects of our challenge design, some of which will be covered later in this section.

Students were grouped in teams to model the creative design process of an infrastructure project, requiring many soft skills that can be challenging, but rewarding to work through as a teenager. For a design project to work, each person on the team must work collaboratively within their individual skill sets to produce an individual result that will contribute to the whole. We mirrored this teamwork in our programme and defined which roles students will fulfil in our programme, and how each role will interact with the other roles. We created roles that students will choose to perform during the challenge based on aspects of a real structural engineering project. After being placed into teams of three, the students will be able to choose whether they wish to act as the group's primary architect, structural engineer, or project manager. We researched the primary goals and objectives of each of these roles within a construction project by utilising Young Crossrail's resources on Crossrail's servers and provided simplified descriptions for the students to give them direction in their hands-on challenge. In addition to providing simplified job descriptions, we researched several accomplished engineering employees that work in each of the three roles and created case studies for each of the employees. We placed an emphasis on researching equal numbers of both male and female engineers and ensured that each role description included at least as many case studies of women as it did men. We analysed these case studies to identify key characteristics of how individuals attained their position and how they have succeeded in that particular role. We presented both the characteristics and case studies in the student brief manual to help students connect their own skill sets to potential future careers in STEM.

Finally, to create challenges that both encourage students to work collaboratively and utilise their learned skills, we researched key stage four maths and physics standards and incorporated the appropriate material from these subjects into the three phases of the challenge.

Design Phase

We framed our design phase around the housing crisis that the city of London and its policy makers currently face. We designed a simulated landscape that reflects simplified versions of different geographic regions within the greater London area. We researched zoning laws and utilised population growth statistics provided by the UK government to calculate a proportionally accurate percent population increase for our simulated landscape, which we discuss in greater detail in our results section. We also utilised structural engineering textbooks (Hibbeler & Kiang, 2015) to identify common structural engineering materials commonly utilised in different housing complexes, such as structural steel for multi-story apartment complexes and average costs for materials and percent of the materials utilised in building schemes (e.g. a certain percent of the budget on average is allocated to cement for the foundation). We synthesised these statistics to identify an appropriate amount of material teams should have access to and selected an amount of funds that students will utilise to budget their final deliverables for the design of their blueprints. Moreover, we researched average building timelines for housing complexes with costs of labour to create a simulated timeline that students will modify and include in their blueprint. We did a preliminary timed trial run in which we designed several possible blueprints to determine the average amount of time it took us as designers to complete the project. We provided ambassadors with our supplementary materials and trial run findings and collected their feedback on estimates for a timeframe for the design phase for key stage four students. We synthesised this feedback with our trial run outcome to arrive at an estimated amount of time that we believe students would need to complete this portion of the challenge.

Bid Phase

Our bid phase allows teams to present their blueprints to the ambassador before they transition into the build phase. We researched costs for poster boards and markers that students will utilise to create posters for their bids. We travelled to local crafts stores and researched competitive online prices from online retailers to find budgeted options for craft materials that ambassadors and future programme facilitators can purchase to implement the programme. To identify online retailers, we performed online searches of particular products and selected retailers that had both the lowest prices and were located in the UK to minimise shipping costs and timeframes (for a complete list of materials needed for our programme, where we obtained them, and at what cost, please see appendix B). We performed a trial run of the preliminary bid phase as designers and gathered ambassador feedback via surveys to identify an estimated amount of time that teams will need to complete this portion of the challenge.

Build phase

Our build phase tasks students to translate their ideas into a deliverable. We utilised low budget craft materials to represent structural engineering materials (e.g. craft straws represent structural steel beams and pipe cleaners to function as structural joints). We again identified the most cost effective methods of acquiring the materials by travelling to several craft stores and searching UK-based stores online and identifying the most affordable materials. After comparing and purchasing low budget materials, we ran several build trials utilising our design phase blueprints to identify which materials could be utilised effectively. After these trials, we refined our list of materials, removing underused materials and adding new materials that we initially had not incorporated. We also timed our build process and surveyed STEM ambassadors to estimate an appropriate amount of allotted time for student teams.

During the build process, ambassadors will provide students with conflicts that structural engineering projects commonly face (e.g, the price of steel has risen by 15%. How will this price change affect your build process?). We interviewed structural engineers working within Crossrail, as well as performed literature reviews, to identify these common problems.

Objective 2 - Method 2: Student and ambassador guides

In addition to developing challenges that ambassadors can implement in classroom settings, we created supplementary ambassador manuals and student brief manuals that will help ambassadors to facilitate the programme and provide students with pertinent information that they can reference during the challenge. We researched previous ambassador programmes that

Young Crossrail ambassadors have implemented to identify key characteristics of their ambassador and student manuals. After studying several handbooks and manual resources, we constructed a template that follows the same progression as the researched materials to produce a consistent product that aligns with the direction of Young Crossrail's other programmes.

Ambassador guides

Our ambassador guide covers both technical aspects of programme implementation as well as student considerations. To introduce ambassadors to our challenge and frame the problem they will present to the students, we researched and presented statistics about the housing crisis and population growth. We recorded notes and documented our trial runs of our challenge during its design, and synthesised the results to create a set of objective modules for our programme. The objective modules function as step-by-step objectives that outline key parts of each hands-on challenge phase (e.g. the objective modules of the bid phase would include poster creation, student presentation, and bid assessment components). These sections contain information about each portion of the challenge phase, including descriptions of the module and its relevance to the phase, common problems that teams face in that module, and ways to address struggling teams in that module. We utilised the notes from our trial runs to create the first draft of this section of our guide and gathered ambassador feedback on the draft via digital surveys to improve the draft's content.

We used our insights from the ambassador programmes and interviews (described in objective 1) to create supplementary discussion-based sections for ambassadors to facilitate after the design, bid, build portion of the programme. In particular, we reflected on a STEM professional speed networking event that we attended, an event in which groups of students had brief, guided discussions with professionals in particular fields to learn more about how students can pursue a career in that field. We utilised discussion questions that STEM professionals covered at the event, as well as interviewed professional graduate engineers and apprentices, to develop discussion topics for ambassadors to pose to students both before and after the challenge. The questions aim to identify career paths that students can take to pursue careers in

STEM (e.g. which A-levels to take to prepare for a civil engineering major at university), as well as address common questions about what persons working in structural engineering projects do in their particular fields. Since we focused on structural engineering in our programme design and STEM covers a large number of career paths, we limited our discussion topics to careers advice within structural engineering projects. We interviewed ambassadors to identify where we should implement this portion of the challenge in our programme.

We also researched the WISE Campaign's gender-inclusive online educational resources (WISE, 2016) and created a section in which we addressed both the importance of gender-inclusiveness in our programme and also developed ambassador guidance on how to promote gender-inclusivity when facilitating the programme. We presented the manuals to ambassadors to gather feedback about their initial design and content and adjusted the manuals accordingly.

Student brief manuals

After we designed our challenges and ambassador guides, we created student brief manuals to answer common questions and give the students instructions for each task. We designed three distinct guides, one for each role, to address the objectives of each team member. To design the guides for these specific roles, we reviewed the literature and researched specialists in each specific role. We used this information to ensure our challenges and guides reflected actual work done by specialists in these areas. By defining these specific roles, we were more equipped to explain those areas of engineering to students and implemented similar roles in our student manuals. Student manuals will contain pertinent materials only to that specific role's objectives (e.g. the structural engineer student brief manual will contain the costs and properties of each individual build material, but will not contain the total allotted money for the project). Ambassadors will inform students that each group member has some portion of the needed information, and students will need to exchange information and collaborate in order to create their deliverables.

Objective 3: Assess and improve the programme

Our methods to achieve the assessment portion of objective three were two-fold: we surveyed ambassadors and pilot tested a component of our challenge in order to assess its effectiveness. We used observations and constructive criticism from pilot testing and survey results to revise and improve the programme.

Objective 3 - Method 1: Pilot testing

Our team also had the opportunity to implement a truncated version of our programme in a classroom of real students. This pilot test took place at Sherborne Girls' School, Dorset on Monday 18 April. Our host, Jo Massey, is a practising structural engineer and physics teacher at Sherburne. She allowed our team to pilot a portion of our programme to her all-girls classroom of 13 and 14-year-old physics students. Since we had only an hour with the students, we chose to do a truncated version of the design phase, a portion of the challenge which we estimated would take roughly two hours to complete. We confirmed the visit and requested the students be prepared with calculators, pencils, paper, and protractors for their challenge design phase. When we pilot tested the programme, our team and Ms Massey functioned as the STEM ambassadors and programme facilitators to assist the teams throughout their design phase. This was particularly helpful as we gathered feedback on how smoothly the programme ran, the difficulties that occurred, and how well our guides provided instructions for the participants. After we facilitated the programme, we met with a team of STEM educators to review our materials and gather additional feedback. We examined both the materials used to facilitate the programme and ways we could improve them, as well as the programme's relevance to student academics and STEM education as a subject. We also gauged how well students could follow the student guides. We observed and recorded all questions relating to the guides and edited each section that students found unclear to be clear for future participant use.

Objective 3 - Method 2: Ambassador feedback

Young Crossrail's network of over 250 ambassador volunteers delivers a variety of STEM outreach programmes under the umbrella of Young Crossrail and many of the ambassadors also participate in other outreach programmes like STEMnet. While these ambassadors do not have extensive training in the delivery of educational programmes, many of them have extensive practical experience in running such programmes, and thus, their assessment of our programme was invaluable to the quality of the programme, specifically in the assessment of the ambassador manual.

On 22 April 2016, we emailed our programme outline and supplementary materials (Appendix D) along with our set of research questions, to the STEM ambassadors we interviewed during our initial design. We asked the ambassadors to review our programme outline and supplementary materials and provide additional feedback on their beliefs of how well the programme addressed our research questions, as well as potential final revisions that we could make to the programme. This email is in Appendix C.

We requested that ambassadors provide feedback by Wednesday 27 April 2016 and stopped taking responses on Thursday 28 April 2016.

Objective 3 - Method 3: Improving the programme

We reviewed the data from ambassador feedback and sorted the qualitative responses into two categories: exclusionary and inclusionary.

We defined exclusionary responses as those that would incite a change in our programme that would satisfy that respondent, but could have a negative impact on other respondents (e.g. the respondent asked for the programme to be redesigned using building material of a higher cost and quality because that respondent was willing to invest more money into the programme.) That change would likely alienate many other respondents that do not feel the same way. Exclusionary responses that obtained wide support were given special consideration on a case-by-case basis.

We defined inclusionary responses as ones that would incite a change in our programme that would benefit all respondents (e.g. the respondent asked for a better definition of a word in a section of the ambassador guide.) This change would likely be beneficial for all respondents and therefore, we would address that comment no matter how many respondents concur.

Chapter 4: Results and analysis

4.1. Programme design

In order to develop a programme that Young Crossrail could utilise effectively, we first needed to derive exactly what made a STEM programme effective. To develop our programme to engage key stage four students and be administered by ambassadors from Young Crossrail and other organisations, we first gathered stakeholders' criteria of effective STEM ambassador programme through interviews and observations. Stakeholders include Young Crossrail and IStructE liaisons, STEM programme ambassadors, STEM professionals, and students with whom we pilot tested our programme. The following chapter synthesises and analyses stakeholders' criteria for a successful STEM programme.

4.1.1. Young Crossrail and IStructE liaisons

In our first meeting with our sponsor liaisons, Lauren Hillier of Crossrail and Nick von Behr of IStructE, we spoke about the merits and limitations of the previous years' IQP results. Ms Hillier, being more versed in these programmes, advised that our result should be simpler and more easily implemented than the "Build your own digital railway" programme, but should also be more interconnected than the four unconnected and individualised programmes developed by Handel et al. (2014) (L. Hillier, personal communication, 23 March 2016). We decided that the best way to address these concerns would be to develop a programme that could both be implemented all at once and be implemented over multiple sessions. Mr von Behr of IStructE, who has not worked with Crossrail or WPI before, communicated that the programme should have some structural engineering context and reflect one or more real-world problems that structural engineers can solve in their careers (von Behr, personal communication, 15 March

2016). Both liaisons stated their concerns about time and cost commitments that ambassadors could face when implementing the programme. We decided that the best approach would be to design a programme that uses low-cost materials and can be implemented easily by ambassadors with little time commitments for the preparation of the activity. Ms Hillier also emphasised that this programme could be part of Young Crossrail's learning legacy document that Young Crossrail will submit as a portion of Crossrail Limited's synthesis of lessons learned as a resource for future large-scale infrastructure projects. We were told that while Young Crossrail will be phased out in September 2016 and our programme will be taken over by IStructE, the programme should carry the Crossrail name and values, while also incorporating a structural engineering focus, reflecting the interests of IStructE. We, therefore, developed a comprehensive package (programme and all supplementary materials) so that it could be carried on by anyone who reads the learning legacy document.

