Bus Bots for the London Transport Museum

An Interactive Qualifying Project
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by
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Abstract

The London Transport Museum (LTM) asked us to design a digital activity that would foster engineering skills as well as teamwork, creative thinking, and communication among 7-11 year olds. In collaboration with Telent and the LTM Learning Team, we developed a screen-based interactive game that supports 1-4 players and features participants designing London bus routes and programming traffic lights. Provisional testing indicated the game was engaging and promoted the desired learning outcomes. Through tinkering, the Bus Bots activity inspires adaptation, creative problem solving and teamwork skills. Nevertheless, we recommend additional testing with 7-11 year old children in the museum setting to identify further refinements.

Executive Summary

The London Transport Museum (LTM) aims to both preserve and showcase the heritage of London's transport systems and encourage future engineers by fostering curiosity in both the transport industry and STEM. In order to address the growing need for STEM skills in the UK by inspiring passion for engineering in their young visitors, the LTM's Learning Team has established a number of interactive activities for school groups and families. Each activity is designed to teach valuable engineering skills to its participants. Our team was brought in to create such an activity, one that incorporates digital technology as well as teaches its participants about programming. The activity was to be designed to encourage adaptation, creative problem-solving, teamwork, and systems thinking, as well as be engaging and enjoyable. It also needed to be extensible, made both for a short drop-in activity and a longer workshop.

In order to design and create this activity, we first evaluated the best practices in the design of digital museum interactives through research and interviews with LTM Learning Team member Elizabeth Poulter. At her request, we looked into the 'tinkering' teaching technique as guidance on how to create a program that teaches engineering skills to children. We determined more specific and varied design criteria through interviews with the Learning Team, with Telent (the activity sponsor), and with appropriate third parties. We then developed, tested, and refined prototypes of the original activity; first developing an original design plan and then receiving feedback through video calls and surveys. We made improvements to this prototype based on the feedback we received. We also developed and delivered training guidance on the activity for the LTM staff, creating documentation on the activity's design and how to run it. Lastly, we made physical prototype recommendations for future extensions to the activity after talking to the LTM staff and doing our own individual research.

Our main deliverable is the source code of a fully-functional digital, screen-based activity prototype that incorporates our findings on activity design into its playstyle. It integrates the initial design criteria as well as traffic timing and modelling simulations on behalf of Telent and role distribution and a storyline on advice from the Learning Team.

The activity is run from a web server which shows a large, cartoon-style map of London with various recognizable landmarks, including the Transport Museum. Visible are a number of

roads with traffic lights and bus stops labelled “a” through “m” (Figure ES1). This interactive image can be projected on a surface or shown on a large monitor.

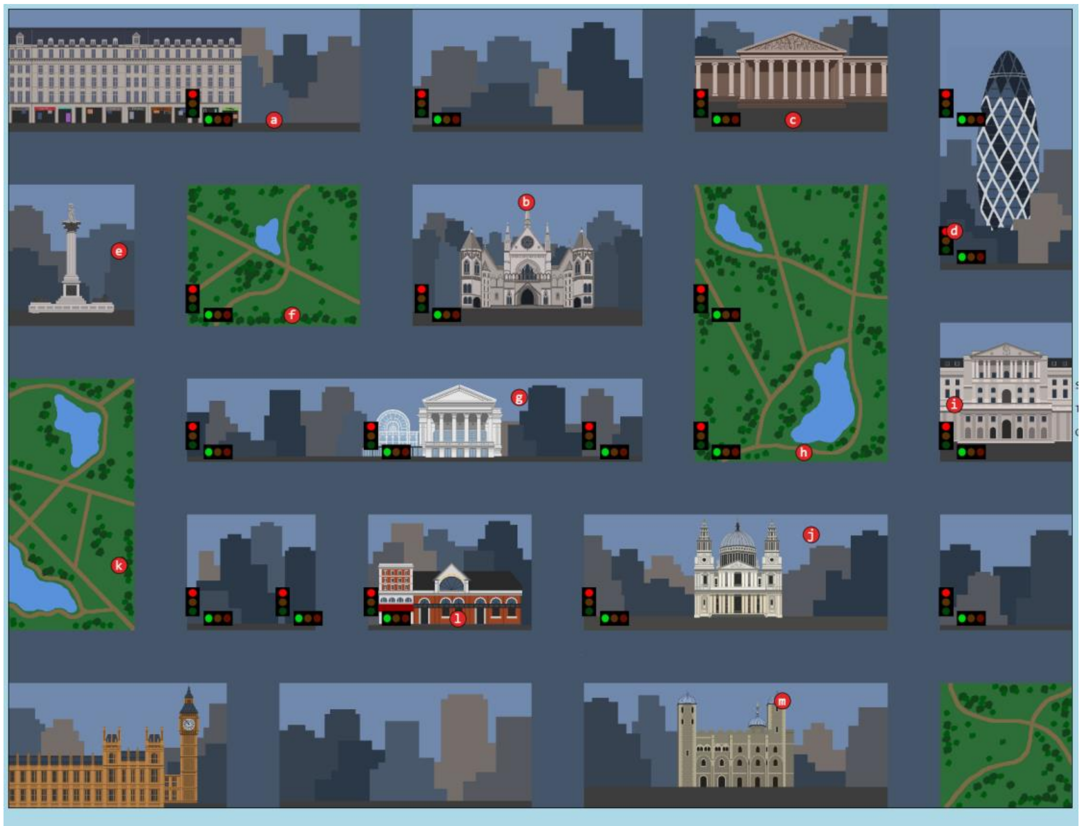

Figure ES1 *Urban Map (Main Game Screen)*

Up to four participants can connect to the activity through any device, including the iPads the LTM can supply for controllers. Upon connecting, each controller is assigned one of two different roles: (1) a bus route planner or (2) a traffic light controller. Each bus route controller is given a list of the bus stops, from which they can create a route for their own bus. The traffic light controller is given a selection of block coding statements from which they can build a small, plain-English program for the traffic lights to follow. When each player has completed their tasks, a simulated day begins on the map, where buses follow the assigned routes and traffic lights obey the created program. During the day, simulated passengers will travel to destination stops using the bus routes, and a score will be assigned based on how quickly the passengers were able to travel to their destinations throughout the day. The participants’ goal is to achieve as high of a score as possible with the most efficient bus route and traffic systems.

Multiple bus routes with minor points of overlap result in a more efficient route than a single bus route can provide, so the activity encourages participants to work as a team as each bus route planner coordinates their bus route in cooperation with their partners. Meanwhile, the role of the traffic light controller is equally important to the success of the team, as more efficient traffic light programs will lead to higher scores. It is also designed to teach young participants about basic programming procedures and practices. Both roles in conjunction encourage participants to utilize systems thinking. Participants being able to see the simulated day play out encourages them to experiment, learn from their failures in prior simulations, and adapt in creative ways, as there is no predetermined configuration to yield the highest score.

Our team also assembled a list of recommendations to develop this prototype into a full-fledged, polished activity in the future. These developments could take the form of updates to the software to deepen the design and user interface (UI), or even integrate physical components, such as programmable robots, to replace the interactive screen. For example, an option to adjust the difficulty of the game would allow for different visitors to explore the activity in different depths, and Raspberry Pis could be used to construct physical bus robots.

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Chapter 1: Introduction

It is well-documented that there is a shortage of STEM skills in the UK. Recruiters struggle to hire staff with the right skills and the shortage costs businesses £1.5 billion per year in recruitment efforts, inflated salaries, additional training, and other expenditures (Emsi, 2018). The occupation cluster of IT Professionals is projected to grow by the largest number of jobs, with around 40,000 jobs expected to be added by 2026. The clusters of IT Technicians and Engineers are also set to grow considerably with nearly 10,000 jobs added in each sector (Esmi 2018). Though there is a general shortage of STEM skills in Britain, demand for each individual skill varies across different occupations and industries. Additionally, the shortage includes soft skills such as leadership and creativity, not just hard skills such as knowledge of programming languages or information security (Esmi, 2018).

