Playful Science Engagement and Interactive Interpretation Prototyping: An Exploratory Study for the Science and Industry Museum

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Abstract

Facilitating playful, informal learning about scientific subjects is both a rising and challenging area of research. Science museum settings offer an interesting opportunity to study this topic through the perspective of visitor engagement with STEM content and collections. Directed by a real-world brief from the Science and Industry Museum, the researcher investigates how digital interpretation techniques can be developed and explored to encourage playful, family-friendly engagement with steam engine science. Furthermore, the researcher examines how engagement with playful interactive interpretation prototypes could be measured and compared through the lens of intergenerational conversations and utterances with science capital themes.

The study centres on the creation of a collection of STEM interpretation prototypes designed and developed by the researcher to engage museum audiences with steam engine science using a playful, family-friendly approach. High-fidelity prototypes are examined using a mixed methods evaluation system focussed on a discourse analysis scoring scheme. The researcher labels this investigated development phase as *proto-scoping* and explores its potential to guide the direction of audience-driven interactive interpretation design. The findings demonstrate how visitor discourse is not only a useful indicator of family engagement and meaning-making but can also be a valid tool to compare one interactive interpretation approach to another. The results suggest a positive correlation between user enjoyment and science capital-themed discourse during the evaluation of two advanced prototypes designed to answer the same interpretation brief.

The work proposes an adjusted approach to the development of interactive interpretation in science museum settings by highlighting the value of visitor-driven, playful engagement and participatory prototyping. The proto-scoping strategy, trialled through this research, encourages creativity, exploration and audience agency in the early phases of interpretation design. Fundamentally, it demonstrates how playfulness and science capital development can be rooted in both the designed solutions *and* the creative practice.

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Dedications

For my parents, Ruth and Dennis Handford.

To Ruth, for the sacrifices you made in raising your brood and enabling us to pursue our dreams. To Dennis, for your unyielding encouragement and enthusiasm.

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Glossary of Acronyms

AHRC – Arts Humanities and Research Council.

CDA – Collaborative Doctoral Award.

HCI – Human computer interaction.

SIM – Science and Industry Museum: Industrial partner museum to this collaborative doctoral project. The museum is located in Salford, Manchester, UK and is part of the wider Science Museum Group.

SMG – Science Museum Group: The public body organisation that manages SIM and four other science museums across the UK: Science Museum (London), National Railway Museum (York), National Science and Media Museum (Bradford) and Locomotion (Shildon).

STEM – Science, Technology, Engineering and Maths.

AR – Action research.

PaR – Practice as research.

PD – Participatory design.

UX – User experience.

Chapter 1: Introduction

This thesis presents an investigation into family-friendly engagement with steam engine science in a public museum setting. The focus lies in making a specific set of five engineering concepts accessible and relatable to a diverse visitor audience (families with children aged four to eleven) using playful exhibition interpretation methods supported by digital technology. During the period of this study, the researcher uses the process of creative practice to explore a new approach to the development of science-focused interactive interpretation using audience-driven, comparative prototyping.

Exhibition interpretation in the context of a museum or historic site serves to enrich audience experiences by communicating the wonder of their collections (McKew, 2022, p. 3). Exhibition interpretation works to support meaning-making, provoke emotions and provide connections between visitors and their immediate environment (McKinty, 1999). It could also be described as a "*revelation based upon information*" (Tilden, 1977, p. 9) which seeks to empower visitors to form opinions, understand relationships/ issues/concepts and draw conclusions (McKinty, 1999). This research looks at museum *interactive* interpretation in particular, a term that encompasses the use of a variety of physical or digital methods to engage audiences with exhibition content. It puts emphasis on the role of the visitor in the process of meaning-making and can also be referred to as 'hands-on, minds-on' approach, where exhibits or installations offer something to physically engage with as well as something to think about (Adams, 2002, p. 2).

As well as creating prototypes for novel interpretation concepts, the exploratory study pilots a new audience-driven framework for exhibition interpretation development in answer to a specific design brief and emergent research questions. The researcher examines how the developed interpretation prototypes could be compared using the lens of science capital-themed intergenerational discourse with a view to measure engagement and achieve more successful, audience-centred design outcomes.

The study contributes to the fields of interactive interpretation design, development and prototyping within the specific context of science museum exhibitions. The work is conducted under the direction of the Power Hall Exhibition Content Team at the Science and Industry Museum. This creative research was driven specifically to help inform design decisions for the reinterpretation of the new Power Hall exhibition, however, the methodology and findings from this study are transferable to other exhibitions and science museum settings.