4.1.2. STEM programme ambassadors

In our several meetings with STEM ambassadors, our interviewees emphasised the importance of how content development affects programme success. To create a successful programme, we asked several STEM ambassadors how they defined success in programmes they facilitate. Josh Milton, a 23-year-old graduate engineer and Young Crossrail ambassador, emphasised that the level of student engagement ultimately defined a successful STEM ambassador programme. Milton explained that he had noticed that appealing to students' interests by allowing them to engage in a wide variety of roles, rather than focusing on one, in particular, best engages the most diverse groups of students (Milton, personal communication, 16 March 2016). By focusing on one particular role rather than several, some students may not have the opportunity to discover aspects of STEM that they may enjoy. We decided that the best approach would be to design a programme that incorporates the organisational structure of real-world structural engineering projects and introduces multiple roles and stakeholders rather than just the structural engineer's role.

We also asked ambassadors about the best methods for implementing our finished product after its development. Andreas Schoeler, a mechanical engineer and STEM ambassador for Crossrail, emphasised the importance of proper ambassador instruction in successful STEM ambassador programmes. Mr Schoeler discussed a successful STEM speed-networking ambassador programme (where students meet with ambassadors for a short amount of time around a table to ask about their STEM experience) that he attended, and noted that it was successful because the programme designers created clear content via interview questions that ambassadors could use to engage the students (Schoeler, personal communication, 21 March 2016). According to Mr Schoeler, having well developed and easily implementable materials can be deciding factors when creating a programme as much as the programme itself. To address this suggestion, we combined this knowledge with research we performed on existing STEM ambassador programmes and created supplemental programme content for both students and ambassadors that explains both the objectives and methodologies of the programme.

4.1.3. STEM professionals

Based on our literature review, we opted to use the effectiveness of hands-on activities that reflect real-world problems to frame our programme. We suspected that students would learn about STEM careers and gain an understanding of where they can apply their engineering skills while using this approach. When asked, the professional engineers that we interviewed said they followed STEM careers was because they had good skills in STEM subjects, but they wanted a place to apply them in the real world. Mr Milton, like most of the engineers that we interviewed, said that he was always good at physics and maths, so he chose mechanical engineering as a career path because it used both of his favourite skills and allowed him to contribute a tangible product to society (Milton, personal communication, 16 March 2016).

We tried to find examples of some specific real-world engineering projects that we could parallel when designing the activities. Several respondents' examples of engineering activities mentioned designing a train station or bridges using structural engineering skills, but also mentioned that these projects are already overused by several STEM programmes. There are already STEM programmes using activities about building bridges with materials like spaghetti and marshmallows (Hillier, personal communication, 15 March 2016). Mr Milton suggested that we do something unique to other STEM ambassador programmes because repetitive activities can leave students uninspired (Milton, personal communication, 16 March 2016). To avoid repetition, we tried to choose a real-world issue that is both relevant to the modern UK and includes the use of structural engineering and other STEM skills. In our interview with both Mr Schoeler and Mr Chang (a graduate mechanical engineer at Crossrail), we talked about real-world engineering projects happening around London today and they mentioned the development of Graphene, a very strong, light, and new building material. Mr Chang mentioned the unique way that the engineers of the Leadenhall Building, or "the cheese grater," have built an elevator inside one of the largest buildings in London, building only off one side of the elevators, rather than fully around the elevator shaft, leaving a larger floor area undisrupted (Schoeler & Chang, personal communication, 21 March 2016). These recommendations led us to a conversation about the housing crisis in London, a relevant and challenging new problem for policy makers and engineers alike.

In our interviews with STEM professionals, we tried to understand what piqued their interest in STEM fields and careers. Most respondents were interested in STEM fields at young ages due to building toys like Lego or role models that were perhaps even relatives. Mr Milton recommended us not to force children into engineering if they are interested in different career paths. Both Milton and Schoeler stated that by the age of 14-16, students have specific subjects that feel proficient in and they like. Instead of focusing on turning an artistic personality towards mathematical engineering, they recommended that we highlight all facets of an engineering project, including the jobs that might bring in an artistic personality, like architects or advertising teams (Milton, personal contact, 16 March 2016). We also interviewed several Crossrail employees who are not engineers, and they stated that they thought that because they were not great at engineering and maths, they should not pursue engineering as a career, but are happy that they got the opportunity to work alongside engineers and call themselves STEM professionals for an engineering project that has an impact on greater London (Groom, personal communication, 21 March 2016). Interviews with Crossrail staff helped us to see that we can not only provide inspiration through STEM activities, but also, help end the misconception that engineering is all about maths and physics, and therefore help people get the relevant information they need to pursue a career in STEM. In our interviews, we learned that engineering is a very vague and broad term in the UK. The term “engineer” is unprotected in the UK, leading to many misconceptions about the career. The mechanic that works on your car has the same right to call himself an engineer as the woman that has a patent for a prosthetic leg (Langdown, personal communication, 21 March 2016). It is most effective to explain what engineers do and give examples that describe how broad the term engineering actually is in practice. Most of the engineers we interviewed describe engineering generally as ‘problem solving' that can apply to a wide range of subject matter.

Through our research and interviews, we identified several issues that led to a lack of engineers in the UK. One of the issues that we often identified was that students do not have a clear understanding of the career options they have as engineers or the paths that they can take to pursue those careers. In our interviews, we talked about different paths that students can take after school: pursuing an apprenticeship or going to university. Mr Usher said that we need to try to show the students the path to be an engineer and give them direction so they can understand future career path opportunities (Usher, personal communication, 15 March 2016). Many respondents highlighted the importance of apprenticeships versus the traditional university programme for some students that may not learn as readily in a classroom setting. Both pathways are viable options towards the same engineering career and apprenticeships are underutilised in Mr Kanu’s opinion. Most students are not aware of the options that they have before they enter university. Now, young people have the opportunity enter apprenticeships that include real-world working experience instead of a university programme. Some people do not enter an apprenticeship because their parents think that university is the traditional way of learning and is, therefore, the correct path to follow. Mr Kanu recommended that we explain the pros and cons of apprenticeships so that people know better the choices that they have (Kanu, personal communication, 23 March 2016)

4.1.4. Synthesis

Based on the data collected and the synthesis of our results above, Table 1 outlines the major criteria for our programme design.

Table 1 – Major stakeholder criteria for programme design

Stakeholder	Major criteria
Young Crossrail and IStructE liaisons	● singular, multi-faceted programme ● structural engineering based ● low budget ● learning legacy
STEM programme ambassadors	● hands-on programme ● student engagement ● strong supplemental materials
STEM professionals	● model real-world problems ● inform about engineering ● academic and career advice

Each stakeholder group holds different interests but contributes criteria to a programme that hopes to engage and satisfy all stakeholders listed.

4.2. Programme Overview

Our challenge will task teams of three students to design, present, and create a model of a housing complex suited to house 200 people. Students will be given anywhere between 4.5 and 6 hours (depending on ambassador preference) to complete their challenge. Before the hands-on challenge portion of the programme begins, the STEM ambassador team that will facilitate the programme will give an interactive introductory presentation that introduces students to structural engineering and the housing crisis. The ambassador team will comprise of a one to three ambassador to student ratio, which will be necessary for the hands-on portion of the programme. After the introductory presentation, ambassadors will break students into teams of three to begin the hands-on portion, with one ambassador accompanying each team of three students.

Once the challenge begins, students will first choose one of three roles that they will fulfil in their groups: the project manager, primary architect, and structural engineer. Each team will have an individual STEM ambassador who will assist the group throughout the entirety of the challenge, answering student questions and helping to resolve conflicts the team may face. First, the students will work on the design phase of the programme, which will take teams roughly one and a half to two and a half hours to complete. The teams will choose from one of three housing complex designs: one large apartment building, two to three multi-storey townhouses, or about a dozen two-family homes. After they choose their land plot, teams will work together to design the exterior and footprint of their building or buildings. When the students create the footprint and exterior, they will begin individual work based on the roles they chose. The architect will develop floor plans for each of the floors in their buildings. Architects will fit appropriate flats within each footprint for each floor. The structural engineer will take the building exterior and footprint and identify which materials their team can use to build the structure(s), and what quantity of those materials they will need. The project manager will create a timetable for building their structure(s) and additional amenities like the electrical and heating and air conditioning systems by creating a schedule with associated time constraints for each amenity. The project manager will also create a budget with the materials the structural engineer chooses to utilise. The design phase is the most time and labour intensive portion of the challenge, and will require the most ambassador assistance. Because of this time constraint, we recommend the aforementioned one to one ambassador to team ratio. Common tasks that ambassadors will face throughout this portion of the challenge will include assisting in floor plan design, assisting in structural engineer material quantity calculations, and assisting in timetable optimization. After the design phase, students will transition into the bid phase.

In the bid phase, the teams will create a poster presentation of their programme design and present it to their ambassadors. This portion of the challenge promotes public speaking and communication skills, both valued in structural engineering projects. This phase will take roughly half an hour for teams to complete. Students will present their individual findings and deliverables from the design phase (e.g. the architect will present and explain her finalised floor plans), and will answer any questions the ambassador may ask. Ambassadors will constructively critique student designs in this phase and ultimately accept the student bid after they decide the team has created a sufficient product. As each team design will be different, ambassadors will use their best judgement to determine when the team's design is ready based on student effort, deliverable quality, and student creativity. After the ambassadors accept the team's bid, the team will transition into the build phase.

In the build phase, the team will use associated low budget materials to create a model for their structures that represent the structural designs they created in the design phase and presented in the bid phase. Depending on team designs, this portion of the programme will take students an estimated one to one and a half hours to complete. Students will only build the exterior skeleton for their buildings, and do not have to create individual floor designs. Students will not focus completely on making a precise scale model for their finished products as creating accurate scalars are above the level of most key stage four student, and rather will focus on creating structures that are structurally stable and reflect the concepts they devised in the design phase. Students who designed multiple buildings with the same designs (most likely the students who chose to do the one dozen two-family homes) will not need to create multiple of the same model, and should instead focus on creating well-built models for each unique design. In this phase, the ambassadors will work with the teams to optimise their structural models by showing students efficient ways to utilise their materials and assist students should they struggle to make their building structurally stable.

After the challenge concludes, all of the teams will present their finished builds and discuss in an ambassador-led open discussion what challenges their teams faced, what successes they had, and areas where they can improve. Finally, ambassadors will lead a discussion with all of the teams to connect the challenge with real-world engineering problems that students may face should they choose to pursue a career in the field. Ambassadors will also offer careers advice to students about different courses that they can take for their A levels, as well as educational paths they can take as either academics or apprentices to pursue careers in structural engineering.

Supplemental guides

Both our liaisons and the ambassadors we interviewed stressed that a successful programme requires excellent supplementary materials. We, therefore, developed several supplementary guides for students and ambassadors to refer to throughout the programme to aid in its implementation. When designing our guides, we referred to manuals used in previous Young Crossrail STEM ambassador programmes, such as the 2014 IQP *Clockwork Challenge* and the 2015 IQP *Build Your Own Digital Railway Challenge*, and altered the content to fit the programme we designed. The supplemental ambassador and student guides follow the structure and content that we describe below.

Ambassador manual

We developed an ambassador manual that each ambassador can utilise throughout his/her programme facilitation. We developed multiple sections for the manual to aid the ambassadors in each aspect of the challenge, which we describe below. For the complete ambassador manual, please refer to Appendix D.

Welcome and Introduction

The welcome and introduction section provides a brief summary of the purpose of the manual and background of the challenge at hand. It includes a brief list of ambassador expectations that the guide covers in greater detail in subsequent chapters and explains the importance of ambassador facilitation within projects. The section as a whole allows ambassadors to develop an understanding of the entire programme and the key aspects of their role in the programme's success. This section also introduces ambassadors to the design, bid, build approach. The guide covers the ambassadors' roles in greater detail in the ambassador expectations and requirements section.