As a response to this shortage of STEM engineers, British schools have adopted teaching techniques designed to give children a mindset for engineering. Activities designed with engineering principles such as creative problem-solving in mind can also help to foster a passion for STEM education outside the classroom. Museums have evolved similarly, working to inspire curiosity, develop problem solving and teamwork skills, and make their exhibits more interactive and engaging.

The London Transport Museum (LTM) encourages its younger visitors to consider careers in the transport industry by inspiring a passion for STEM learning. Our goal was to create a digital activity for the LTM based on the bus transport system to teach children about transportation and programming while also building valuable engineering skills. To achieve this goal we:

- Evaluated current and best practices in the design of digital museum interactives;
- Determined the design criteria for the proposed LTM activity;
- Iteratively developed, tested, and refined prototype designs of the digital activity; and,
- Developed and delivered training guidance on the activity for LTM staff.
- Make physical prototype recommendations for future extensions to the activity.

The product that we created with this process is a prototype activity that may need additional refinement in the future. It can be augmented with physical components, the nature of which we describe in the Chapter 4.

Chapter 2: Background

In this section we review the importance of STEM education relative to society as a whole. We then explore the demand for STEM skills in the UK and the state of formal STEM education in the UK as a motivation for our project. After this, we examine how children learn engineering skills, how inquiry learning is implemented in museums, and the best practices in the development of interactives.

The Importance of STEM Education

STEM education has become increasingly important in the 21st century. Science, technology, engineering, and mathematics have enormous impacts on our lives, and knowledge of these fields is now necessary for us to understand our world and make informed decisions. Scientific and technological innovations have become increasingly important as we face the challenges of a changing world, and students must develop a proficiency in STEM far beyond what was once acceptable if they are to succeed in such a dynamic and technologically advanced society. (National Science Foundation, 2007).

The goal of STEM education in childhood is to create problem solvers, increase scientific literacy, and inspire passion for STEM in the hope that children will pursue a career in a STEM field. Engaging in STEM programs and activities outside school can help children see the implications of what they are learning in the world and in their lives. Additionally, the more freeform, application-based nature of activities outside school can generate a greater interest in STEM fields (Engineering for Kids, 2016).

Demand for STEM Skills in the UK

There is a well-documented shortage of STEM skills in the UK. Recruiters struggle to hire staff with the right skills and the shortage costs businesses £1.5 billion per year in recruitment efforts, inflated salaries, additional training, and other expenditures (Emsi, 2018). Of the eight STEM occupation clusters identified by Emsi, the occupation cluster of IT Professionals is projected to grow by the largest number of jobs, with around 40,000 jobs expected to be added by 2026. The clusters of IT Technicians and Engineers are also set to grow considerably with nearly 10,000 jobs in each sector. Figure 1 shows a more in-depth view of projected job growth across all 38 STEM occupation clusters to 2023 (Esmi 2018).

Though there is a general shortage of STEM skills in Britain, demand for each individual skill varies across different occupations and industries. Additionally, the shortage includes soft skills such as leadership and creativity, not just hard skills such as knowledge of programming languages or information security. Figure 2 shows the top skills requested by British employers collected from job postings over one year (Esmi, 2018).

Figure 1 Projected job growth across all 38 STEM occupation clusters from 2018-2023 (Emsi, 2018).

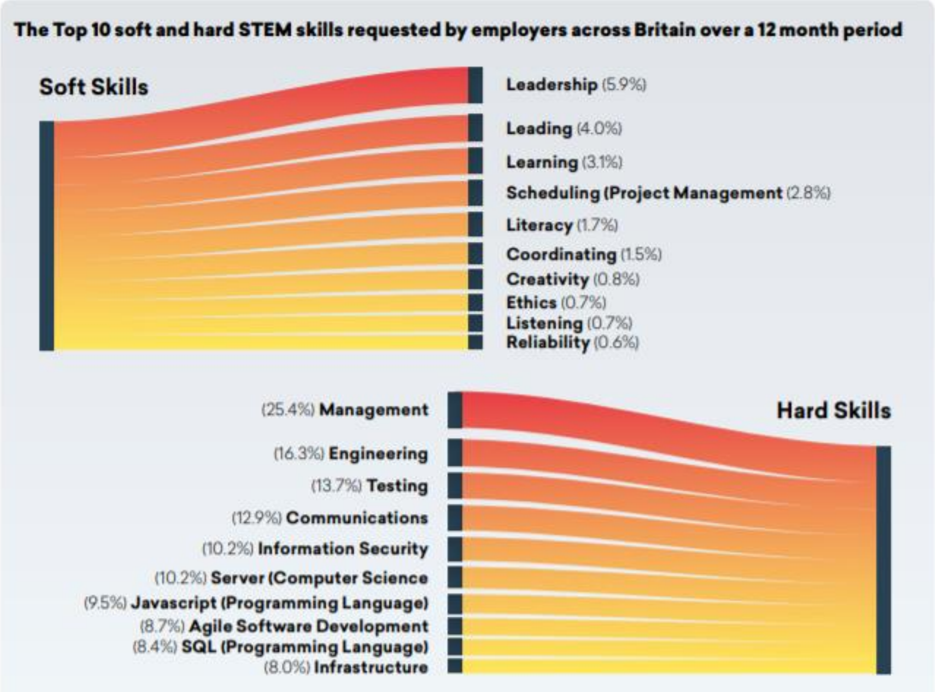


Figure 2 Top 10 soft and hard STEM skills requested by employers across Britain over a 12 month period (Emsi, 2018).

Formal STEM Education in the UK

As there is no unified government STEM skills program, responsibility for STEM education is spread across various departments within the government. The Department for Education (DfE) and Department for Business, Energy & Industrial Strategy (BEIS) play key roles in promoting STEM education. While the DfE holds most of this responsibility, the Ministry of Defense and other departments run their own STEM related programs. The government also allocates additional funding to higher education institutions for expenses such as the teaching of high-cost STEM subjects and the enhancement of STEM teaching facilities (National Audit Office, 2018).

While the government does much in terms of funding for STEM programs and initiatives, there are several concerns surrounding its ability to remedy the skills shortage. For instance, the government has no set definitions of STEM skills and STEM jobs, which makes it difficult to collect data and determine how to target programs (National Audit Office, 2018). Additionally, there is a concern that “the lack of formal coordination across [the] government creates a risk that the overall approach is not cohesive, strategies that support STEM are not aligned, and emerging issues are not dealt with in a timely way” (National Audit Office, 2018, p. 14). These issues support the importance of the role of informal education in remedying the STEM skills shortage, as smaller institutions can act more immediately to aid in remedying the skills shortage and can focus on more individual problems.

How Children Learn Engineering Skills

In May of 2014, the Royal Academy of Engineering published a report titled *Thinking Like an Engineer*, which hypothesized that the dearth of British engineers was due to a lack of understanding about how engineers think (Lucas, Hanson, & Claxton 2014). They hypothesized that the most effective way to address the shortage of STEM engineers was by encouraging all designers of learning experiences for students to create educational activities that better reflect the behaviors of engineers.

The report aims to quantify the distinctive thinking styles of engineers and present them as an understandable set of behaviors which they label 'engineering habits of mind' (EHoM). The Royal Academy of Engineering determined these behaviors through a series of interviews, surveys, and seminars with engineers and engineering educators (Lucas, Hanson, & Claxton, 2014). The report represents the key findings in the model below, which shows a series of concentric rings highlighting the ideas that are most essential to the engineering mindset (Figure 3). Table 1 presents brief descriptions of each of the EHoMs portrayed in the middle ring of Figure 3.