1.1 The Power Hall

In October 2019, at the start of this practical, collaborative research project, the Science and Industry Museum (SIM) in Manchester was at a poignant moment in its curatorial developments. The organisation was about to embark on a major redevelopment of the Power Hall which had been closed in readiness to start major roofing works, this in turn would lead to the internal redesign and reinterpretation of the exhibition space.

The Power Hall houses one of Europe's largest permanent collections of 19th and early 20th-century working steam engines, the majority of which were built in Manchester (Science and Industry Museum, 2022). A photograph of the previous Power Hall exhibition can be seen in Figure 1-1 below.

Figure 1-1: The Power Hall in September 1998 (Science Museum Group Collection, 1998).

The museum's universal plan was to approach the new Power Hall with a fresh narrative for the situated exhibition that would put the human-engine relationship at the heart of the interpretation story. An extensive evaluation had already taken place of the previous Power Hall visitor experience before its closure (and before the researcher's arrival to the project). This was conducted by the Science Museum-based Audience Research and Advocacy team. The results of this review found the Power Hall, in short, to be too static and lacking in sensory and interactive experiences. The evaluation team recognised that the exhibition interpretation was too text-heavy, and visitors had little opportunity to get involved with the collection and content. The team also identified that written interpretation required more visual support and the tone of the new exhibition should be more personal and straightforward. Conversely, several strengths were also identified which included the direct social links to Manchester along with the impressive and unique objects, especially when demonstrated in action. This Collaborative Doctoral Award (CDA) was designed specifically to support the Science and Industry Museum content team in their exploration of potential interpretation ideas for this reimagined space.

As the Power Hall planning evolved over the first six months of the CDA, a project brief was assigned with which to focus the research and development. This briefing document (as seen in Appendix A) provides important context for the study and grounds the research within the confines of an explicit compound of five engines. This area of the exhibition space is known as 'All Shapes and Sizes' since it contains a mixture of engines designed for a variety of uses but all with five key engine parts in common (cylinder, crank, flywheel, governor and belt). The essence of the later developed brief outlined the family-friendly focus, helped to give direction to the review of literature and brought more clarity and depth to the preliminary research.

1.2 Research Aims

Within this CDA the researcher looked to investigate opportunities for a more human-centred and playful approach to the reinterpretation of steam engine science in the Power Hall. The overall project ambition (in line with the collaborative partner brief) was to generate digitally enhanced interactive interpretation ideas that could make visitors feel more connected to complex steam engine science and engineering concepts through accessible, joyful and family-friendly methods.

Via the development of prototype concepts, directed by the collaborative partner and informed by theoretical research, a variety of interactive interpretation ideas were explored and examined. This takes place through a synthesis of evaluation techniques including iterative user testing, observations, questionnaires and later, an original discourse analysis system. This thesis draws upon and connects the studies related to science capital (Archer, 2018), social constructivist ideologies (Wertsch, 1985) and the work of researchers Allen (2002) and Ash (2003), who have previously developed discourse analysis coding schemes and dialogical inquiry methods for evaluating learning in museum visitor-talk. Science capital is an educational theory that brings together an understanding of how people from all backgrounds engage with STEM (Archer, 2018), section 2.1 of this thesis describes the term in more detail.

The research explores how experimental and comparative prototyping of interpretation approaches can be built into the lifecycle of museum exhibition design through early-stage visitor consultation with particular attention to how concepts can encourage intergenerational STEM conversations and family engagement. The identification of learning talk between the participants offers a valuable resource to shed light on whether users are making meaningful associations with the science and engineering content through verbalised connections and reflection (Allen, 2002; Ash, 2003; Silverman, 1995), and in effect, building on their personal science capital (discussed in more detail in the literature review, section 2.1 and the theoretical framework, section 3.2.2). Through this data point, the research also aims to identify if the prevalence and depth of the documented science-related conversations and utterances have a correlation to a visitor's perceived enjoyment of the interactive interpretation experience.

The researcher attempts to develop and trial this process of time-efficient prototype evaluation in order to compare the STEM engagement success of one playful prototype to another. The research aims to demonstrate how comparative prototyping and scoping techniques could be integrated into an interpretation project timeline to generate a more engaging, science capital-focused and family-friendly product. The described work aims to establish the affordances of family orientated interpretation as opposed to exclusively child-focused or adult-focused techniques. It hopes to convey how modalities of digitally enhanced interpretation can help to encourage and support the engagement of whole families or intergenerational groups alluding to more valuable, memorable and accessible interaction experiences (Benckendorff et al., 2018; Jewitt, 2012). And finally, it aims to add support for the use of discourse analysis for evaluating family engagement with STEM interpretation, defending its use as evidence of meaning-making and engagement within an informal learning environment.