Programme rules and modules

The programme rules and modules section explains the main learning objectives, rules, and ambassador expectations of the students participating in the programme. The rules section provides a list of the technical aspects of the challenge. This section includes time or resource constraints and group sizes. The section also contains ambassador expectations of students like deliverables and student behavioural expectations. Finally, the section includes an overview of the modules, outlining the tasks that students will need to complete individually and as a team throughout the challenge. The section provides ambassadors with guidelines needed to facilitate the programme and stages and behaviours to look for in their students.

Expectations and requirements of ambassadors

The expectations and requirements of ambassadors section outlines what the ambassadors should focus on to facilitate their challenge. The section begins by explaining why ambassadors are important to challenge success, and the goals of the ambassador. Ambassadors are not simply facilitators for programmes; they need to create proactive environments where students feel enthusiastic about the challenges they undertake. The expectations of ambassadors section highlights behavioural patterns that ambassadors should follow in their facilitation and includes information about how to communicate with students and how an ambassador's behaviour can influence a student's experience. The expectations of ambassadors section addresses how ambassadors should act when interacting with students. The requirements of ambassadors section includes logistical information like ambassador time commitments, level of student interaction, and general programme scheduling. The section explains the ambassador's role in the design, bid, and build approach.

Student design brief

The student design brief provides a presentation and explanation of the challenges which the ambassadors will deliver to students. It highlights pertinent information from other sections, such as student expectations and rules, as well as key stages of the programme. This section presents ambassadors with the challenge in greater detail and helps them to understand its mode of operation. The section also includes the challenge's main deliverables so ambassadors will have an idea of the end goal of the programme.

Conflict resolution

The resolution section offers resources for common problems that students and ambassadors may face throughout the course of the challenge. This section highlights resolutions to technical problems, such as ways to handle damaged parts of student deliverables. It also includes methods for resolving group conflict if the challenge is group oriented or ways to work with disengaged students. Finally, this section includes discussion questions for the specific challenge that the ambassadors lead after the hands-on portion of the programme. These questions are open-ended and allow participants to reflect on and learn from their activity.

Student manual

The student manual contains pertinent information to assist students in their challenges. It contains a synopsis of the rules, materials, expectations, and deliverables for the student, allowing the student to refer to it throughout their challenge. The section also contains supplementary materials that students may require when completing their challenge (e.g. how to use a protractor). We developed several student manuals, each specific to the three different roles. While the structure of the manuals is consistent between them, the content of the manuals is specific to each role. Refer to Appendix D for the complete student manuals.

4.3. Programme revisions

While initially developing our programme, we did not gather student input on our design process. Student input during programme creation has several limitations; students do not necessarily understand programme design, development, or implementation, nor should they be expected to understand. We instead developed our programme and then piloted it with a group of students at Sherborne Girls' School in Dorset. We worked with a key stage three physics teacher, Jo Massey, and her class of thirteen and fourteen-year-old students. Because we only had one hour to implement the pilot test of our programme, we decided to test only the design phase of the programme. When we got to the Sherborne Girls' School, we did not have time to do a presentation before we started doing the design phase, but spoke shortly about why we were there and what our programme was about. That lack of a detailed introduction to our programme affected the tempo of the implementation of our programme; we suspect that the introduction would have allowed students to catch on more quickly than the students did in our pilot test at Sherborne.

We gave them the student guides, explained their team and individual roles, and asked them to start working on their tasks with the help of the student guides. A lot of students had a hard time understanding what to do, even though we clearly told them to read and follow their individual role guides. The difficulties that students faced showed us the importance of the introduction presentation and the importance of clear student guides. There were in total seven teams of three in our pilot test and the three of us acted as ambassadors. Each of us tried to answer the student questions, check on teams to see if they have progressed, and if not we tried to help them out to move on. Some of the teams or individuals took to their tasks fairly easily but others were confused and needed some help.

After the pilot testing was done, we had a one-hour meeting with STEM teachers of Sherborne Girls' School, where we had an opportunity to present our programme to them and show them the developed supplemental materials. The teachers liked the idea of our programme and showed a willingness to implement it at the school once the programme was fully developed and finished. They said that our programme was a fun and smart way to engage young students in STEM. One of the teachers recommended that we consider having a longer timeframe for the programme in order to increase the quality of the products that the students create. One teacher also suggested using Building Information Modelling (BIM) or AutoCAD, a software application for 2D and 3D computer-aided design (CAD) and drafting, in our design phase, so that students will be able to create more professional designs using computer design tools. Ms Massey, who attended the pilot testing of our programme, also recommended that we make the student guides less text-heavy and add more clarity by adding pictures and highlighting important phrases.

After receiving feedback from teachers about our ambassador and student guides, we changed the guides to make them more clear for students and added more guidance for handling the programme to the ambassador guides. We sent the redeveloped guides to Young Crossrail ambassadors, who we previously interviewed, and asked them to review the guides and answer three research questions about the programme (email in Appendix C).

In response to our inquiry, "Do you believe our programme will effectively pique student interest in STEM?," several respondents reported that that the programme will definitely pique interest in STEM and will get students thinking about different aspects of being an engineer; since young people are strongly affected by the lack of affordable housing it should engage their interest. It shows how STEM subjects can give students a way to tackle some issues directly affecting them. Steven Leung claimed that "housing will forever be a social and economic topic as well as political and environmental issue for many decades to come – so widely speaking it should be in the interests of everyone."

In response to our inquiry, "Do you believe our programme will challenge the students academically?," the respondents recommended that we require the ambassador to bring calculators for students and keeping the timeframe to be six hours or longer. Helen McCarthy, a community relations officer at Crossrail, even remarked that the soft skills (teamwork, problem solving, and communication) will be as important as the STEM ones.

In response to our third inquiry, "Do you believe that this programme can be easily implemented?," the ambassadors thought that the programme is easily implemented as we have given so much guidance already; the fact that we have included pricing and materials guidance means it is just a resource gathering exercise for the ambassador which should not be too time-consuming. Some respondents commented that the major challenge to implementation will be finding the 'right people' (ambassadors with good communication and engineering skills) to deliver it. They said that there are lots of growth and learning opportunities in our programme, and hopefully that will encourage ambassadors to get involved.

Chapter 5: Conclusions and recommendations

5.1. Project synthesis

The *Build your own city* challenge is an open-ended programme that any STEM ambassador can deliver over the course of a day or split over the course of multiple after-school sessions. The challenge allows students to collaborate in teams of three to plan, design, present, and construct a model housing complex that will help London to continue sustainable growth. The programme requires each team to pick a student to play each of the main executives in a construction project: project manager, architect, and structural engineer. During the challenge, the team completes relevant tasks that mirror the basic job descriptions of the STEM professional roles that they are playing. The ambassadors, volunteers that act as mentors and resources to each team as they progress, will deliver the programme. The goal of the programme and for the ambassadors that implement the programme is to engage and inspire students in a way that piques their interest in a socially-relevant STEM topic and to inform those interested students about the choices that they can make to pursue a STEM career.

Based on the programme requirements that stakeholders communicated to us, we concluded that a time-flexible programme delivered by ambassadors or teachers ensures easy implementation. Rather than being constrained by time restrictions, facilitators can schedule the programme to fit their needs best. The context of the housing crisis lends itself more towards ambassadors with a background in construction but utilises the basics of any design process. These basics -- design, bid, and build -- are already familiar material to most teachers and ambassadors, and the housing crisis places these concepts in a real-world context. The time constraints for the programme are generally fluid, but we suggest that the programme should be implemented over multiple sessions, totalling at least six hours in length. The students should have at least two hours to complete the design phase, at least one hour to complete the bid phase, and at least two hours to complete the build phase, including time at the end for the ambassador(s) to wrap up the programme with some reflections and careers advice. The future programme developers can spread out these minimum time suggestions over many weeks, especially because each phase builds on the previous one. Students are able to work on their projects over time and can build on their successes and learn from their failures. The final result allows at least one student to take home a finished product that they created through a design process. Students, therefore, have evidence that they can do the basic requirements of each STEM profession modelled and are more likely to see themselves in that profession later in life.

We designed the programme with all of the stakeholders' requirements in mind, but the programme can always be improved and interpreted through new implementation approaches. In order to ensure implementation of the programme and secure a legacy for Young Crossrail we outline several recommendations that will improve the programme's deliverability and overall quality.

5.2. Recommendations

We highlight a list of recommendations for Young Crossrail and/or IStructE to carry out in regards to our programme to ensure that future programme developers can implement the programme effectively and improve it accordingly. As Young Crossrail's programme will end in September of 2016, we also developed these recommendations for Crossrail's learning legacy to ensure the programme can be delivered by other STEM outreach programmes.

5.2.1. Full pilot testing of the programme

While we were able to pilot an abbreviated version of the programme's design phase and gather preliminary participant feedback, the programme's six-hour timeframe prevented us from piloting the programme in its entirety and collecting feedback from student and ambassador participants on the entire programme. The pilot test revealed weaknesses in our timeframe, the clarity of our guidebooks, and the engagement of the students. While we jokingly call our pilot test a "qualified failure," we do conclude that pilot testing is an essential part of developing and maintaining a quality ambassador programme. We recommend pilot testing the full programme with all of its phases. Young Crossrail liaises with nine partner schools and our first pilot with Sherborne Girls' School was well received. These ten schools would be excellent candidates for further pilot testing, since Young Crossrail has an already existing relationship with them. In addition to having existing relationships, the ten schools also have diverse groups of students from many different demographics that can offer different perspectives on their experiences with the programme. We also suggest running these pilot tests with wider variety of students including different genders and cultures, so that the future programme developers identify aspects of the programme that might hinder some students from engaging. In the event of a complete pilot test, facilitators should confer with participants in a post-programme discussion or survey whether the programme piqued student interest in the subject matter, and if any aspects of the programme were particularly unclear, challenging, or disengaging. Throughout our programme design, we had limited student input.

We also recommend taking as much time as needed to complete the programme during pilot testing in order to achieve better results. We observed that the students' product quality increases proportionally with time. The teachers at Sherborne Girls' School suggested that the opportunity for students to work on their project for additional time will produce a better end product. Those teachers cited a similar experience when leading a modelling project and said that although the programme can be completed in six hours, the quality difference in the final product will be measurable if we spread out the programme. However, we recommend that if the programme designers give students double the time to complete the programme, then the time in between phases should be increased proportionally to avoid overwhelming students.

5.2.2. Continued development of the programme

Through our interviews and while attending STEM ambassador programmes we learned that key stage four students aged 14-16 have already decided upon their subject interests, limiting STEM programming influences on them.

We recommend that future ambassador programmes aim to engage students of younger key stages and age groups. Students working through our programme will already have taken their GCSEs and have chosen a career path. While Young Crossrail, as well as several other STEM outreach organisations, have some ambassador programmes geared towards younger students, their resources are limited. We recommend the future programme developers to work on different versions of our programme for different key stage students. By adjusting content to meet the abilities of younger students, we believe our programme can better pique student interest in STEM and therefore inform more students of career opportunities before they choose their academic paths. We also recommend that future programme developers who develop STEM ambassador programmes for students in higher key stages, such as key stage three and four, focus less on piquing student interest in subject matter and more on informing students about career paths they can take to engage in a specific field. As students in these key stages have already chosen their academic paths, informing them about the different careers they can pursue within those academic paths will benefit them more than working to pique their interest in subject matter that they have already chosen to disengage from or study.

5.2.3. Limitations of paralleling real-world problems

Although paralleling real-world problems with STEM ambassador programme has many advantages, doing so also creates drawbacks in programme design and implementation. When designing a STEM ambassador programme that parallels real-world content, designers will discover the impracticality of including all of the real-world problem details. Because of this limitation, the designers need to save only a handful of real-world details and need to eliminate or alter the others. For example, when working on our design phase, we were trying to calculate and parallel the real-word sizes and scaling of the buildings, but we realized that children will not be able to make buildings that are proportional to real-world buildings with simple materials and with limited time and motivation.

We recommend that programme designers focus more on engaging students via interactive programming rather than solely content accuracy, because more real-world accuracy requires more or too much effort from student participants and might lead to student disengagement. While our programme utilises basic structural engineering concepts such as floor planning and model construction, the programme does not require that students build their models completely to scale. Doing so would detract from student engagement and focus on unneeded details. Although this process can require more critical thinking from designers on which aspects to alter, it allows for simpler ambassador facilitation and better student comprehension. We recommend that programme ambassadors choose carefully what the main learning objectives are and choose only the details of the real-world programme that are relevant to these learning objectives.