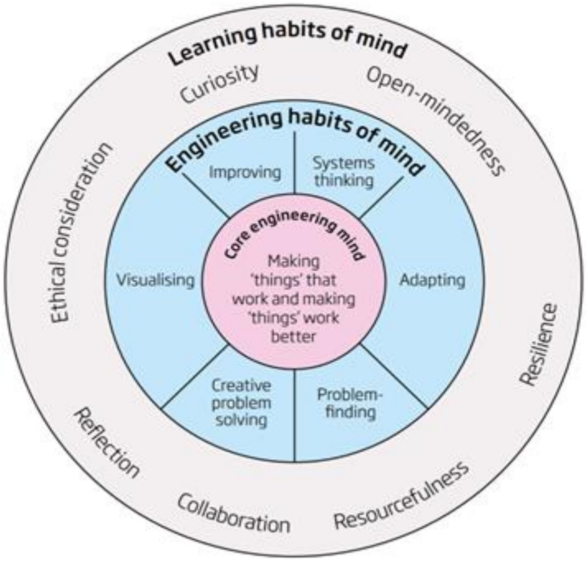
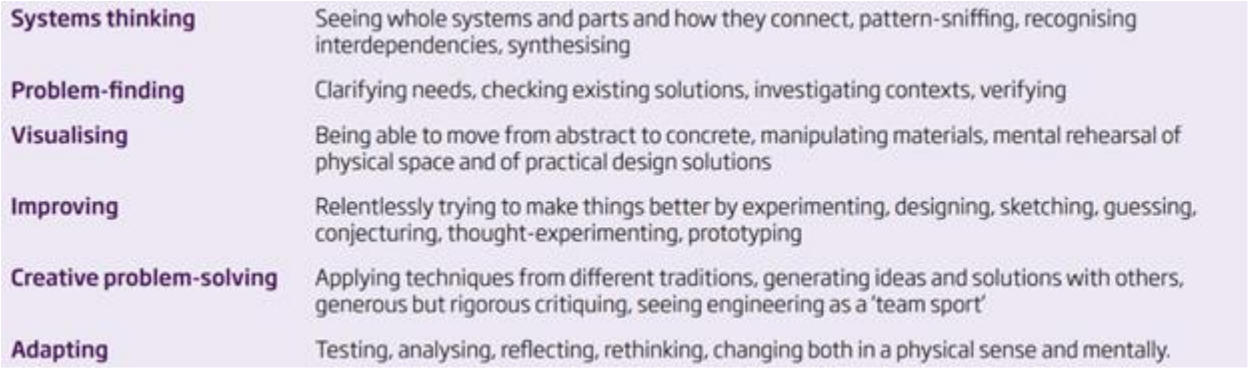


Figure 3 The Engineering Habits of Mind (2014).

Table 1 Brief descriptions of each Engineering Habit of Mind (2014).



Systems thinking	Seeing whole systems and parts and how they connect, pattern-sniffing, recognising interdependencies, synthesising
Problem-finding	Clarifying needs, checking existing solutions, investigating contexts, verifying
Visualising	Being able to move from abstract to concrete, manipulating materials, mental rehearsal of physical space and of practical design solutions
Improving	Relentlessly trying to make things better by experimenting, designing, sketching, guessing, conjecturing, thought-experimenting, prototyping
Creative problem-solving	Applying techniques from different traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a 'team sport'
Adapting	Testing, analysing, reflecting, rethinking, changing both in a physical sense and mentally.

Thinking Like an Engineer served as inspiration for the University of Manchester's Tinker Tailor Robot Pi (TTRP) study that began in September of 2014. The project was designed to implement engineering education in the curriculums of students aged 5 to 14 (The Association for Science Education, 2017). This study employed the word "tinkering" to describe the process of "exploring through fiddling, toying, messing, pottering, dabbling and fooling about, with a diverse range of things that happen to be available, in a creative and productive pursuit to make, mend or improve," (The Association for Science Education, 2017, p. 6) which it proposed in opposition to the traditional learning process to better encourage an engineering mindset. Activities that utilized tinkering and EHoMs included students developing methods to transport a tennis ball across a playground without touching the ball, having students create appropriate model transport containers for various zoo animals, and installing a life-size Native American *tipi* within the classroom (The Association for Science Education, 2017).

The TTRP study found that students whose curriculums implemented learning activities designed to encourage EHoMs and the tinkering process demonstrate more independence in learning for themselves, develop a better mindset on failure, and engage in the engineering process with enthusiasm. Students were found to visibly enjoy these activities, and engagement in the classroom increased in several situations. Teachers noted that the activities reward perseverance, collaboration, and exploration, which are not only helpful in the classroom but also form core tenants of the EHoMs described above which can help foster future engineers (The Association for Science Education, 2017).

Tinkering is an effective approach to the process of inquiry learning, which suggests that scientific learning should be characterized by the application of scientific method rather than memorization of information (Bell, 2010). The theory of inquiry learning is based on the assumption that humans develop knowledge through natural curiosity (Andrini, 2016), and can be defined as “the process of posing questions and investigating them with empirical data, either through direct manipulation of variables via experiments or by constructing comparisons using existing data sets” within the realm of scientific education (Quintana, Reiser, et al. 2004, p. 341). Curricula and activities based on inquiry learning have been found to improve student achievement, build motivation for learning, and proven to be more effective than teacher-based models (Andrini, 2016). Tinkering, by definition, is also built on the concept of posing questions and answering them with experiments. Its effectiveness at improving student motivation for learning and independence shown by the results of the TTRP project mirror the proven successes of inquiry learning models.

How Inquiry Learning is Implemented in Museums

Inquiry learning is not limited to the classroom and can be applied to a vast number of contexts (Scardamalia, 2004). One such context is that of the museum. While classrooms are generally formal and structured, museums are more informal learning environments and encourage participants to learn what they want to at a pace they feel comfortable with (Hawkey, 2004). By allowing their visitors to experience activities of their own accord, museums encourage one of the fundamental aspects of inquiry learning: learning through self-motivated curiosity. Museum exhibits and activities have the benefit of being able to teach people in a fun and interesting manner that does not rely on a set structure (Hawkey, 2004).

Museums can be classified into two different categories: “first generation” museums and “second generation” museums. First generation museums are traditional and object-oriented, centered around artifacts “with no presentation of a broader context” (Pedretti, 2008). In contrast, second generation museums focus on helping visitors understand their world. Second generation museums are more modern; they focus on the present and future rather than history, providing access to people of all backgrounds, and aiming to create engaging experiences through learning by doing rather than through didactic methods of teaching (Pedretti, 2008). This parallels current inquiry-based and experiential approaches to formal teaching in the classroom.

An important aspect of second generation museums is the use of interactive exhibits. An interactive exhibit is an exhibit that “has clear educational objectives which encourage individuals or groups of people working together to understand real objects or phenomena through physical exploration which involves choice and initiative” (Caulton, 1998). The effectiveness of interactive learning has encouraged museums to rapidly integrate more interactive elements into their exhibits. This began as introducing additional technologies into preexisting exhibits, but has evolved into much more. Today, most children’s museums and museums of science and technology can be expected to hold a wide range of different interactive exhibits (Hawkey, 2004).