1.3 Research Questions and Methodological Approach

As described above, this body of CDA work has been conducted under the direction of the Power Hall Content Team at the Science and Industry Museum who were looking to explore digitally enhanced and playful interpretation approaches to engage family audiences with steam engine science. The creative outputs have been developed to inform the ideation of design concepts for the reinterpretation of the Power Hall. To this end, the main research question is proposed as follows:

Main question: How can digital interpretation techniques be developed and explored to encourage playful engagement with steam engine science?

In working towards an answer to this main question, two subsidiary questions emerged during the creative work.

Subsidiary questions:

1. To what extent can engagement with playful interpretation prototypes be measured and compared through the lens of science capital-themed learning talk?
2. Does the prevalence of science capital-themed learning talk correlate with the visitors' perceived enjoyment of playful interpretation?

Due to the real-world, exploratory and interdisciplinary nature of the study, the methodological approach used to answer the research questions can be defined as a combination of *practice as research* and *mixed methods* because the work draws together creative practice processes (Bulley & Şahin, 2021) through ideation and prototype development, and traditional academic research methods in the form of quantitative and qualitative evaluation and data collection (Hesse-Biber, 2010).

To expand, design thinking and creative problem solving are used as the main tools to explore ideas and develop concepts to address the Power Hall interpretation design brief and to address the main research question. Qualitative visitor study strategies of questionnaires and observations are used to progress the creative inquiry and quantitative data is gathered via discourse analysis codification and comparison.

From a holistic view, the practice is used to trial a nuanced approach to a proposed classification of prototyping (coined for this research as proto-scoping) and offers the opportunity to explore its advantages and limitations as an interpretation design methodology for Science Museums. In addition, the developed artefacts are evaluated to form the basis for testing a novel discourse analysis framework designed exclusively to assess and compare interactive science interpretation prototypes through the lens of science capital themes.

The practice research and mixed methods approach (explained in closer detail Chapter 3:2 of the methodology chapter) brings the value of creative practice to the fore whilst still enabling more traditional elements of research and data collection. The designed outputs (all created independently by the researcher during the course of the CDA) have facilitated the capacity to examine proto-scoping as a playful, audience focussed methodology for exploring a variety of prototyped solutions to the same design inquiry. The practice has led to the development and testing of a new evaluation system for comparing one interactive prototype to another and allowed the researcher to identify data patterns between suggested science engagement and perceived user enjoyment.

1.4 Research Aspirations

Firstly, the results of this research intend to inform both current (the Power Hall) and future exhibition interpretation approaches and strategies at the Science and Industry Museum and possibly the wider Science Museum Group. The prototyped ideas provide an opportunity for the Science and Industry Museum to test out different interpretation delivery methods with their visitor audience without long-term commitment and expensive monetary investments. The work also looks to demonstrate how using methods to encourage conversational family/group engagement could prove significant to the ultimate success and enjoyment of a commissioned interpretation artefact.

From a broader perspective, this study intends to further champion practice research as a rigorous and valid approach to academic scholarship. This work aspires to become an additional example of how practice research is critical to the investigation of creative challenges and is an essential tool to explore experimental concepts and specialist solutions. Here, the design rationale and practical application are paramount to the investigation and the practice is incorporated into both the methodology and the outcome.

1.5 Ethical Considerations

All research involving people via the collection and analysis of data is subject to ethical and safeguarding considerations offering external assurance in the rigour of academic projects (Candy, 2006). The research in this thesis draws on the ethical guidelines from the British Educational Research Association (BERA, 2018) as well as guidance from the University of Salford Research Ethics Committee and support hub. Participants involved in the Power Hall research were given a participant information sheet (Appendix B) they were then asked to consent to the research (Appendix C). Additionally, the project was explained to children in advance, and they were informed that the research was voluntary. There was no obligation for visitors or children to participate, and they could leave at any time without penalty or judgment. Information letters explained that observation would be undertaken but no personal information would be collected and there would be no use of video, photography, or audio recordings. Any images of children used in this thesis and creative outputs (e.g. in the augmented reality demonstration in 4.2.1.4 and the Think Tank fieldwork visit in Appendix K). are of the researcher's own children. Consent for their use is given by the researcher (their mother). Formal ethical approval was received from the University of Salford for the data collection of the study in March 2020 (see Appendix D).