5.2.4. Computing and technology use in our programme

Many engineering careers require competency in computing technologies, specifically through computer-aided design, or CAD. By exposing students to this approach earlier, if budget allows, students can begin to comprehend and develop proficiency with engineering computer softwares. Most stakeholders suggested the use of AutoCAD or similar computer modelling software in the design phase of our programme. We designed our programme so that facilitators can implement at little cost and with limited prior structural engineering knowledge. CAD software requires both time to learn and finances to purchase software licensing. Because of the ambassador time and capital constraints advised by Young Crossrail's director, we decided not to explore using CAD in our programme. However, the STEM ambassadors, educators, and professionals we interviewed commented that future facilitators with resources that allowed for the use of these programmes could utilise them to create a more authentic and immersive experience for students.

We recommend that, if a future facilitator has the resources and funds to utilise these software packages effectively, students should be able to model their designs in CAD software. Several programmes exist to do so, and facilitators could identify programmes that best suit their skill sets and budgets. For our particular programme, we recommend the use of AutoCAD, 3DS Max, or SketchUp for building three-dimensional or two-dimensional models of each team's building during the design phase. Moreover, if ambassador skillset and budget allow, we recommend students be able to print three-dimensional buildings or sections of those buildings via 3D printers, as they continue to function as a relevant and widely used technology in several engineering project designs.

5.3. Conclusion

Through fourteen weeks of research, observation, design, and re-evaluation, we have attempted to isolate the core elements that comprise a successful STEM outreach programme for the legacy of Young Crossrail and IStructE. We used those core elements to develop a complete outreach programme with materials to support its widespread implementation. While we did not pilot the entire programme, we have developed a professional relationship with relevant schools that will ease the process of piloting considerably for both Young Crossrail and IStructE. After piloting both organisations will polish the programme for widespread distribution through ambassador programmes around the UK and it will serve as a learning legacy for the Young Crossrail programme through its continued use by IStructE.

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Appendix A: Plan for initial interviews

Preamble

Hello (Participant Name),

We would like to thank you for participating in a key informant interview. First, we would like to introduce ourselves:

(Introductions in no particular order)

Our home institution, Worcester Polytechnic Institute (WPI), in Massachusetts, United States has sent our group to design educational resources for key stage four students in the Young Crossrail programme.

We will be conducting an informal interview. This interview will follow a guided conversational approach but will not be solely scripted. During this interview, we hope that you can help us to identify real-world problems that STEM employees would find in their profession, as well as provide insight into STEM ambassador programmes facilitated by Young Crossrail/IStructE.

We would like to inform you that:

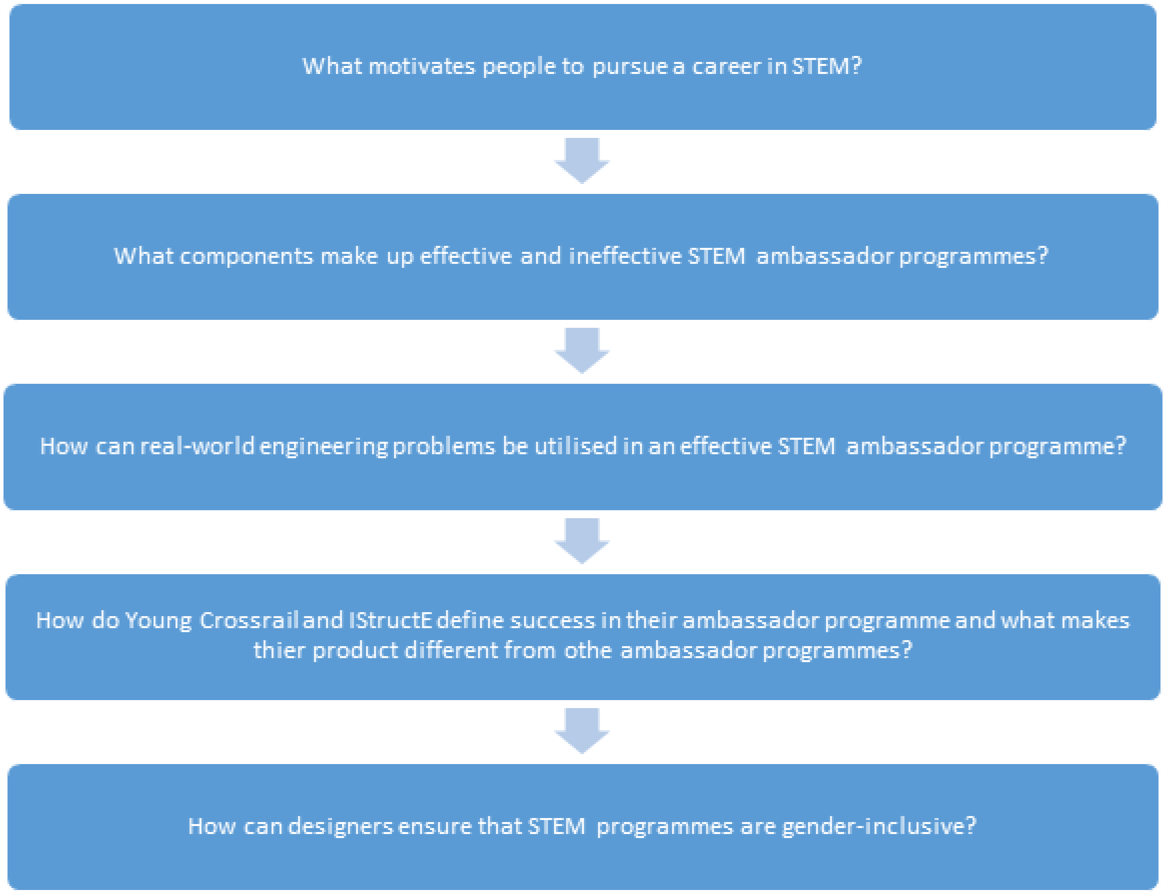
- Participation in this research is voluntary
- Participants may end their participation at any time.
- Participants need not answer every question in an interview or survey.

We hope to quote our interview participants in our final report, including your job title and/or role in the ambassador programme; therefore, our research is NOT completely anonymous and confidential. If you would or would not like to release your name and/or verbatim responses, please let us know now.

All requests for anonymity and confidentiality will be honoured. If you choose to allow us to publicise your name/responses, you will be given an opportunity to pre-approve the publication of any quoted material should you request to review the content. In addition to using your name and job title, we would also like to record this interview for transcript purposes. If you are or are not comfortable with us using an audio recording device for transcript purposes, please let us know now.

End of preamble

Figure 1: informal interview conversation flow-chart



The displayed subsections on the above flowchart show the transition of discussion topics during our informal interviews.

Research question: What motivates people to pursue a career in STEM?
Expert: STEM employee, STEM programme ambassadors
Possible interview questions:

1. When did you first know that you wanted to work in a STEM field and what inspired you to do so?
   a. Did you have any mentors and/or role models?
   b. Did you participate in STEM ambassador programmes or STEM clubs as a child and if so, do you feel that pushed you in the direction of a STEM career?
   c. Was there any other inspiration? (e.g. family member with cancer may push you towards oncology)
2. What components of your career do you find most rewarding and exciting and how do you think that relates or could relate to a key stage four student?

3. Why did you choose to work where you do?
4. What factors deter people from pursuing careers in STEM?
    a. Do you believe that societal factors act as bigger deterrents than academic factors?

How will this information help us to complete the objective?

We will use these questions to identify motives for STEM engagement. We will use the answers gained in interviews to incite student interest in potential future STEM career paths while minimising student disengagement.

Research question: What components make up effective and ineffective STEM ambassador programmes?

Expert: STEM employee and ambassador

Possible interview questions:

1. Have you noticed different levels of engagement among students in programmes that you have overseen?
    a. If so, what do you think caused these differences?
    b. What are good ways to approach disengaged students?
    c. What mistakes do ambassadors make that can lead to lower levels of student engagement?
2. How do you evaluate a STEM ambassador programme's effectiveness?
    a. What roles do both student and ambassador feedback play in this evaluation? Is one more important than the other?
    b. What roles do educational merit and student enthusiasm play in this evaluation? Is one more important than the other?
3. If you have personally overseen the delivery of an educational resource, which components of this specific resource do you view as most impactful on student engagement?
    a. At what point in the programme did you view that the students began to engage?

How will this information help us to complete the objective?

We will use the information gathered from these questions to design age-appropriate challenges and activities for our programme. We will design the challenges to engage the most students while minimising ineffective procedures.

Research Question: How can real-world engineering tasks be utilised in an effective STEM ambassador programme?
Expert: Crossrail employee who volunteers as a STEM ambassador
Possible interview questions:

1. What role do you play in the Crossrail project?
    a. Do you think an effective educational resource can be made by simplifying and remodelling engineering tasks that you have performed on the Crossrail project?
        i. If so, which ones and why?
2. Which previous tasks within the Crossrail project have a significant STEM and structural engineering focus?
    a. Which tasks do/would students find interesting or uninteresting?
    b. Which tasks incorporate multiple facets of Structural Engineering outside of the build process alone? (e.g, finance, design, project revision, etc.).
3. What approach do you think we should take, while trying to simplify the Crossrail engineering tasks?
4. How do you effectively design the difficulty of simplified challenges to target specific key stage students?
    a. What kind of activities do you think are too simple or complex for key stage four students?
5. What timeline have you found to be most effective for key stage four STEM ambassador programmes?
    a. How long of a programme do you recommend?

How will this information help us to complete the objective?

We will find interesting parts of tasks on the Crossrail project and better understand how to simplify and transform those real-world tasks into challenges for our programme.

Research question: How do Young Crossrail and IStructE define success in their ambassador programmes and what makes their products different than other ambassador programmes?
Expert: Young Crossrail or IStructE ambassador
Possible interview questions: *Note, Young Crossrail/IStructE denotes that the terms are interchangeable depending on the ambassador's affiliation*

1. What experience have you had with the Young Crossrail/IStructE ambassador programme?
    a. Have you interacted with students and/or educational resources?

2. Have you participated in any other STEM ambassador programmes?
    a. What role did you play? (facilitator, observer, event planner)?
    b. What were the difference that you noticed between Young Crossrail/IStructE and these other programmes?
3. Do Young Crossrail and IStructE care more about quantity of students exposed to the programme or about the level of participant engagement?
4. Are you, as an ambassador, trained to evaluate the success of the finished Young Crossrail and/or IStructE programmes?
    a. How are you trained to do so?
    b. What metrics do you use to define that success/failure?
    c. What metrics do you personally feel define success or failure?
5. How do you think that we can ensure the learning legacy of Young Crossrail?
    a. What would you define as a good legacy?

How will this information help us to complete the objective?

We will use this information to define our direction when creating the challenges and activities as well as evaluate and improve our programme based on Young Crossrail principles and protocols.

Research question: How can designers ensure that STEM programmes are gender-inclusive?
Expert: STEM ambassador
Possible interview questions:

1. Is your programme specifically designed to be gender-inclusive?
    a. If so, what means did you use to achieve that result?
    b. What are common misconceptions about making programmes gender-inclusive?
    c. Has your programme identified ineffective gender-inclusive approaches?
        i. Why were the approaches ineffective?
2. If you have overseen a programme, what was the ratio of boys to girls that participated?
    a. If you did notice a large difference, what factors do you think contributed?
    b. Did the ratio affect the engagement of a specific gender?
3. What are major factors that contribute to the gender gap in STEM?
    a. What ages or particular development stages are specific areas of concern?
    b. What steps can be taken to prevent women from being deterred from STEM?

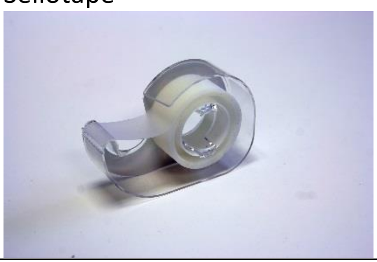
How will this information help us to complete the objective?

We will utilise these answers to identify potential causes of gender inequality in STEM. We will identify effective approaches that STEM ambassador programmes utilise to create a programme that best addresses the issue of gender inequality while minimising potential ineffective means.