Several studies have shown the benefit of these kinds of interactive exhibits. Museum visitors have been observed staying at interactive exhibits for longer and, when interviewed, claimed to have more fun at a highly interactive exhibit compared to a non-interactive counterpart (Allen, 2004). A study by the exploratorium also found that exhibits that focus on Active Prolonged Engagement (in ways that parallel our definition of interactive exhibits as they both prioritize users forming their own conclusions based on meaningful interactions) increase user engagement. This was studied by noting how many meaningful questions the users ask themselves or their companions compared to other exhibits. Not only did they notice an increase in user engagement, but the amount of time that people spent at an exhibit increased by a factor of three compared to the control exhibits. (Exploratorium. 2017).

Best Practices in Development of Interactives

In order for an interactive exhibit to be successful, it needs to be designed with the audience in mind. This means determining learning outcomes during the design process and understanding how to instill these outcomes in different types of learners. Research in this field has led to a better understanding of what features make interactives successful.

Figure 4 The bicycle activity at Carasso Science Park (Shaby, Assaraf, Tal 2017)

People gravitate towards familiarity. For example, in a 2016 study that researched what made an interactive exhibit successful, researchers found that students particularly enjoyed participating in a bicycle exhibit in Carasso Science Park (Shaby, Assaraf, & Tal 2017). In the exhibit, students pedal on electronic bicycles and watch the graphics on the screen of bikers going around a track as shown in Figure 4. One of the key factors that researchers found with this exhibit is that students easily understood what they needed to do to interact with the exhibit: pedal. This familiarity is called affordance. Affordance can manifest itself in many different ways. For example, if a person sees a handle, they might assume that it can be grabbed or pulled. When they see a button on the other hand, most people will know to push it. These innate clues allow users to quickly understand how to interact with an activity and reduces the opportunity that users have to become discouraged and move on to another exhibit (Allen, 2004). In the time limited context of a museum activity, this allows participants to spend more time deeper engorged in an activity.

Additionally, it is important for the goals of an interactive to be clear to its audience. For example, in the bike exhibit mentioned above, students pedaled, and saw the results in the form of a bicycle race on the screen. Because the idea of a race was familiar to the students partaking in the activity, they knew that the goal of the exhibit was to pedal harder than the others. This friendly competition turned the bicycle activity into a game (Shaby, Assaraf, Tal 2017).

As shown by the bicycle activity, games are a great way to encourage engagement with an activity. While competition is important, it can also lead to cooperation. For example, in the Drops and Hits exhibit that Shaby observed, students vied to achieve the highest score and beat out their competition. However, they still needed to work cooperatively to use the exhibit together (Shaby, Assaraf, Tal 2017).

In fact, students enjoy exhibits that require teamwork (Shaby, Assaraf, Tal 2017). Social interaction is important to enhance learning experiences. People who talk to others both inside and outside the museum add additional information and context for themselves or others during subsequent visits (Hawkey, 2004). People who go to museums in groups usually positively affect their depth of understanding through talking about the varying ways each group member interacted with exhibits (Diamond, 2010).

An exhibit that demonstrates the implementation of all aforementioned traits is Oztoc (Figure 5) at the New York Hall of Science. In Oztoc, users play in groups that simulate creating fishing lures. Participants make these lures by placing blocks on an interactive table to make circuits. Using blocks as the main method of interaction with this exhibit is an example of affordance, as humans instinctively know when they see blocks that they should be placed. Similarly, the LEDs and the virtual fish demonstrate visibility, as the LEDs let the user know when they make a valid circuit, and the amount of fish they catch allows them to confirm that the circuit they made is working properly. Collaboration with others reinforces the concepts being conveyed.

Figure 5 Oztoc (Lyons, et al., 2015).

Pros and Cons of Digital and Physical Interactives

Digital interactives have become a valuable tool in enhancing the museum experience. Touch screens allow visitors to explore complex 3D models; virtual reality at historical museums transports the viewer to the past; and art created by artificial intelligence challenges the perceptions of museum-goers. These are just a few examples of how technology is being used to create immersive, engaging interactives.

Nonetheless, technology can also detract from an experience when not implemented with care (Nolan 2016). Museums are viewed by many as a place of refuge and reflection, a place to connect with new ideas or appreciate the past. Because it is possible for technology to act as a distraction from the museum experience, it is important that technology-based interactives be used in a way that encourages creativity and meaningful interaction (Nolan 2016).

However, technology can be beneficial to museum interactives. It attracts younger audiences and allows the creation of immersive experiences that would be impossible using only the physical (Alexander 2019). As a result, it aids the shift of the idea of museums as pretentious and outdated to the idea of museums as community centers for learning and exploration. When implemented well, digital interactives can also be just as effective as purely physical interactives. This is exhibited in a study using the Tower of Hanoi puzzle, as participants improved their problem solving skills using a digital puzzle equally as well as participants using the physical version (Flynn, Richert & Wartella, 2019).

Museums must consider how technology can support rather than overshadow an experience and aim to find a balance between the use of digital and physical elements. Museums should not incorporate technology simply because it is available, but instead identify an interactive's audience, purpose, and how the interactive will benefit the audience in order to determine how technology can be used effectively. This helps to ensure that technology is used as a tool rather than as the experience itself (Nolan 2016).

Learning Outcomes

Just as participants will look at the goals an activity will set forth to guide them, exhibit designers need to understand their objectives before developing this activity. These learning goals (also called learning outcomes) fundamentally shape the planning process. By starting with an understanding of what an activity wishes to accomplish, designers can focus on the specifics of how to achieve these goals. An example of five Generic Learning Outcomes can be seen in Figure 6 where the Arts Council UK has defined its goals. It is important to note that different organizations will have different outcomes based on their purpose.

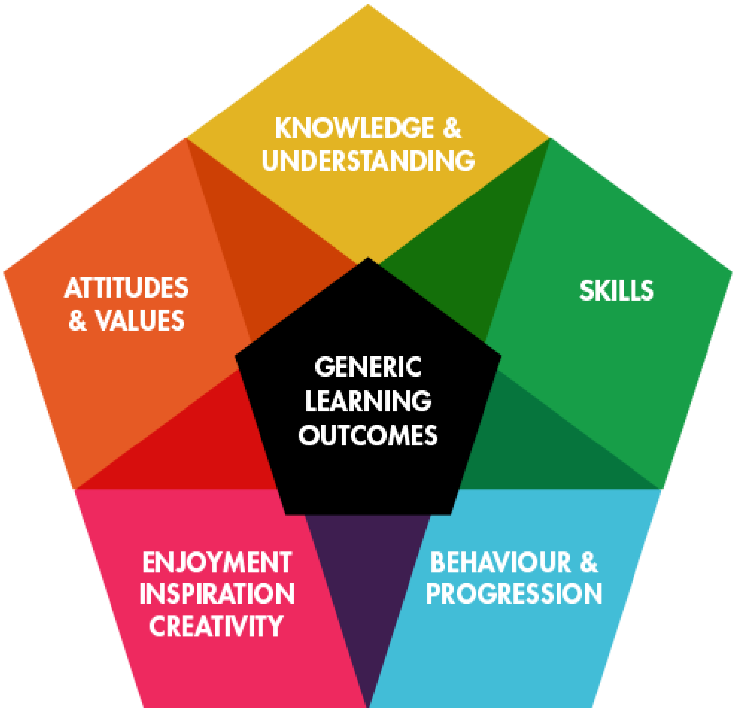


Figure 6 Generic learning outcomes: a diagramatic view (Arts Council England, n.d.).

The learning outcome of "enjoyment, inspiration, and creativity" encompasses goals such as "having fun" and "being surprised" (Arts Council England, n.d.), and is an integral part of all museum activities. While they might not be part of the final goals that the museum had in mind, this is an example of an intermediary goal used to achieve the final goals of skill development as well as knowledge. Enjoyment is a great tool because it encourages engagement.