1.6 Research During Unprecedented Uncertainty

As a precursor for this report, it is necessary to draw attention to the specific timing of the practice research; the period of the COVID-19 pandemic being acutely noteworthy. The practical developments of the designed prototypes outlined in this thesis occurred primarily during the period of February 2020 through to December 2021, during a phase of significant social and economic uncertainty and turbulence. Especially significant to this work were the modes in which humans were (and were not) interacting with each other, with spaces and with information. The CDA spanned across all of the COVID-19 lockdowns and key questions were continually raised about whether these were permanently changed times of human engagement, resulting in disturbed and disrupted design ideation. There was also a great deal of concern about the future security of the cultural, heritage and arts sector as a whole. In a report by the International Council of Museums (2020) analysing almost 1,600 responses from institutions across the world, 82% anticipated a significant decrease in their departments and almost 13% feared their museum would need to permanently close. These global perspectives and notions of insecurity had substantial implications on the design decisions and pathways taken in this practice research. Furthermore, the amount of direct museum visitor participation in relation to the generation of the prototypes was severely impacted due to the timing of the pandemic lockdowns. In the preliminary stages of research planning, visitor consultation was intended to take place much sooner in the practice research timeline, but due to museum closures, this stage of development was forced to take place in a later and more compact time period.

Also of significance, was the public and media scrutiny surrounding the Science Museum Group and their connections with fossil fuel organisations. In April 2021, this came to a head with the announcement of their decision to have Shell as their main sponsor for their 'Our Future Planet Exhibition'. This opportunity was intensely and publicly criticised by environmental groups, activists, the media and scientists alike (Lister-Fell, 2021). Correspondingly, in April 2021, it was revealed that the Science and Industry Museum had been awarded over four million pounds in funding by the Public Sector Decarbonisation Scheme which was to be used (within a very limited amount of time) to transform their environmental sustainability (Macdonald, 2021). The reinterpretation of the Power Hall exhibition was put on pause for many months while the development and repair work was reassessed, and the exhibition narrative and content focus were reconsidered in light of the aforementioned occurrences.

It was impossible, during this period, not to proactively adapt ideas and approaches according to these social concerns and industry direction. It took time to discover ways to implement and test those ideas through an agile process of discussion, illustration and prototype realisation. These ideas and design decisions are described in detail in the future chapters of this report.

1.7 Thesis Outline

This thesis consists of six key chapters; this first chapter has offered an overview of the practice research and situated it within the collaborative environment of the Science and Industry Museum and more specifically the Power Hall. It has set out the background of the study and introduced the nuances and unique circumstances of this real-world challenge.

The research questions have been provided along with the research aspirations and ethical considerations.

In chapter two a review of existing literature is presented. This attempts to explore the significant themes that this multi-disciplinary work encompasses, this includes informal STEM learning, playful engagement, user experience design and prototyping situated in the field of science museum exhibition interpretation. The review presents a summary of what we currently know about the value of intergenerational conversation and its positive links to science capital development, particularly in a heritage setting. The literature highlights the differences in engagement needs and motivation regarding adults and children, and their use of exhibition interactive interpretation. Despite the disparities, it emphasises the benefits that mutual engagement and shared attention can bring to an informal learning situation, when parents/caregivers and children experience and socially engage with interactive interpretation together. The review identifies a need for a more effective and creative approach to developing, prototyping and evaluating playful, family-friendly interpretation in relation to STEM exhibition concepts.

Moving forward, chapter three is used to outline the rationale for the design and research methodology of this study. The philosophical stance is presented along with the conceptual and theoretical frameworks for this creative and industry-grounded research.

It features methods and tools used in the main phases of the design, development and evaluation process for a collection of interactive interpretation prototypes for the Science and Industry Museum. The methodology of the research is broken down into three key phases (discovery phase, development phase and evaluation phase) and an explanation and strategy for each phase is provided.

Chapter four provides a detailed presentation of the research. It delivers a robust approach to the study by describing the creative inquiry and practical developments regarding the realisation of multiple interpretation concepts through the trial of an exploratory prototyping approach. It deals with the dynamic nature of this investigative assignment and draws attention to the necessity of flexibility and adaptation within a museum interpretation brief. The chapter describes the three main phases of research that took place during the CDA. The 'discovery phase' provided the foundation of design research and early ideation. The 'development phase' featured the creation of collection of interactive interpretation prototypes in answer to the design brief. It also involved the development of a strategy for the comparison of one prototype to another through the lens of STEM-focused intergenerational conversations. Finally, the ‘formal evaluation phase’ was used to assess the success of the two key interpretation concepts created during the development stage and to trail the newly developed evaluation strategy based on family engagement with steam engine science from the perspective of science capital. The results of the user testing are presented in readiness for analysis and discussion in the succeeding chapter.