Appendix B: Modelling materials

Model material	Cost and location
Art Straws 	**Link:** https://www.amazon.co.uk/Artstraws-Long-Pack-Assorted-Colours/dp/B00F38PBNU/ref=sr_1_2?ie=UTF8&qid=1461594042&sr=8-2&keywords=art+straws **Price:** £5 for pack of 300 **Recommended amount**: 1 for 4-5 teams
Drinking straws 	**Link:** https://www.amazon.co.uk/Amscan-International-Flexible-Neon-Straws/dp/B000VOERT0/ref=sr_1_3?ie=UTF8&qid=1461594131&sr=8-3&keywords=drinking+straws **Price:** £2 for pack of 225 **Recommended amount**: 1 for 3-5 teams
Lolly sticks 	**Link:** https://www.amazon.co.uk/PLAIN-WOODEN-STANDARD-LOLLY-STICKS/dp/B004LLR926/ref=sr_1_2?ie=UTF8&qid=1461594166&sr=8-2&keywords=lolly+sticks **Price:** £2 for pack of 100 **Recommended amount**:

Cardboard 	**Link:** https://www.amazon.co.uk/420mm-Cardboard-Corrugated-Sheets-Dividers/dp/B00JMCVO7A/ref=sr_1_3?ie=UTF8&qid=1461594208&sr=8-3&keywords=cardboard **Price:** £9 for 10 pieces of 420mm x 297mm **Recommended amount**:
Aluminium foil 	**Link:** https://www.amazon.co.uk/Aluminium-BacoFoil-Everyday-Kitchen-Cutterbox/dp/B0130Y3A2W/ref=sr_1_4?ie=UTF8&qid=1461594265&sr=8-4&keywords=aluminium+foil **Price:** £8 one roll **Recommended amount**:
Paper 	White Paper **Link:** https://www.amazon.co.uk/HP-Office-Multifunctional-Paper-80gsm/dp/B000JTKDCW/ref=sr_1_5?ie=UTF8&qid=1461594297&sr=8-5&keywords=paper **Price:** £5 for 500 sheets **Recommended amount**: -or- Coloured Paper **Link:** https://www.amazon.co.uk/Assorted-Coloured-Bright-Paper-Sheets/dp/B004VAB45A/ref=sr_1_2?ie=UTF8&qid=1461594369&sr=8-2&keywords=coloured+paper **Price:** £3 for 100 sheets **Recommended amount**:

Pipe cleaners 	**Link:** https://www.amazon.co.uk/Creation-Station-Pipe-Cleaners-White/dp/B003N1U39G/ref=sr_1_4?ie=UTF8&qid=1461594422&sr=8-4&keywords=Pipe+cleaners **Price:**£2 for 150 4mm pieces **Recommended amount**:
Sellotape 	**Link:** https://www.amazon.co.uk/25mm-40m-Clear-Tape-Pack/dp/B005SSMGM4/ref=sr_1_44?ie=UTF8&qid=1461594623&sr=8-44&keywords=tape **Price:** £6 for pack of 12 **Recommended amount**: One for 1-2 teams
Glue 	**Link:** https://www.amazon.co.uk/Elmers-E1322-118-2-Glue-All-Multi-Purpose/dp/B0038DZZ9W/ref=sr_1_5?ie=UTF8&qid=1461594569&sr=8-5&keywords=glue **Price:**£3 for 1 **Recommended amount**: One for 1-2 teams

Appendix C: Email to ambassador stakeholders

Seth Macdonald

From:	Seth Macdonald
Sent:	22 April 2016 13:53
To:	Steven Leung; Adam Usher; Joshua Milton; Matthew Chang; Andreas Schoeler; Matthew Langdown; Cathy Groom; Helen McCarthy; Joseph Kanu; Hannah Sexton
Subject:	WPI STEM programme

Good afternoon!

About a month ago, Reed, Vato and I interviewed you to gather information and ideas for a STEM outreach programme. We have worked hard to create something that is both challenging and engaging for students and easy to implement by educators. I have attached the results of our project for your perusal. We would greatly appreciate any comments, concerns, and/or feedback you'd like to offer, while we do realize that the content is rather large. The first page introduces our programme and all the supplemental guides follow.

If you do choose to offer feedback, will you please attempt to answer these three questions in the best detail possible?

Do you believe our programme will effectively pique student interest in STEM?

Do you believe our programme will challenge students academically?

Do you believe that this programme can be easily implemented?

Thank you again for helping us out; if you do plan to give feedback, please reply by Wednesday 27 April as we are leaving the 29th!
Seth MacDonald

build your own city.pdf

Appendix D: Programme Materials (please see supplemental document for higher resolution copies)

Challenge Overview

Our challenge will task teams of three students to design, present, and create a model of a housing complex suited to house 200 people. Students will be given anywhere from 6 hours or more (depending on ambassador preference) to complete their challenge. Before the hands-on challenge portion of the programme begins, the STEM ambassador team that will facilitate the programme will give an interactive introductory presentation that introduces students to structural engineering and the housing crisis. The ambassador team will comprise of a one to three ambassador to student ratio, which will be necessary for the hands-on portion of the programme. After the introductory presentation, ambassadors will break students into teams of three to begin the hands-on portion, with one ambassador accompanying each team of three students.

Once the challenge begins, students will first choose one of three roles that they will fulfil in their groups: the project manager, primary architect, and structural engineer. Each team will have an individual STEM ambassador who will assist the group throughout the entirety of the challenge, answering student questions and helping to resolve conflicts the team may face. First, the students will work on the design phase of the programme, which will take teams roughly one and a half to two and a half hours to complete. The teams will choose from one of three housing complex designs: one large apartment building, two to three multi-storey townhouses, or about a dozen two-family homes. After they choose their land plot, teams will work together to design the exterior and footprint of their building or buildings. When the students create the footprint and exterior, they will begin individual work based on the roles they chose. The architect will develop floor plans for each of the floors in their buildings. Architects will fit appropriate flats within each footprint for each floor. The structural engineer will take the building exterior and footprint and identify which materials their team can use to build the structure(s), and what quantity of those materials they will need. The project manager will create a timetable for building their structure(s) and additional amenities like the electrical and heating and air conditioning systems by creating a schedule with associated time constraints for each amenity. The project manager will also create a budget with the materials the structural engineer chooses to utilise. The design phase is the most time and labour intensive portion of the challenge, and will require the most ambassador assistance. Because of this time constraint, we recommend the aforementioned one to one ambassador to team ratio. Common tasks that ambassadors will face throughout this portion of the challenge will include assisting in floor plan design, assisting in structural engineer material quantity calculations, and assisting in timetable optimization. After the design phase, students will transition into the bid phase.

In the bid phase, the teams will create a poster presentation of their programme design and present it to their ambassadors. This portion of the challenge promotes public speaking and communication skills, both valued in structural engineering projects. This phase will take roughly half an hour for teams to complete. Students will present their individual findings and deliverables from the design phase (e.g. the architect will present and explain her finalised floor plans), and will answer any questions the ambassador may ask. Ambassadors will provide constructive feedback on student designs in this phase and ultimately accept the student bid after they decide the team has created a sufficient product. As each team design will be different, ambassadors will use their best judgement to determine when the team's design is ready based on student effort, deliverable quality, and student creativity. After the ambassadors accept the team's bid, the team will transition into the build phase.

In the build phase, the team will use associated low budget materials to create a model for their structures that represent the structural designs they created in the design phase and presented in the bid phase. Depending on team designs, this portion of the programme will take students an estimated one to one and a half hours to complete. Students will only build the exterior skeleton for their buildings, and do not have to create individual floor designs. Students will not focus completely on making a precise scale model for their finished products as creating accurate scalars are above the level of most key stage four student, and rather will focus on creating structures that are structurally stable and reflect the concepts they devised in the design phase. Students who designed multiple buildings with the same designs (most likely the students who chose to do the one dozen two-family homes) will not need to create multiple of the same model, and should instead focus on creating well-built models for each unique design. In this phase, the ambassadors will work with the teams to optimise their structural models by showing students efficient ways to utilise their materials and assist students should they struggle to make their building structurally stable.

After the challenge concludes, all of the teams will present their finished builds and discuss in an ambassador-led open discussion what challenges their teams faced, what successes they had, and areas where they can improve. Finally, ambassadors will lead a discussion with all of the teams to connect the challenge with real-world engineering problems that students may face should they choose to pursue a career in the field. Ambassadors will also offer careers advice to students about different courses that they can take for their A levels, as well as educational paths they can take as either academics or apprentices to pursue careers in structural engineering.

The Institution of Structural Engineers

Build Your Own City - Ambassador Guidebook

As the ambassador, you are your programme's facilitator. Your role is to introduce students to the challenge, answer any questions they have throughout the challenge, and work to resolve conflicts struggling groups may have. While you may not be a formal educator, remember that your attitude and level of engagement in the programme directly influences what your students learn from it. Your objectives for this programme are to:

- Engage students in the programme and answer challenge related questions
- Create an environment to the best of your ability where all students can thrive, regardless of personal traits
- Answer student questions and resolve conflicts that arise
- Inform students about career opportunities in STEM
- Gather feedback on the programme to improve upon its future implementation

Programme Rules and Expectations

The programme rules and expectations section explains the main programme rules, and student expectations of the challenge. This section provides a list of the technical aspects of the challenge. This includes key technical aspects such as time or resource constraints and group sizes. The section also contains participant expectations like deliverables and behavioural expectations. Remember, student behaviour and engagement is the most important aspect of this programme. Students who are well-behaved and engaged are far more likely to succeed in the technical aspects. For references to student task expectations, please refer to the student brief manuals for each role and each challenge phase. These guides outline the student objectives in detail, as well as the methods by which they should approach their objectives.

Technical constraints

- Students must be in teams of no more than three students
- Each student must fulfil at least one role on the team, and there may only be one of each role on each team
- Students will have approximately 60 minutes to design their structure, 15 minutes to create and present their bid, and 60 minutes to build their finished deliverables (time constraints are up to ambassador discretion, these are just recommended guidelines)
- Student budgets may not exceed £15 million (financial constraints are up to ambassador discretion, these are just recommended guidelines)

Behavioural expectations

- Students are expected to treat all ambassadors and other participants with respect
- Students are expected to treat all materials with respect
- Students must listen to ambassador instructions and guidance (within reason)
- When conflict arises in a group, students are expected to work collaboratively with their teammates and ambassador in the best interest of the group as a whole

Students who fail to meet technical constraints and deadlines may be met with point deduction at the ambassador's discretion. Students who fail to meet behavioural expectations may face consequences such as point deduction, disqualification, or other penalties at the ambassador's discretion.

Ambassador Expectations and Requirements

Ambassador participation is integral to programme success. As the ambassador, you are expected to abide by all ambassador expectations and requirements in order to ensure that teams can accomplish their tasks efficiently and effectively.

Expectations

- Be on time and prepared to teach each lesson. This includes having necessary materials and reviewing all content beforehand.
- Treat all students with equal respect, regardless of age, sex, gender identity, ethnicity, nationality, and socioeconomic background.
- Utilize additional resources as you see fit. This includes referencing listed supplementary structural engineering literature and gender inclusivity content.
- Adjust content to best suit your needs as an ambassador and the students' needs as participants. This includes editing the introductory PowerPoint or other supplementary content as you see fit, adjusting time constraints for challenge parameters, or reworking group sizes and role expectations as you see fit.
- Utilize survey material for both yourself and participants to evaluate and improve the programme.

In addition to behavioural expectations, all ambassadors are must have a set of technical requirements. These requirements are as follows:

Requirements

- Have basic understanding of the structural engineer, primary architect, and project manager roles in a structural engineering project
- Have a basic understanding of the housing crisis facing the greater London area
- Be able to present and elaborate on supplementary PowerPoint presentation
- Able to address the needs of student teams and work well with other ambassadors
- Understanding of maths trigonometry and budget creation to assist students in their design phases

Ambassador roles throughout the programme

Design phase

Work with your designated group of students to help them accomplish their team and individual tasks. The team tasks for this phase are:

- Identify square footage needed for buildings
- Create building designs

In addition to helping the team as a whole, you will work to help the individual students with their respective roles. The individual tasks for this phase for reach role are:

- Architect
  - Create a floorplan for each floor of the building/buildings
- Project Manager
  - Create a timetable and budget for the construction
- Structural Engineer
  - Create a structural design for the building or buildings

Bid phase

Approve or critique your team's design. As a team, the students need to

- Create a poster and presentation for their project design

Ask them to explain their design approach and reasoning behind their design. Ask them to explain what worked and what they could have improved. In particular, each student must

- Architect
  - Explain their floorplan and why they chose that design
- Project manager
  - Explain their budget and how they created their timetable
- Structural Engineer
  - Explain their structural design and why they chose their materials

Build Phase

In this phase, students will be constructing models of their designs using available materials. Students do not have individual roles in this portion of the challenge. Rather, they need to demonstrate strong team dynamics by working together to create their final product. Your primary role in this portion of the challenge is to aide students in their structure creation by helping them to appropriately measure and cut their materials, as well as offer advice when needed. Students do not need to build their models to perfect scale, but should rather focus on constructing models that reflect their building design and characteristics (shape, building materials, and creative aspects).