This can be seen in the bicycle exhibit described above. Furthermore, according to a study on tinkering by Bevan et al, "if learners are not engaged in terms of being actively involved, educators feel that something is not working" (Bevan et al, 2015). If students are not actively participating in the activity, they are unlikely to learn much from it. Additionally, in order to understand if an activity is engaging, Bevan et al. claims that researchers must define in measurable terms what outcomes from the activity they expect to achieve. For example, initial indicators for engagement include how long subjects spend on the activity and the facial responses to the activity (Bevan et al, 2015).

Effective engagement can facilitate the learning outcome of “knowledge and understanding”. Goals included in this outcome are “deepening understanding” and “making links and relationships between things” which correlate to the “problem solving” EHoM described previously, as learners use their deepened understanding of a problem to find solutions. An example of using a deepened understanding to problem-solve can be found in Bevan et al.’s study where a young boy was struggling with the circuit he was tasked with creating. As he began to take apart the circuit, he realized that he could plan the next iteration on paper before building it, therefore naturally discovering a problem-solving skill.

The London Transport Museum aims to foster STEM education and engineering skills in its young visitors to inspire an interest in the transport industry in London. It accomplishes this through interactive exhibits and workshops that employ inquiry-based learning strategies to give its visitors an engineering mindset to problem-solving. We will design a digital activity for the LTM that teaches digital skills needed in the modern transport industry, and encourages these engineering mindsets.

Chapter 3: Methodology

The goal of this project was to design a digital activity for the London Transport Museum's Key Stage 2 visitors that teaches them problem solving and teamwork skills and that reflects real-world transport engineering. This activity was designed so that it could later be extended to incorporate physical components. The LTM specified that the activity should be themed around bus travel and require students to manipulate several variables, such as coding buses to follow different routes, interacting with traffic lights and pedestrian crossings, and reducing congestion (see Appendix A for the original project brief). We designed a project according to the specifications of the LTM through five primary objectives:

1. Evaluate current and best practices in the design of digital museum interactives.
2. Determine the design criteria for the proposed LTM activity.
3. Iteratively develop, test, and refine prototype designs of the digital activity.
4. Develop and deliver training guidance on the activity for LTM staff.
5. Make physical prototype recommendations for future extensions to the activity.

We achieved these objectives through the tasks shown in Figure 1 and discussed in detail below.

Objective 1: Evaluate Current & Best Practices

We evaluated the best practices in creating and delivering digital interactives by supplementing our initial background with more research into activity design and interviewing activity designers. We also evaluated the current LTM interactive activity standards through interviewing the Learning Team.

Because of our inability to evaluate museum activities and exhibits in person due to the COVID-19 pandemic, our research into the development of interactives was conducted through review of research papers and museum websites. We conducted this research in order to properly evaluate the current standards for construction of digital activities. We supplemented this research with an interview of ExpLoring Exhibits & Engagement founder Betsy Loring on April 3rd, 2020, to get a designer's perspective on the process of activity creation and the effectiveness of our own design. In particular, Ms. Loring shared advice about the exhibit *City Science: The Science You Live* exhibition she developed and installed at the EcoTarium: A Museum of Science and Nature in Worcester, Massachusetts. The questions we asked Ms. Loring can be found in Appendix B. The results of our research and interview can be found in Chapter 4.

Objective 2: Determine Design Criteria

We identified a preliminary set of design criteria for the digital activity based on the original project brief, our background research, and initial conversations with our sponsor. We refined these initial criteria based on information we gathered under Objective 1 and through a set of informal conversations with LTM staff and representatives of Telent. More information about our design criteria can be found in Chapter 4.

Objective 3: Iteratively Develop Activity

Once our preliminary research was conducted, we focused on the conceptual design, development and testing of our activity. This was an iterative process as shown in Figure 3; we looped through the design, implement, and test steps until we were able to produce a completed activity which met all goals identified.

In the design phase, we considered the design techniques and best practices analyzed in interview sessions and experiences at other museums. We also ensured that the design was in accordance with LTM safety guidelines. In consecutive iterations, we determined how to refine the prototype by identifying successes and shortcomings of previous iterations and determining ways to address those shortcomings. In the implementation phase, we implemented the design using the requirements identified during the design phase and refined the prototype. We were unable to test in person due to COVID-19, since we completed the project remotely from the U.S. To test our activity, we dispersed the prototype to our peers and contacts at the LTM, scheduling meetings over email. We called the participants using the Zoom video conferencing app, and asked each participant to talk through their thought processes and actions while they played the game. Care was taken to ensure that the participants were well-informed about the purpose of the research and the anonymity of the evaluations and observations, and we followed all other testing protocols put forth by the LTM. Afterwards, we asked the participants a series of

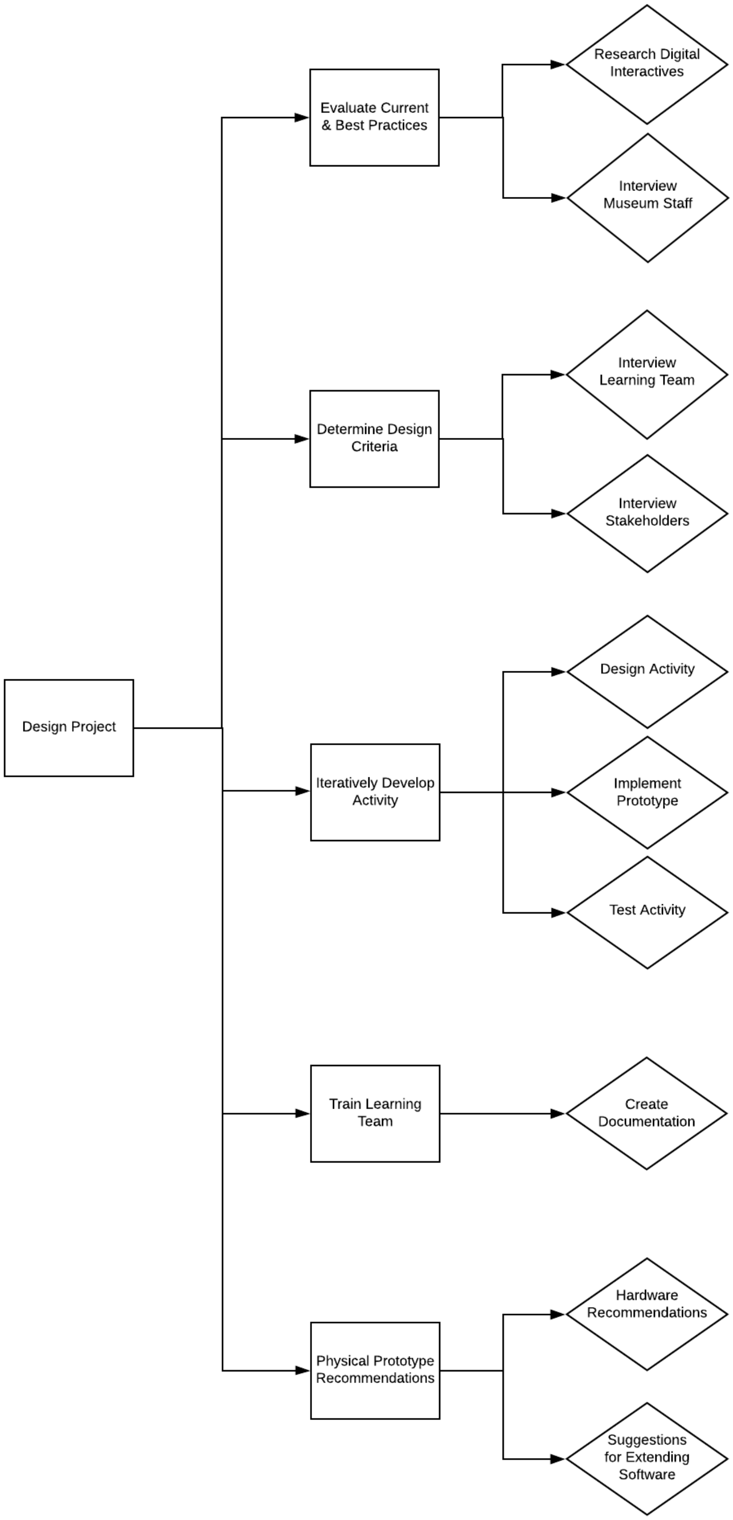


Figure 7 Chart of objectives and tasks necessary for project completion.

questions about their experience testing their activity (as shown in Appendix C), and recorded their answers. We have included a summary of these observations in Chapter 4 of this report.