In chapter five the results of the evaluation process involving the two key prototypes are discussed and analysed. The prototypes, which are carried forward to the main data collection phase, are used with the intent to theorise how advanced project ideas and prototypes could be compared and scrutinised with a focus on audience participation. ‘Proto-scoping’ is discussed as an integral part of newly devised audience-led framework for science museum interactive interpretation development which recommends a preliminary, playful and participatory exploration phase before the creation of a refined design brief and the commissioning of a chosen interpretation concept. The chapter aims to then draw together the main outcomes of the study and critically review them against the existing field of STEM interactive interpretation design. The researcher analyses whether this approach to interactive interpretation prototype evaluation has the potential to elucidate concept ideas that have significant potential for family-friendly and social science engagement.

Chapter six presents a research summary with a key focus on the outcomes and contributions to knowledge within the field of interactive interpretation development for science museum settings. Taking each question in turn, statements are made about how this thesis has been able to generate a collection of answers and conclusions. The researcher describes the limitations and challenges of the study and closes the thesis by offering recommendations for future research in this field.

Chapter 2: Literature Review

The Science and Industry Museum, like many science museum settings, aims to provide inspiring, memorable, and engaging educational experiences for its broad and diverse audience. They have a resounding philosophy of awakening curiosity through active participation and social interaction (Science Museum Group, 2022a); this departs from the more predictable and prescribed environment of formal, classroom-based learning. The site-specific distinction of the museum affords an anchoring perspective for the analysis and investigation found within this thesis.

Although the themes of this research do fall within the much broader sphere of 'museum studies', this literature review does not attempt to define or investigate issues connected to the traditional perspective of museums such as collections, curation, cataloguing, historical narratives, political agendas and heritage governance (Basu & Modest, 2014; Macdonald, 2006; Robbins et al., 2021). This research instead finely targets the nuance of supporting social meaning-making in science museums with a focus on the topics of informal STEM learning, playful engagement, user experience design and prototyping situated in the field of science museum exhibition interpretation. These interdisciplinary themes have been chosen due to direction from the collaborative partner and because they have the capacity to deliver the framework for examining the potential benefits and challenges of developing family-friendly, exploratory, digital interactives specifically in the context of a science museum space.

2.1 Informal STEM Learning and the Science Museum Group

For the purpose of this site-specific study, the term informal learning is defined as self-paced, free-choice learning that happens in a non-structured experience, outside of the formal education environment, this may include social, interactive and multifaceted opportunities that engage diverse learners from a variety of different age groups (Falk et al., 2007; Gong, 2022; Koutsika, 2020). Museum learning is often considered a sociocultural practice and a tool to bridge the gap between home and school learning (Ellenbogen et al., 2007; Falk et al., 2012). Yoon et al. (2012, p. 206) describe the nuances of informal learning within a museum environment to be fluid and sporadic, typified by learners quickly seeking out consumable content in bite-sized chunks. It is these characteristics that make designing informal learning experiences for museums both interesting and challenging.

The Science Museum Group has a long-standing reputation for informal learning and upholds a significant role in growing science literacy in the UK (Science Museum Group, 2019c). Achieving scientific literacy is fast becoming an indispensable skill as society leans towards STEM as an answer to many contemporary problems. The UK Government strives to secure a sufficiently skilled workforce to support the growth of STEM industries and to achieve its ambitions of becoming a 'science and technology superpower' (UK Parliament, 2022).

In recent years *science capital* has become a widely recognised education theory, a concept that is said to provide a foundation for young people and their attitudes towards STEM subjects and career aspirations (Winterbottom et al., 2018, p. 10). Like *science literacy*, *science capital* is concerned with knowledge, skills and an appreciation of science, but it additionally includes more personal life experiences and attitudes based on what you or your family do, who you know and what your cultural values may be. It brings together an understanding of how people from all backgrounds engage with STEM and how this can be boosted through a wide variety of science-related experiences and environments. (Archer et al., 2016).

Archer et al. (2015) indicate that an individual classed as having 'high science capital' would have had access to many positive and high-quality science resources, experiences and spaces. They would be confident in their scientific skills and do science-related activities in their out-of-education time. They are likely to know people who work in science-related jobs and are more inclined to think of science as being 'for them'. In comparison, an individual with 'low science capital' would have less confidence in their skills, have fewer personal connections with people working in a scientific field and have less engagement with out-of-education science experiences. Students who leave school with low levels of science capital are therefore less likely to choose to follow a science-related career path.

The science capital concept is not an evaluation tool, and it is very difficult to measure how a particular experience has made an impact on it (Science Museum Group, 2021c, p. 13). However, by applying measurable observation on what makes people feel more associated and connected with science, organisations like museums and science centres can help to incrementally grow a person's science capital through increased levels of positive science engagement (Archer et al., 2015).