Design Phase

In the design phase, you will primarily work to assist students throughout the design of their building structure, materials, budget, and timeline. You will work both individually with students in specific roles, as well as with teams as a whole, to ensure that teams can accomplish their goals on time and effectively. Below is a chart listing both individual role and team objectives for the design phase.

Architect	Structural Engineer	Project Manager	Team
Design Building Aesthetics	Work with materials	Create building timeline	Create poster deliverable
Design Floorplan	Develop superstructure design	Create budget	Present bid

While the students have individual tasks that they must perform, they will work with each other to accomplish both their individual tasks and their team objectives. The next page includes a complete timeline of how each team should be progressing through their challenge. For example, while the project manager works with the architect to develop a building(s) design, the structural engineer will be working with structural materials to identify the properties of each one. Then, the structural engineer will work with the project manager to create a budget based on the design of the building(s) that the architect created using the material the structural engineer identified. Meanwhile, the architect will develop the individual floorplans for each floor of the building(s). For a comprehensive breakdown of each objective, refer to the student manuals for each respective role.

Crossrail | The Institution of Structural Engineers

Ambassador Programme

Roles	Design Phase: Concepts	Design Phase: Decision	Design Phase: Development	Design Phase: Development	Bid: Analyse	Bid: Combine	Bid: Present	Build Phase: Construct
Architect			Design room plans	Design floor plan	Finalise floor plan			
Project Manager	Design structure based on land plot	Share the concepts and decide on one	Design timetable	Create budget	Finalise budget Finalise timetable	Combine their work in one presentation and create team goal statement	Present to ambassador	Build model based on building design
Structural Engineer			Determine structure materials		Finalise structure			

6

Crossrail

The Institution of Structural Engineers

7

Conflict Resolution

As the ambassador, you will be tasked with helping the students resolve conflicts that they may encounter throughout the programme. Below are some common conflicts that students and teams face, and advice for how to address those conflicts should they arise.

Common Conflicts

Conflict: Two students in a team have a conflict over which role they prefer
Resolution: Work with the students and the other group members to find a role choice that best suits each student. If a compromise between role assignments cannot be found, potentially exchange role objectives between the two conflicting members (e.g. the architect may swap their building exterior design with the project manager's timetable design in order to find compromise between the two students)

Conflict: One student in a team is not engaged in meeting their objectives causing other team members to cover the extra work.
Resolution: Work with the student to identify why they do not want to do their portion of the work (uninterested, apathetic, bored, etc.) and find a way to reengage the student. For example, if the architect does not want to design the façade of their building for the structural engineer, offer suggestions to the student or work with them to make a more creative design.

Conflict: Students are struggling at a certain point in their challenge, or do not know how to get started with an objective.
Resolution: Help the students identify what aspect of the challenge confuses them and help them to find a direction on their own. Try to avoid giving them the answer and instead offer them hints as stepping stones.

For all of the conflict that you face, use your best judgment and common sense to resolve the problem. No two students are alike, and thus no conflict will have a definitive best solution. Remember that a frustrated student leads to a disengaged team. Try to see the conflict through the student's perspective and do your best to involve the student in the programme.

Discussion Questions

What worked well for your team during the design, bid, and build stages of the programme?

What did your team struggle with during the design, bid, and build stages of the programme?

What new things have you learned about engineering?

Why did your team choose to build the structure(s) the way you did?

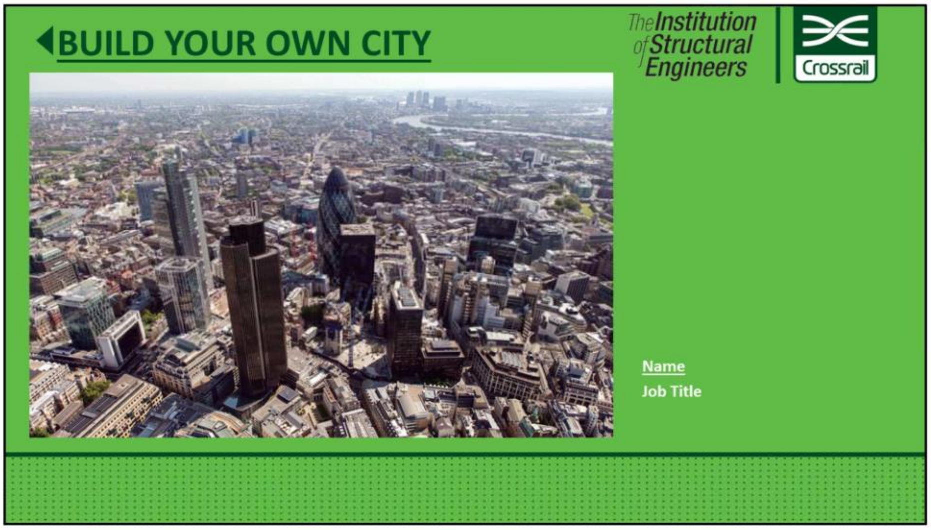
Can you see any relationships between the challenges and your schoolwork?

What did you particularly like about the programme?

What did you particularly dislike about the programme?

What aspects of the programme were the most challenging?

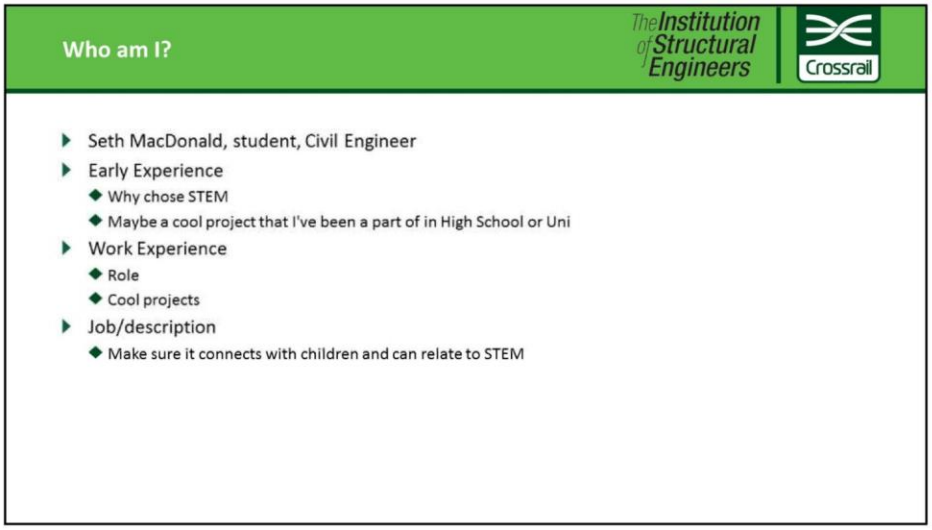
What aspects of the programme were the easiest?



Complete your name and job title

"Hello and welcome, my name is [*enter name*] and today I'm here to lead a hands-on challenge and talk about engineering. Today we're going to be talking about construction and all of the different roles that work together to organise a huge project like this."

1



Customise this slide to fit your personal details

Your introduction and profession

What is your job title?

What do you do for work/who do you work with?

What is your educational and professional background?

You are a real person, just like them! Share a challenge you've overcome to get where you are now or ask them if they share any of your favorite hobbies

Position: "I work for Crossrail as a Student Consultant in the Young Crossrail Programme helping to create new activities for students, like you."

2

Education/Job Experience: "I'm a current student from the United States. I'm studying Civil Engineering. My job experience includes summer work at a small company near home making 3D computer models of buildings."

This slide has many objectives. Some of them may stand out to you as more important than others. Remember that you have a strict time constrain; try to include as much information as you can, but mind the time limit.

To begin this slide, you might ask the students the prompting question at the top, **"What does an engineer look like?"**
Give some time for the students to answer and encourage a discussion.
If the students are reluctant to answer at first, you might ask some questions about the appearance of engineers
(e.g. What do they dress like when they go to work? Are they old, or young?, etc.)

After you are satisfied with the discussion, or the student starts to become disengaged, **flip through each photo individually asking, "Is this an engineer?"**
All of the photos are of engineers in some form or another; remember to have the students come up with the answers on their own.
You may even poll the students by a show of their hands for either believing the person is an engineer or not an engineer.

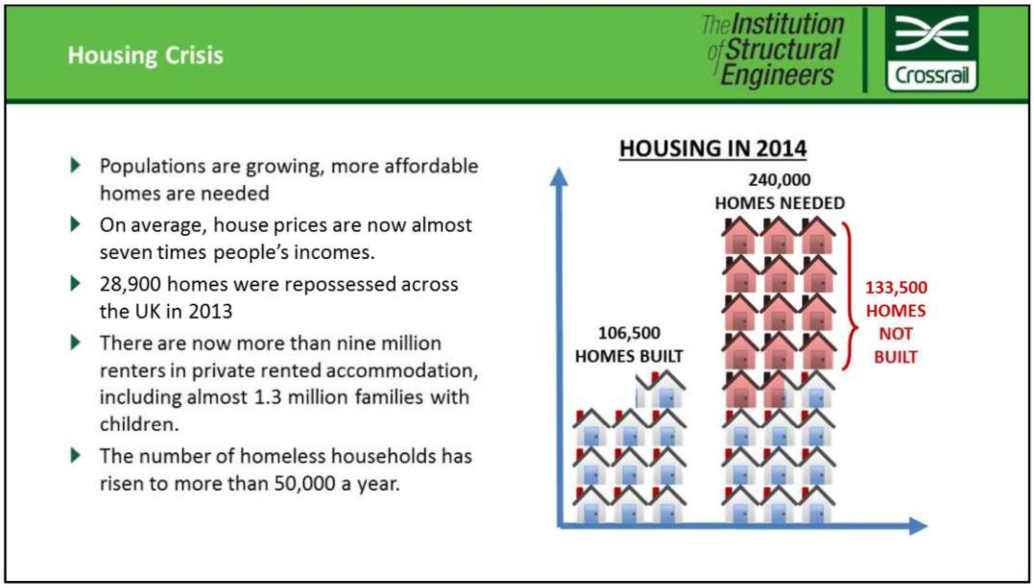
The photos above flip in this order:

Yes, this woman is a biomedical engineer; she could be working on a cure for cancer!
Yes, this man is an operations engineer; he is making sure that his data center is operating at it's highest potential!
Yes, this woman is an engineer, too; she is leading a meeting of her peers!
Yes, this man is an transport engineer; he is designing a generator to produce electricity for electric cars!

Sorry! Trick question, this woman is an engineering apprentice; working her way to becoming an engineer!

3

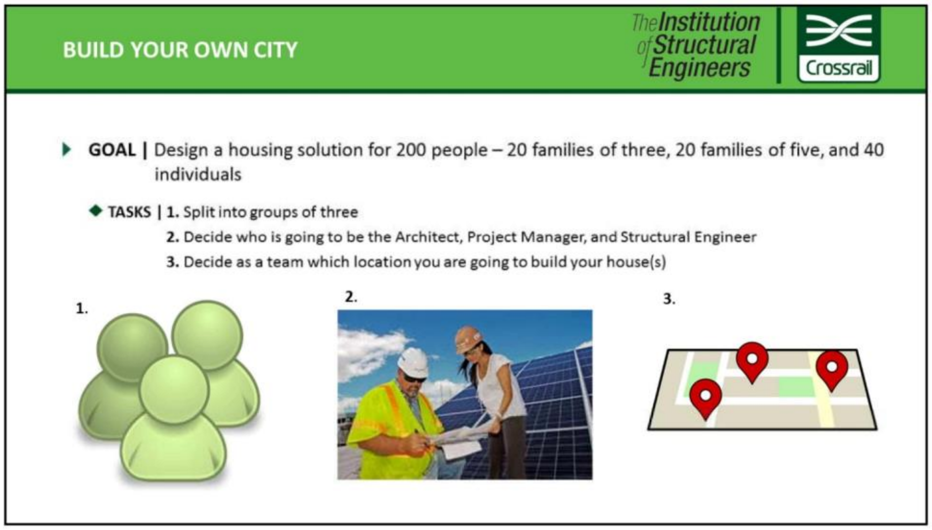
"One example of what engineers can accomplish while working together is the Crossrail project. Crossrail is delivering a new railway for London and the Southeast that will we called the Elizabeth line when it's finished in 2018. The Elizabeth line will bring 1.5 million more people into the city each day. Most notably, the Crossrail project bored 42 kilometers (26 miles) of new tunnels through central London to make this new Elizabeth line possible! The engineers at Crossrail have even thought about sustainability: LED lighting in stations will save energy costs and for every pound spent, the economic benefit of the project will bring in almost double that cost in new business totaling 43 billion pounds! It's amazing what engineers can do when they work together."