Objective 4: Train the Learning Team

After we completed the developmental phase of the project, we taught the LTM Learning Team how the activity works, how to mediate the activity, and how to perform maintenance. To accomplish this, we created documentation describing how the activity works and other necessary details. The documentation includes:

1. How to set up the activity for use and how it works.
2. How the activity may be completed and how it can be scaled for complexity.
3. Ideas or guidelines for mediating the activity and encouraging children.
4. Lists and diagrams of all parts used.
5. A link to the source code.
6. Any additional information that we find necessary for the Learning Team to know about the activity.

While the Learning Team are experts in the educational field, we needed to keep in mind that, according to Liz Poulter in our initial interview, their experience with technology was limited to “iPads, Facebook, and PowerPoint presentations”; therefore, all documentation produced as deliverables are easy to use and free of engineering-exclusive terminology.

Objective 5: Make Hardware and Software Recommendations

We have determined what hardware components would be required to adapt this project into a fully physical activity. We have also created several recommendations on how to proceed with editing the source code we created for this activity. In order to determine this, we talked with the LTM staff to determine what a future budget would look like, as well as examined our own design criteria. See Chapter 4 for more information.

Chapter 4: Findings

Our original briefing for this project included a number of design criteria that we clarified further in conversations with our first sponsor liaison, Elizabeth Poulter. We adjusted these criteria due to the COVID-19 situation and added other design points after interviews with the LTM Learning Team and representatives of Telent. Later in this section, we explain our final design for the project, which reflects these criteria.

Evolution of Design Criteria

In the initial project brief shown in Appendix A, the LTM wanted the team to develop a digital activity tied to the Key Stage 2 (i.e., 7-11 year olds) technology curriculum. The LTM wanted the activity to build “problem solving, communication, and creativity skills” that encouraged thinking with an open mind and integrated teamwork.

Our initial interview with Elizabeth Poulter (Poulter, February 5th, 2020) clarified that the activity should be suitable as an “informal, drop in activity or expanded to a workshop”. She explained that the activity should be extensible, allowing for a variable level of difficulty to extend the length of time and depth at which participants are engaged in the activity. For example, a young child visiting with their family could play for ten minutes, but a school group could use the workshop version for an hour, with increasing difficulty as participants played for longer. At Ms. Poulter’s advice, we also decided that our activity design should build on the best practices promoting EHoMs (see Chapter 2), including ‘tinkering.’ Tinkering entails providing participants with a clear goal and a wide set of tools, and encouraging experimentation and learning from failure.

While we did not have a fully-constructed initial design before our planned trip to London, we had informally discussed possible ideas for the final shape of the project. In order to properly convey key attributes of the London bus system in an easily-digestible manner for children in Key Stage 2, we decided that the activity would involve the movement of one or more buses across a small area that the students could see in full. The students would operate in teams of four, corresponding to the number of iPads available for use at the LTM. Our team did not yet decide if the viewable area would be a physical landscape on a table with a physical robot representing a bus, or a large screen showing an urban landscape with animated icons of buses and other traffic.

Due to the COVID-19 pandemic, however, we were unable to travel to London, and a second interview with Ms. Poulter over video call (April 29, 2020) redirected our focus. Creating a physical product would be no longer possible due to our inability to access a lab or build collaboratively. Ms. Poulter suggested instead that, while we build a screen-based activity, we also give suggestions for parts and tools required for another group to eventually build a physical version of the activity in the future. Our group decided to make the activity fully web-hosted, as it would be the best way to work on the project remotely and play the final project using individual iPads as separate controllers.

We met with representatives of Telent on April 1st, 2020. In this interview, we discussed Telent's traffic modelling practices, and what kind of real-life variables factor into how traffic lights operate (for example, how many cars are stopped at the opposite traffic light). We also discussed the bus countdown system and its impact and effect on the transport system. Our group decided that, in order to properly integrate Telent's goals into the design of our activity and to properly establish roles for each participant with a controller, at least one participant would be in charge of creating code for the traffic lights in the digital area. Their code would use the real-life variables discussed in the interview. In our initial Telent meeting we also discussed the idea of a player controlling the bus countdown system, but discarded this option in favor of simplifying roles and avoiding the use of elements that would be too complex for the intended audience.

We had a series of meetings with the Learning Team to solicit feedback and further develop our design criteria. By talking through our design with the team, we were reminded that each role needs to be equally important and valued. The Learning Team pointed out that the Key Stage 2 curriculum includes knowledge of the basic programming interface Scratch, so we could be comfortable in exploring some deeper programming ideas. Through independent research, we learned of an open source library[1] called Blockly which can be used to abstract complex coding as easily readable color-coded blocks. We decided that because of its resemblance to the Scratch programming language, this option would be familiar to students. The Learning Team lastly

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[1] In the context of software, libraries are collections of 'functionality' which may be used by engineers to more easily develop programs.

recommended that we develop a storyline to invest players in the activity; for example, players could take on the role of a Telent employee in a future London where the bus system needs to be developed.

Initially, we planned to use four iPads and five Micro:Bits in the activity. A block-coding app would be installed on each of the iPads to interface with the Micro:Bits. Because we would have been programming iOS devices, we would also have needed a Macintosh computer with Xcode installed to develop a custom interface where students would interact with the activity.

Because of COVID-19, we changed how the final project would be delivered to students. As we no longer had access to iPads to test our software, we moved to a web-app based architecture that could be run on any device with a browser. This allowed us to remotely test our activity with people who might not have iPads in their home. To achieve this, we researched common methods to develop webapps with deployment flexibility in mind. This means that our code could run on many different platforms with minimal changes. Additionally, we utilized Figma software to develop a mock user interface (UI) and streamline our UI development process.

Table 2 Table of design criteria for activity

Category	Criteria
Audience characteristics	● Age 7-11 (Key Stage 2) ● School and family groups
Theme	● Bus travel ● Storyline
Hardware	● iPad ● Entirely screen-based OR Combination of digital screen-based interface and physical objects (e.g., bus bots and other vehicles, signals, Micro:Bits)
Software	● Figma ● Blockly
Learning outcomes	● Adapting ● Creative Problem Solving ● Inspire Creativity and Enjoyment ● Systems Thinking ● Teamwork
Duration/delivery	● Part of 45-minute extensible group activity or short drop-in activity ● Mediated by staff/volunteer

Outcome of Design Process

Our design was formulated while taking the design criteria presented in Table 2 into account. In our design, a single main screen displays a digital map with several bus stops placed at landmarks beside the road (Figure 8). The participants’ goal is to create a system of bus routes and traffic light sequences that are efficient and allow virtual passengers to quickly reach any bus stop from any other bus stop. This goal is clear and ties into the real-world design of the London bus system.