Science Museum Group content teams have adopted the science capital-informed approach in their operations and exhibitions to enable and empower more diverse audiences to access the opportunities and wonders of STEM. The Science Museum Group believes that rather than concentrating on filling the gaps in a visitor's science knowledge, they need to provide more opportunities for visitors to connect with science and see where it has value in their lives, both now and in the future (Science Museum Group, 2020, p. 15).

According to the publication: Science Capital in Practice (Science Museum Group, 2021c, p. 14) The Science Museum Group believes that a science capital approach to exhibition content and interpretation can be achieved by:

- Focussing on making visitors feel welcome and confident in museum spaces.
- Using language and communication so that all visitors can feel part of science.
- Considering how to connect and relate to audiences' diverse interests, experiences and everyday lives.
- Valuing and building upon the existing STEM knowledge and experiences that the visitor brings with them.
- Making exhibits, communications, recruitment, programmes and marketing inclusive.

In connection with the science capital approach, SMG also embraces a five-tier model of visitor needs which informs their STEM exhibition interpretation. This model has its foundations in Maslow's Hierarchy of Needs (Poston, 2009, p. 348), an assessment tool used in many different professions, where the ideas of needs are addressed in order, starting with the most basic needs for survival before moving up to more complex, self-fulfilment needs. SMG has adapted the model to connect with the entire museum experience and has strong relevance to the STEM interpretation (Science Museum Group, 2021a). Figure 2-1 taken from page 12 of the SMG document: 'Engaging all Audiences with STEM: An Equitable Approach Informed by Science Capital' demonstrates this adapted model and how each segment of the pyramid has connections with the practical approach to the design of interpretive solutions.

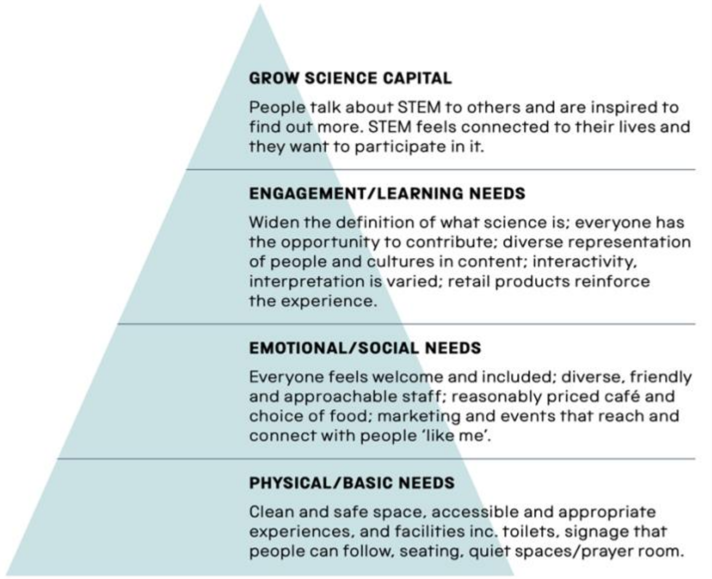


Figure 2-1: SMG's Approach to Interpretative Solutions Adapted From 'Engaging all Audiences with STEM: An Equitable Approach Informed by Science Capital 2021 (Science Museum Group, 2021a, p. 12)

Of particular note to this research are the top two sections of the triangle:

> **Engagement/Learning Needs** …diverse representation of people and cultures in content; interactivity, interpretation is varied…
>
> **Grow Science Capital** People talk about STEM to others and are inspired to find out more. STEM feels connected to their lives and they want to participate in it…

Complimenting this approach is a more specific practical framework for interpretation design which SMG call their 'Audience Engagement Framework'. This document provides clear guidance about what makes a good science engagement experience (Science Museum Group, 2019a). The framework, which can be seen in full in Appendix E, is centred around five key ingredients:

1. Hook – Capturing the visitors' attention and introducing the content. This could be the way the interpretation looks or how it sparks initial curiosity.
2. Inform – How information and content is shared with the audience and how it links to their existing knowledge.
3. Enable – Allowing the audience to get involved, this could be through hands-on activities or asking thought provoking questions.

4. Extend – Making the experience last longer and encouraging visitors to explore further. This might be done through links and signposts, challenges to complete or questions to think about.
5. Reflect – Engagement reflection points should be put in place throughout the design and development of STEM activities and interpretation.

The framework and the guidance elements above provide a reference point a direction for the practical design and development process for the prototypes featured in this project. It helps to inform all stages of the research and feeds into the evaluation tools used to grade the success of a given prototype.