"Crossrail are working hard to relieve the pressure of an overcrowded city by improving transport. They even have community relations officers working around the clock to help accommodate residents who have had to be moved from their homes to build Crossrail. Crossrail have made huge steps to make London less crowed, but more work needs to be done for affordable housing!..."

"London is facing a crisis of a growing population with not enough affordable homes to house this influx of citizens. Housing is increasingly difficult for young people and families to afford, we need to find a better way to house these families."

"One problem that engineers could help solve by working together is the housing crisis in London; in fact, this is the problem that all of you will be attempting to solve today!"



"The goal of today's challenge is to design housing for 200 people – 20 families of three, 20 families of five, and 40 individuals**. Please split into groups of three.** We will work through the second two tasks together."

Architects

KHALIDA AHMED – ARCHITECT

http://www.stephenlawrence.org.uk/case-studies/khalida-ahmed

"I am passionate about residential architecture because when designing a home you are thinking about the family who are going to live there for the next 50 years and that personal consideration with the building is what is important to me."

ASHER BOURNE – ARCHITECT

http://www.stephenlawrence.org.uk/case-studies/asher-bourne

"I wanted to study architecture to ensure my creative output has a direct effect on people, to help them in their everyday lives… I wish to see more of the world and experience the amazing architecture dotted around the globe. I want to work in a practice that makes a difference, one with an informed view of the world and an ambition to improve it."

To help you all pick your roles, we have curated a few case studies for each profession

"Khalida and Asher are two examples of Architects; read what they have to say about why they choose that profession."

7

Project Managers

The Institution of Structural Engineers | Crossrail

ANDY ALDER – CROSSRAIL PROJECT MANAGER FOR WESTERN TUNNELS

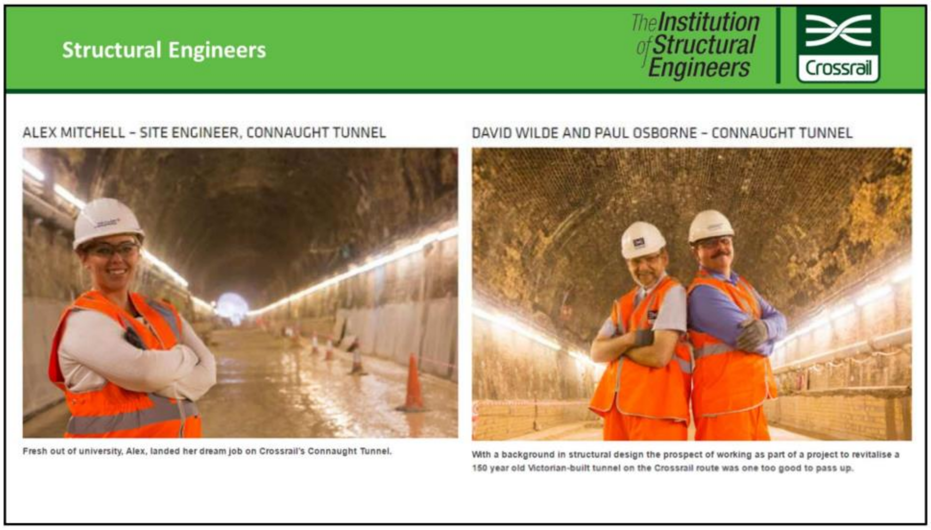
Andy Alder wants to change the world; one engineering project at a time. The 6'4" rugby player and kayaker was destined for building big tunnels.

LINDA MILLER - PROJECT MANAGER, CONNAUGHT TUNNEL

With a CV that boasts serving as a paratrooper and helicopter pilot in the US army, an engineer on a new Cape Canaveral launch complex and now working as Project Manager on the Crossrail project; Linda has been there, done it and probably made the t-shirt along the way.

“Andy and Linda are both Crossrail Project Mangers; read about their careers!”

8



"Alex, David and Paul are all structural engineers for Crossrail; read about their careers!"

"Your team will choose one location on this map to design your housing on; think carefully about cost. If you want your housing to be affordable, the more the land costs, the less you can spend on the building itself."

This is when you will hand out the team design brief…

Team Design Brief

Your team will be working together to create a housing development to give 200 people homes in your new city! You will use the following guidelines to design a building or multiple buildings to house 200 people on your site.

These 200 people comprise 20 families of five people, 20 families of three people, and 40 individuals.

If you have chosen the **city site**, you will be designing one multi-level housing complex with a variety of flats on each floor to accommodate the needs of the residents. The building footprint for this site is 800 m^2.

If you have chosen the **hillside site**, you will be designing two or more multi-level buildings (no higher than four floors) with a mix of flats on each floor to accommodate the needs of the residents. The building footprint for this site is 2600 m^2.

If you have chosen the **community site**, you will be designing about a dozen two level buildings to house families. The largest footprint for these buildings must be less than 210 m^2 and the total building footprint for the site is 4300 m^2.

Your first objective as a team is to design a building exterior. Your building or buildings can be a variety of shapes, from simple cubes to hexagons to circular. Use your creativity to create a design that works best for your team.

After you've determined the rough shape of the building, you need to determine about how much floor space your occupants will need to live in 1 person, 2 person, family of 3, or family of 5 living spaces. The guidelines below will allow you to determine the necessary space of each of these combinations.

Each home/flat will follow these guidelines for space:
Living room - 20 m^2
Large bedroom (maybe for 2 children) - 15 m^2
Bedroom - 10 m^2
Kitchen - 12 m^2
Bathroom - 10 m^2
Extra space/hallway - 10 m^2

For example:

1 x Living room - 20 m^2
1 x Large bedroom - 15 m^2
2 x Bedroom - 2 x 10 m^2

1 x Kitchen - 12 m^2

1 x Bathroom - 10 m^2

1 x Extra space/hallway - 10 m^2

Total = 87 m^2 for a home for a family of three

After you've decided how large each home will be (single, family of three, family of five), you will need to decide how big the buildings you will build will be and exactly how many floors there will be.

Remember, not every floor needs to have the same layout, and not every building needs to take up the same square footing. Houses that will house a family of 5 will have more common areas than houses with 2 individuals and family of 3, so plan your buildings accordingly.

For example –

10 families of three x 100 m^2
10 families of five x 150 m^2
+ 20 individuals x 50 m^2
= 3,500 m^2 of total living space

CITY: If my land plot is **450 m^2**, I divide:
(3500 m^2/450 m^2) = 7.8 floors so **I need 8 floors**

HILSIDE: If my land plot is **2000 m^2**, I divide:
(3500 m^2/2000 m^2) = 1.75 floors so I need 2 floors

Since I have plenty of room for my buildings, I will design my buildings to have gardens. I need to have **at least 2 buildings;** if I pick my footprints to be 500 m^2 each, then the total footprint for both buildings is 500 m^2 + 500 m^2 = 1000 m^2 and 3500 m^2/1000 m^2 = 3.5 floors, which means **4 floors in each building**.

COMMUNITY: If my land plot is 4000 m^2, I have more space than I need! If the **largest footprint is 200 m^2 and each house must be 2 floors**, then I can put one family of five and one individual on the first floor (150 m^2 + 50 m^2 = 200 m^2) and two individuals (2x50 m^2 = 100 m^2) and one family of three on the second floor (100 m^2 + 100 m^2 = 200 m^2). This means that, if each house has two floors of 200 m^2, then each house has a total footprint of 400 m^2. If 3500 m^2/400 m^2 = 8.75, that means **I need 9 houses** to accommodate all my residents. Remember to **account for a street** to access each house.

After the number of homes and floors in each of these homes is decided, it's time to read your individual briefs and get started!

Architect's Design Brief

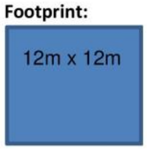
As the architect, you are your project's primary designer. Your role is to design a floor plan and exterior structure for your structural engineer and project manager. While cost is not your primary concern, remember that it does play a role in what your structural engineer and project manager can accomplish.

Your objective for this phase of the programme is to:

- Determine the floorplans for your building or buildings

Use the building designs that your team developed to identify how many people you will fit on each floor, and create a floorplan for each floor that will fit the design of your building. For example, if the footprint of your building is 12 by 12 meters (144m^2), then use that blank space as a template for constructing your floor layout.

Footprint:

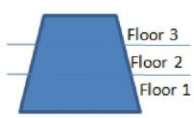


Remember that buildings with slopes and irregular shapes will have different footprints on different floors

If you have trouble utilising maths to calculate these differences, turn to your ambassador for help.

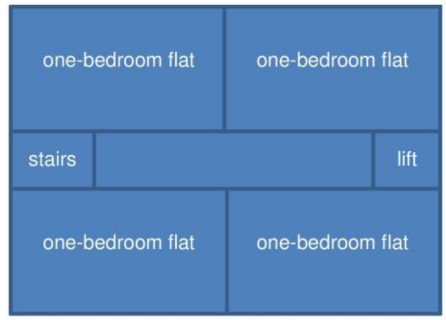
One very simple set of presentation deliverables may look like the example below.

Exterior design:



One bedroom flat:

Floor 1 floorplan



Remember to take creative approaches! Do you have extra space for an outdoor garden? Do you want to use communal bathrooms on smaller floors to maximize space? Ask your ambassador if you have any questions about different creative approaches

Good luck!

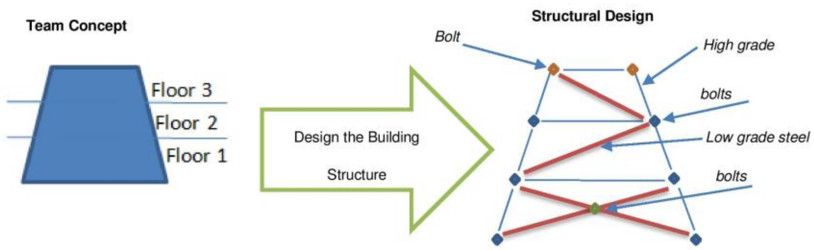
Structural Engineer Design Brief

As the Structural Engineer, you are your project's primary engineer. Your role is to choose structurally stable but cheap materials and design the building structure. While creating a budget is not your primary concern. Your objectives for this phase of the programme are to:

- Design the structure of your building or buildings with the given materials
- Work with project manager to create budget

Create structural design

In this phase of the programme, you will use the allotted materials and your team's building designs to create a structural design for your building. Below is a basic example of the concept translated into a structural design.



Remember that you can use multiple materials in your building design (e.g. high grade structural steel for main support beams and low grade steel for supports). Also, remember that you will need to account for how joints will be attached in your design. The above design illustrates a simple structural design for the accompanied sample team concept. The high grade structural steel supports the exterior and floors of the building, while the low grade steel and bolts act as supporting structures.

Here is a list of building restrictions to keep in mind during your building structural design:

- Low grade steel cannot be used as a main support beam
- Structural wood cannot be used on buildings taller than 2 stories
- Brick cannot be used on buildings larger than 4 stories
- If attaching two walls of structural wood, 10 nails must be placed for each meter of attachment (e.g. if the walls are 2 meters high, 20 nails must be used to attach them)
- Wood glue may only be used to attach roofs to structural wood framed buildings

- 1 bolt must be used to attach two pieces of high or low grade structural steel. 1 additional bolt must be added for each piece of steel beyond the first two

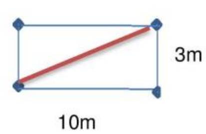
Use these guidelines and your list of materials to create your structural designs. Keep track of all materials you use. If you need any help with the maths for your structural design, remember to ask your ambassador for help.

After designing your structural design, work with your project manager to develop a budget for the building. While you do not need to keep track of your cost, keep track of the materials you use and how much. A basic example of a spreadsheet can be seen below.

Material	Amount
High grade steel	100m
Low grade steel	20m
Bolts	5

Give your list of materials to your project manager so that they can calculate the final budget. Finally, keep in mind the dimensions with which you are building. Each story is roughly 3 meters high. Also, if you choose to build side supports, remember to calculate their distances using trigonometry.

Example of Trigonometry



$3^2+10^2=109$

$\sqrt{109}=10.4$

10.4 is the length of the support beam

If you need help with any of the maths, remember to ask an ambassador for help!