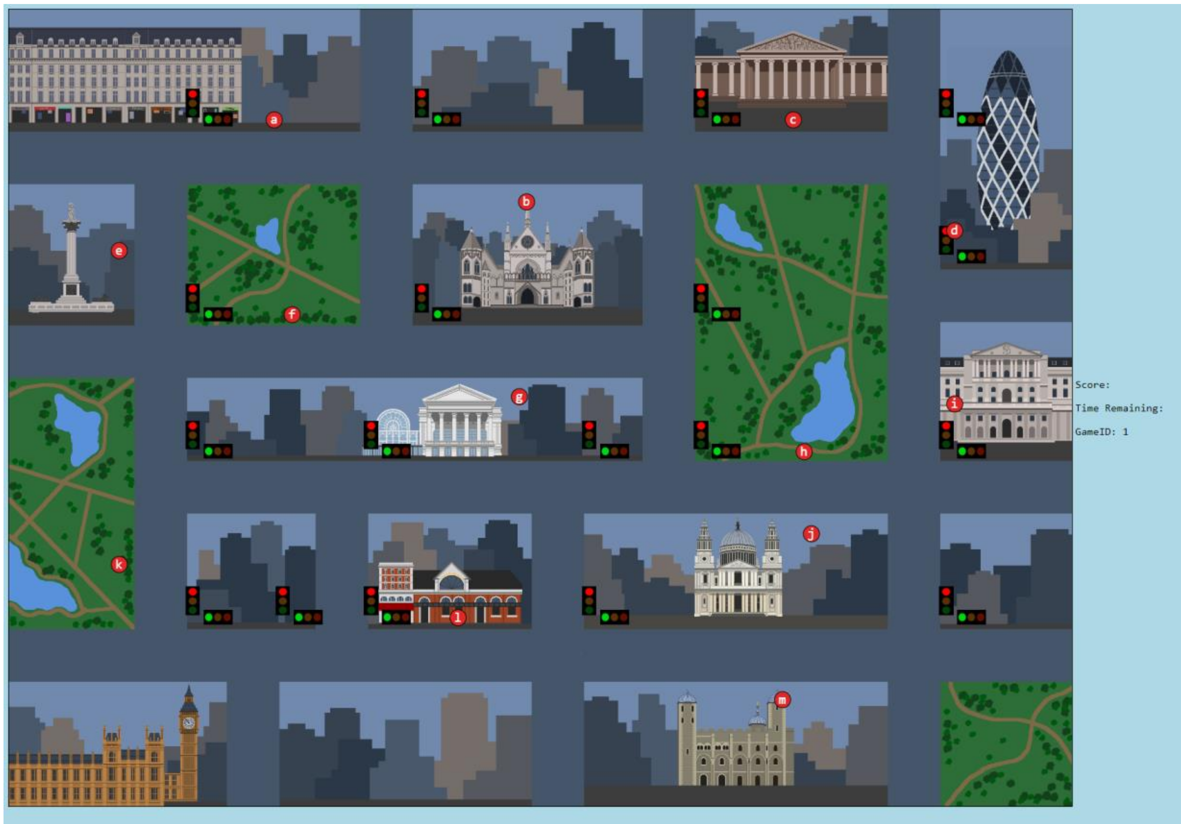


Figure 8 *Urban Map (Main Game Screen)*

Depending on the number of players in the activity, one or more participants are assigned to the roles of Bus Route Designer or Traffic Light Controller, in distributions as shown in Table 3. We expect designing the bus routes to be more challenging than programming the traffic lights, so we assign more players to this role when necessary. Bus route design is also mandatory for the game to run, so there must always be at least one player assigned to this role.

Table 3 *Player role distributions*

Number of Players	1	2	3	4
Number of Bus Route Designers	1	1	2	3
Number of Traffic Light Controllers	0	1	1	1

In the game, Bus Route Designers are given a screen with buttons labelled (a) to (m) on the right as shown in Figure 9. The letters correspond to the bus stops on the map. As the player taps on a button on the right, a corresponding letter is added in sequence to the screen on the left to develop a bus route. As they are forming their route, the main screen (Figure 8) displays their route as a path on the map, encouraging the player to experiment with the order of the bus stops while easily seeing the effect each change will have. This is essential to *tinkering* and inquiry learning.

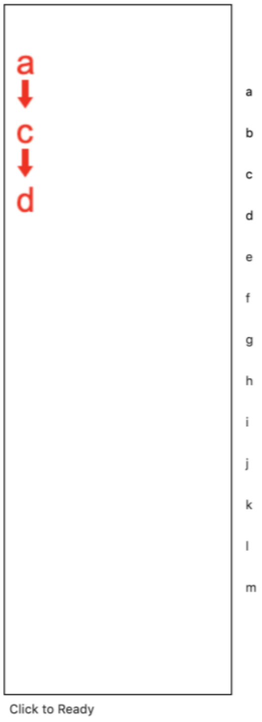
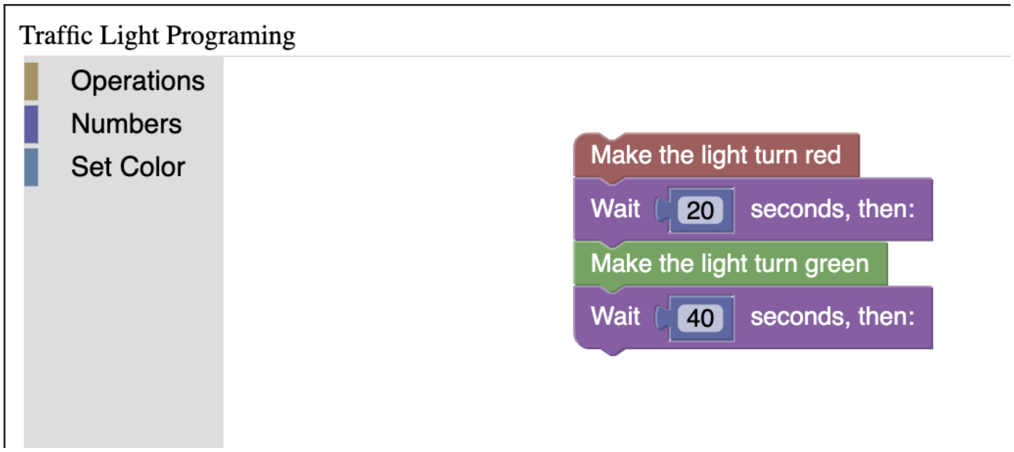


Figure 9 *Bus Route Designer Interface*

Traffic Light Controllers are given a drag-and-drop programming interface created with Blockly, as shown in Figure 10. The players use the tools to program the traffic lights, which corresponds to Telent's role in the transport network. Both route developer and light controller roles are essential to accomplishing the activity's goal. Traffic Light Controllers can create programs that change traffic light colors and have access to elements such as 'conditionals,' which are a fundamental aspect of programming.



```
Make the light turn red
Wait 20 seconds, then:
Make the light turn green
Wait 40 seconds, then:
```

Figure 10 *Traffic Light Controller Interface*

Each player is also given an option to indicate when they are ready to run a virtual "day". Once all players have indicated they are ready, this day will start to play out. During the day, virtual passengers are spawned at various bus stops on the map[2]. Each passenger has a randomly-predetermined destination bus stop in mind for where they want to travel. They also have a mood that turns from happy to grumpy the longer it takes them to reach their destination. These virtual passengers use a pathfinding algorithm to determine what buses they need to get on and what stops they need to get off in order to reach their destination. The day only lasts for a short amount of time, and is designed to let participants see how their bus system works and connects. At the end of the day, the players are shown a score calculated as the mean happiness value.

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[2] In earlier designs of the prototype, virtual passengers spawned at various Tube stops placed on the map, mimicking how real-life London passengers often take the Tube to bus stops. This feature was dropped due to time constraints.