The themes of connection and engagement are repeated terms throughout literature focused on informal STEM learning. London (2020), suggests that a sense of connection is present in all forms of engagement, this could be a connection to a concept, an activity, a place or even a connection to oneself or someone we are close to. Deeper levels of engagement are built on trust and consistency.

The Science Museum Group looks at engagement by seeing if people:

1. Have a meaningful connection with exhibition content
2. Make links to their everyday life
3. Feel like they belong in the museum space
4. Dwell for longer
5. Have positive feelings about an experience
6. Are involved and contribute

Archer et al. (2015) suggest that by increasing a person's positive engagement with science, and therefore their science capital – no matter what their socio-cultural background, they are not only more likely to look at STEM as being 'for them' but also making steps toward a fairer and more inclusive society. In line with this claim, the Science Museum Group states that:

> *"Equity and social justice are integral to the concept of science capital, enabling and empowering everyone to access the opportunities and wonders of STEM"* (Science Museum Group, 2021c, p. 4).

SMG see equity as addressing the importance of making all visitors feel welcome within an environment regardless of characteristics such as age, disability, gender, education or cultural background (Science Museum Group, 2021b, p. 7) The Science Museum Group (2021b, p. 11) recognise that although STEM achieves amazing accomplishments significant to every bit of the world around us, not everyone has a personal connection to it. By offering visitors more opportunities to be inspired by and engaged with science, they believe that they can encourage a wider range of visitors to:

- Recognise a personal relevance to their lives.
- Deepen their appreciation of science.
- Improve understanding and recall with regard to science content.
- Increase the pursuit of post-16 STEM careers and subjects.
- Develop a lifelong connection with cultural institutions.

The researcher observes that the strong organisational drive to adopt such approaches may suggest that the Science Museum Group are utilising these techniques not only to support the growth of visitor science capital but perhaps more strategically, to broaden audiences and build stronger connections with a wider range of visitors.

In practice, the Science Museum Group reports that a science capital approach helps them to engage with new or under-represented groups and to think about new ways of making STEM ideas and content more relatable to a wider range of audiences (Science Museum Group, 2021c, p. 11). As this is a collaborative project driven by the museum, the directive of a science capital approach was to become an important feature and guiding framework of the proposed interactive interpretation outputs to support informal STEM learning. A further critical discussion of this topic can be found in thesis section 3.2.2 regarding theoretical and conceptual frameworks, however, the researcher considered that a *playful* approach to steam engine science was coherent with science capital values and an effective way to engage diverse family audiences.

2.2 Play in the Context of Informal Learning

The concepts of making museum content more accessible and connected to wider and more diverse audiences are of course not new. Researchers and exhibition designers have long been underlining the importance of playfulness and fun as a means to engage young audiences and appeal to more diverse visitors (Derry, 2012; Luke, 2017). The value of playful behaviour has gained increased recognition from researchers and policymakers alike, and evidence is on the rise for its correlation with cognitive development, communication skills and mental well-being (Bergen, 2009; Whitebread, 2012; Zosh et al., 2017). However, despite the growing research regarding its vital importance to learning and development, there has been a marked regression in the focus on play in formal learning settings. Mounting pressures of increased academic standards mean that playfulness is being substituted by test preparation and assessments (White, 2012). The lack of play opportunities in education and the workplace leaves a large gap to be filled in leisure time which could be explored as a contributing factor in the demand and need for play within museums and heritage sites. In contrast to formal education centres like schools, museum institutions are also often in the more fortunate position to have a greater sense of freedom, funding, and time, to think more imaginatively about how to spark a sense of creativity and fun (D'Souza, 2018).

Play behaviour can be challenging to define, mainly due to its many different forms, contexts and disciplines (Miller, 2017). In the book: *Homo Ludens: A study of the play-element in culture,* Huizinga (1955) refers to play as standing outside 'ordinary' life and as being 'not serious'. He also describes the concept of play as having no material interest and within its own boundaries of time and space. For the purpose of this study, the researcher looks at play outlined from the context of family-focussed science museum settings where playful engagement behaviour is exploratory and fluid but also guided, directed and motivated by the exhibition objectives (Yoon et al., 2013).

Navidi (2016) explains that play provides an opportunity for individuals to focus on the process or means rather than a final result, allowing for more explorative or interactive behaviours. This might include exaggeration, repetition or an experiment in sequence change. Likewise, White (2012) supports that contemporary characterisations of playful behaviour focus on several significant criteria including; being pleasurable, intrinsically motivated, process-orientated, actively engaging and non-literal. In a similar manner, Smith and Roopnarine (2018) draw upon both traditional and contemporary definitions of play and break *true play* into five characteristics:

1. Self-chosen and self-directed (something the player wants to do)

2. Intrinsically motivated (not done for a reward outside itself)
3. Guided by mental rules (the play must have some bounds otherwise, it breaks down)
4. Imaginative (a degree of mental removal of the player from the real world)
5. Conducted in an active but stress-free state of mind (the player has conscious control over their own behaviour and is free to change the state of play if tension becomes too great).