Good luck!

Manager's Design Brief

As the project manager, you are the project's primary manager. Your role is to create a construction timetable and budget for your team's project. Your objectives for this phase of the programme are to:

- Create a timetable for your construction project
- Create a budget for your structural engineer's design

Develop a timetable

Now that you have created your building design with your team, your individual task is to construct a timetable for how you will build your structure. Your timetable will include the estimated time needed for the foundation, building skeletons, roofing, interior walls, flooring, electrical, plumbing, and heating and air conditioning. Below is a basic timetable sample to give you an idea for how to create your own.

	Day 1	Day 2	Day 3	Day 4	Day 5`	Day 6	Day 7	Day 8	Day 9	Day 10
Task 1										
Task 2										
Task 3										
Task 4										

Below is a complete list of the challenges you will need to address with the allotted time needed to complete them and associated restrictions.

Task	Time Needed to Complete	Other Restrictions
Foundation	20 Days	None
Skeleton	40 Days	After foundation Workers get 5 day rest for every 10 days of work
Roof	5 Days	After skeleton
Interior Walls	10 Days	After heating and air conditioning and plumbing
Flooring	40 Days	After heating and air conditioning and plumbing

Electrical	30 Days	After roofing 5 Days of inspection every 10 days of work
Plumbing	10 Days	None
Heating and Air Conditioning	20 Days	Cannot be installed when Electrical is being worked on

If you have any questions or concerns during your timetable design, remember to ask your ambassadors for help.

Create a budget

In this phase of the programme, you will work with the structural engineer to create a budget for your model. Remember, the structural engineer is the primary constructor, and your job is to offer financial advice and create a budget based on their plans. Remember to include both the total costs and total quantities of each of your materials in your budget. This is a basic example of a budget sheet.

Material (Cost)	Quantity	Total Cost for Material
High grade steel (£45/m)	10m	£450
Low grade steel (£30/m)	5m	£150
Steel roof (£5/m^2)	10m^2	£50
Total Cost for All		£650

When developing your budget, be conscious about how you choose to spend your money. Points will be awarded for good budgeting and aesthetics, so work with your structural engineer and architect to maximize appearance while minimizing costs. If you have any questions about how your budget is being created, ask your ambassador for help.

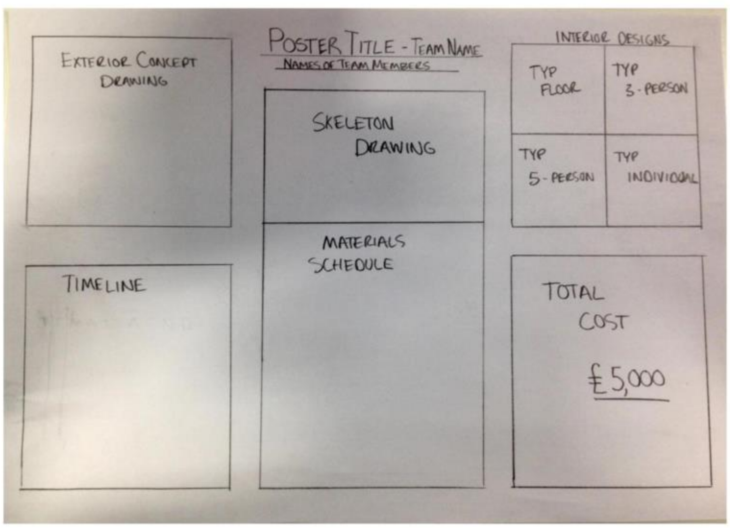
Good luck!

Team Bid Brief

In this phase of the challenge, your team will be working together to **create a poster and a presentation** to explain your design product. Your team will have **45 minutes** to complete these tasks before the presentation begins! Each team member has already finished his/her deliverable(s) for this presentation, but you must work together as a team to arrange your ideas on a poster and practice how you will present your ideas. You should **first plan how you will use the space on the poster**, fitting each of the following things on your poster, organized by each team member's deliverables:

Architect	Exterior concept drawing
	Interior floor plans (typical floor, typical five person flat, typical three person flat, typical individual flat)
Structural Engineer	Skeleton drawing
	Materials schedule
Project Manager	Timeline
	Total cost

Before you begin to cut and paste your individual parts onto this poster, it might be a good idea to do a concept drawing, like the one below, which shows the **poster layout** before you develop it:



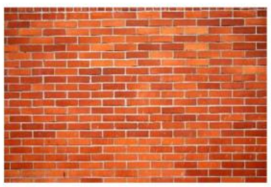
After you have finished the poster based on your original layout, you need to decide how you will explain the components of your poster. During your presentation, you will need to take your ambassador through **how and why each of you made the decisions that you did** when designing your building. Try to explain your design as specifically as you can while still remaining brief!

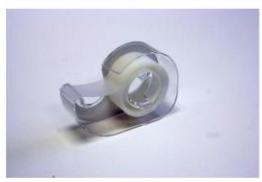
Good Luck!

Team Build Brief

In this phase of the challenge, your team will be working together to **physically build a model** of your housing complex! You will be given **an hour and a half to complete** this task. Try your best to use the materials listed below and build your model based on your structural engineer's design. You will be given enough materials to complete your model, but remember that things may change!

Actual material	Model material	Characteristics
High grade Steel – £45/m 	Art Straws 	• Strong and very structurally stable • Great for creating building skeletons • Can support glass walls and roofs well
Low grade Steel – £30/m 	Drinking straws 	• Great for secondary support • Not strong enough to hold skeleton on own • Great for support between stories

Structural Wood - £30/m^2 	Lolly sticks 	• Inexpensive, great for use in large quantities • Not strong enough to support several stories • Needs gypsum board for finish
Brick Wall - £50/m^2 	Cardboard 	• More expensive than wood • Better for medium sized buildings • Does not need gypsum board for finish
Steel roof/wall- £5/m^2 	Aluminium foil 	• Works well with larger buildings
Gypsum board - £2/m^2 	Paper 	• Finish for structural wood

Steel bolts - £5 each 	Pipe cleaners 	• Holds joints of structural steel together • Need one bolt to attach two pieces of steel • Need additional bolt for each piece of steel
Nails - £5 for 100 		• Holds wood together • Less expensive than bolts • Need 10 nails per meter of wood
Wood glue - £1 per bottle 	Glue  	• Can only be used to attach walls and roofs • One bottle per use

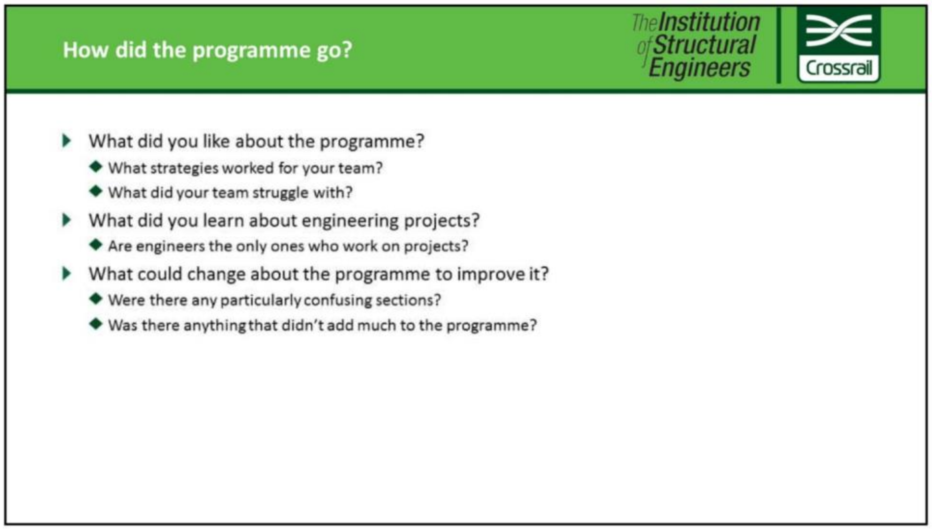
Good Luck!

CLOSING DISCUSSION

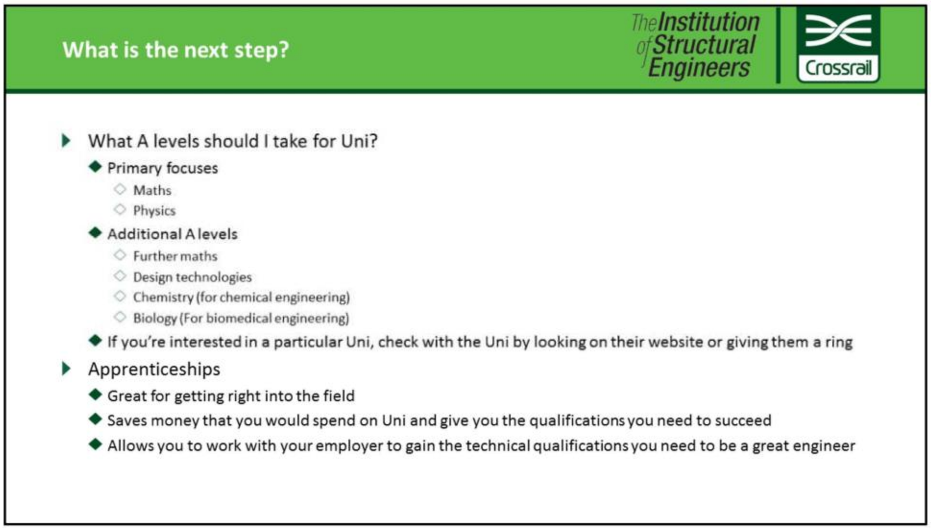
Name

Job Title

1



For this slide, keep the conversation discussion based. You don't need to stick to a script, and you can remove or add questions based on how you chose to facilitate the programme. Just be sure to keep the conversation constructive and engage the students as much as possible.

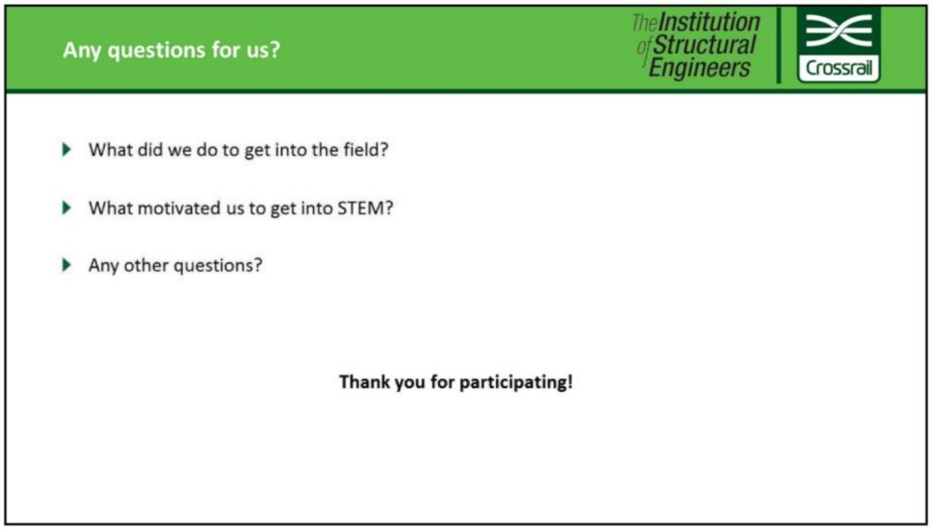


Use this as a discussion tool for introducing participants into the two different paths. Since they are Key Stage 4 students, they are looking at the A levels that they should be taking. Quickly review the above A levels and tell them why they are important.

Maths and physics are important because they form the foundation for many engineering programmes. Even non-engineers focus on these aspects (e.g. the project manager has to use maths to balance a budget and an architect has to have an idea of physics to ensure that buildings are structurally stable in design).

Talk about which A levels you took and how they helped you in Uni as well, and make sure to mention specific A levels if you are involved in a particular kind of engineering that required specific A levels (e.g. biomedical engineers should take biology)

For apprenticeships, make sure you stress that it is an alternative route and not an easier route or a route for students who are not “achievers.” Some people hold perceptions that you should go to Uni to be successful, and apprenticeships are the exact opposite of that. They are for engineers who PREFER hands-on approaches to academic settings, and have several benefits that Universities do not offer. Apprenticeships are just as valid as Universities for successful engineering careers.



Open the floor for questions. Not all groups will have questions, and that's okay. Use this time to field the group of participants for any inquires they may have, and thank them for their participation at the conclusion of this session.