Results of Testing

Testing the activity gave us insight into what elements of the activity may be confusing for participants. We learned that the instructions need to be more structured in the future, as players tended to be confused about what their goal was, and how to achieve those goals. Some players on their first playthrough did not realize that they were planning the route of separate buses, or that their bus routes should include some of the same bus stops, but not be all the same. Players expressed their desire to be able to see more detail on how busses move from bus stop to bus stop. They also wanted to see some indicator of which bus was theirs once the day began.

Players had the most trouble understanding the traffic light programming activity. Players often did not want to make sophisticated programs, instead opting for slight variations on the example provided. They made comments about how they wished they could see more feedback from running the program to get a better idea of how to improve their program. They also asked for more examples that could better teach them how all the blocks worked and what they did. In addition, several glitches were discovered, including buses sometimes not spawning on the Urban Map and certain traffic light programs crashing the game. All bugs encountered during our testing are detailed thoroughly in our documentation.

Not all results took on a critical slant. All participants said that they enjoyed playing and were likely to play if they saw it at a museum. We also were able to observe them improving their understanding of how the game works and of what they were supposed to do after each simulated day. We noted that some players used this information to try and improve their score. To our surprise, on subsequent playthroughs, some participants tried to achieve an extremely low score instead of a high one.

Conclusions and Recommendations

The purpose of this project was to develop a prototype activity that is able to teach Key Stage 2 aged children appropriate skills to succeed within an engineering career. From our interviews with experts within the elementary education field, we were able to design an activity that achieved the learning outcomes that we identified at the beginning of the project. Through the use of tinkering, Bus Bots inspires adaptation, creative problem solving and teamwork skills. In addition to developing this activity, we developed a remote testing plan where we were able to understand how players utilize our activity. We recommend that the LTM solicit additional feedback from staff, Telent, teachers, parents, and children to further assess the game and determine what changes to make in the future.

Furthermore, this prototype activity was designed to be easily extensible. This means that in addition to representing the Urban Map through a large screen, future iterations of this activity can create a physical version of the map and utilize the Traffic Light Programming and Route Designer Interfaces. This structure also provides an important proof of concept of a network structure that future teams can utilize to develop similar activities.

Future additions to the activity may also expand on the instructions for each individual role. In longer play sessions, the virtual day will be simulated multiple times, allowing participants to figure out working configurations through experimentation. However, family visitors who only spend a short amount of time participating may only run the virtual day once, necessitating clarity or even hints in the instructions so a participant's first day can be successful. Future instructions may include tips on how to design a functional bus route, or diagrams with simple examples.

To utilize the Route Designer and Traffic Light Controller UI's for a physical board, future teams will need to design a hardware equivalent of the Urban Map screen which is connected to the internet. This game board will need to be able to understand the messages transmitted over a websocket. To achieve this, we recommend adding a low-powered intermediary computer such as a Raspberry Pi to handle the message transmission and control the board.

A number of additional features suggested from the testing groups could also be implemented to further bolster the design of the activity. For example, the Learning Team suggested that virtual passengers could spawn at various Tube stops on the Urban Map to simulate how real-life London travelers often take buses to specific destinations after riding the Tube to the nearest stop. Passengers in the activity would do the same, simply moving from the Tube stop they spawn at to the nearest bus stop.

In order to appeal to a wider variety of age groups, an option to toggle to different difficulty settings could also be implemented. Whoever is mediating the activity (i.e., museum staff member, volunteer, or visiting teacher) could select the degree of difficulty, which would change the number of stops available on the map, the amount of traffic and numbers of passengers entering the city during the day, and the number of options available to the traffic light controller. A higher difficulty would require a more efficient solution for a higher score, and vice versa for a lower difficulty. This setting would allow smaller parties or family visitors to quickly experiment with the game, while classroom workshop groups could dedicate hour-long blocks to experimenting with their playthroughs.

Another suggestion for the expansion of the activity via software is to publish the game on the LTM website as a standalone web app that can be played by anyone. This was suggested by the Learning Team as a way to increase accessibility to the activity by allowing groups other than visitors to the museum to play the game.

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Appendix A: Bus Bots for LTM Project Description

Elizabeth Poulter, Enjoyment to Employment Manager, January 2020

London Transport Museum (LTM) explores the story of London and its transport system over the last 200 years, highlighting the powerful link between transport and the growth of modern London, culture and society since 1800. LTM's Learning Team works across a wide range of ages from 0-25, delivering interactive and hands-on activities to over 70,000 visitors a year.

The UK transport sector is going through a digital transformation that has created a new demand for digital skills in the workforce. The Learning Team is developing a series of digital skills workshops for children designed to foster these skills in the future education pipeline. As part of this effort, the LTM would like a team of students to develop a digital activity that is suitable for children in Key Stage 2 (ages 7-11) that will exemplify real world engineering in the transport sector.

The digital activity should be themed around bus travel and require students to manipulate several variables, such as coding bots to follow different routes, interact with traffic lights and pedestrian crossings, and reduce congestion. The activity should be:

- based on real-life problem in the transport network (such as the bus countdown system);
- developed in partnership with the Learning Team sponsors;
- designed to develop problem solving, communication, and creativity skills and not focus solely on coding skills;
- built around teamwork, where participants each have roles to solve a problem;
- linked to the Key Stage 2 computing curriculum;
- foster an open mind and flexible thinking;
- and be suitable as an informal, drop in activity or expanded to a workshop

The Museum currently has 5 Micro:bits and iPads that could be used in the activity. The team will need to research, identify and purchase (via Museum's funds) additional materials to develop the ideal 'kit.' The team will trial the activity with children visiting the Museum during school holidays to identify design improvements and modifications. The team will develop a training session for the Learning Team that:

- shows how to run the activity;
- provides insight into the technology used for the project and how it works;
- explains how to maintain the kit;
- and that describes the real-world engineering problem and how technology is used to solve it.

Appendix B: Betsy Loring Interview Questions

First Steps in Science

1. Can you tell us more about the First Steps in Science exhibit?
    1. What does it hope to achieve?
    2. How are you achieving these goals?
    3. What age range does FSIS target?
2. How do you design a project with a variable target demographic?
3. What is “stealth scaffolding”?
4. How do you utilize stealth scaffolding in FSIS?
    1. How can we utilize stealth scaffolding strategies within our project?
5. What kinds of STEM skills have you taught through museum projects?
6. What are some strategies that you have utilized to teach these skills?
7. How do you evaluate the effectiveness of activities you design? Do you have any evaluation tools or methods?
    1. What are the evaluation criteria for FSIS? (She mentioned developing evaluation criteria in her project doc)
8. What are the most important things you’ve learned from front-end research?

General Exhibit Questions

9. At a high level, what is your process for designing exhibits?
10. What are some challenges that you have come to expect from making an exhibit?
11. What are strategies that you find engage children the most?
12. How do you keep the activities that you design engaging and fun for kids?
13. Have you ever designed an exhibit that requires each participant to have a different role? (If not, skip 14)

    In cooperative activities, how do you make sure each participant feels equally valued?

Appendix C: Post-Testing Interview Questions

1. What did you enjoy about the activity?
2. Is there anything that you struggled with?
3. What were the most exciting parts of the activity?
4. Was there anything that you found boring?
5. If you saw this exhibit in a museum, would you be inclined to participate in it?
6. Do you feel like seeing the day play out gave you a good understanding as to how you could improve your score on subsequent playthroughs?
7. Was there anything you think a child might struggle with?
8. Was there anything confusing about the traffic light programming?
9. Were there any actions that you attempted to take that you were not able to?
10. Do you have any other comments?