London (2020) presents play alongside a sense of wonder and creativity for fostering engagement; terminologies which sit particularly comfortably in a museum setting. He describes that by wondering *about* a concept/idea/object (logical thinking) or being in wonder *at* a concept/idea/object (emotional thinking), participants open their minds to new experiences which is conducive to deeper thought and enhanced learning. He also states that in a position of wonder we become more accepting of new information and importantly, as we are usually in an 'out of the ordinary' experience when in a museum exhibition setting, this new knowledge is more likely to be retained and embedded. Similarly, Richards (2003) agrees that using playfulness, fun and humour as a tool to support learning opportunities can be extremely valuable because our brains prefer to remember 'out of the ordinary' information. These points from London and Richards are examples of the common thread which appears to be most thoroughly supported throughout existing play-based literature regarding play being a vital link to informal learning.

In connection with the previously discussed definitions of play, a commercial research project via the Lego Foundation (Marsh et al., 2020) supports five key characteristics for *learning through play* which they state as being:

- Joyful
- Actively engaging
- Iterative
- Meaningful
- Socially interactive

The Lego Foundation suggests that these characteristics can be seen in both non-digital and digital forms of learning through play (a subject to be addressed later in the literature). Whitebread (2012) values play on an equal level to that of language and technology, stating that if it were not for play, such achievements would not even be conceivable. He explains that through clearly associated playful situations such as role-play and object-orientated problem-solving, both children and adults can work through ideas and compound their understanding of the world. Likewise, Vygotsky (1978, p. 100) explains that “a child’s greatest achievements are possible in play, achievements that will tomorrow become her basic level of real action”.

Mardell et al. (2016) propose a ‘pedagogy of play’ framework in order to draw together learning and play. During their research, they were interested in developing specific indicators of what play looks and feels like using three overlapping categories: ‘delight’, ‘wonder’ and ‘choice’. When all three of these indicators are in action during the engagement, playful learning is likely to be occurring. The characteristics of these three indicators are as follows:

- Delight includes a sense of excitement, joy, satisfaction and pride. Learners who feel delighted might smile, laugh or “be silly”
- Wonder includes a sense of curiosity, novelty, surprise and challenge. Learners who feel wonder might be improvising, exploring, creating or imagining
- Choice incorporates a sense of empowerment, autonomy, spontaneity and intrinsic motivation. Learners who are expressing choice might be setting goals, sharing ideas and negotiating challenges (Mardell et al., 2016).

These powerful notions make playfulness an instrumental approach for the creative practice of this study. Through the process of playing, children situate themselves in a better state of mind–body–environment interaction (Lester & Russell, 2010, p. 25). The characteristics of play provide the building blocks for the development of stakeholder discussions and are drawn upon during the creation of the design interventions of this project. The pedagogy of play framework (Mardell et al., 2016) is employed in order to support the engineering-themed learning outcomes outlined within the brief.

As the Power Hall research is particularly concerned with social interaction, it is significant to note that play is the primary context in which children build their emergent communicative skills, understand the behaviour of others, participate in a social exchange, express opinions and share information (Zigler & Bishop-Josef, 2004). Research also demonstrates that play-based learning leads to greater social emotional, and academic success (Krieg et al., 2023). Within the field of museum and exhibition interpretation, the roles of *free play* and *guided play* are frequently examined and are addressed in this review of literature because they offer a child-centred approach to playful learning. Skene K et al. (2022) describe play on a spectrum with free play at one end, and direct instruction at the other; guided play is situated as the "middle ground". Free play can be defined as providing the individual with 'true autonomy', meaning that individuals are fully in control of their own play without intervention or having rules to follow (White, 2012, p. 7), in the case of a science museum environment this might be a play space with a collection of loose components like blocks, crates, PVC pipes or cogs that can be easily moved and used in different ways (Krieg et al., 2023, p. 94). Guided play, on the other hand, is supported by either a facilitator or by introductory guidance providing enrichment, questioning opportunities, or encouraging further learning (Skene K et al., 2022, p. 1163). Similarly, Weisberg et al. (2016) describe guided play as possessing the child-directed nature of free play but with attention to specific learning outcomes and a degree of mentorship. An element of assistance during play can foster more opportunities for active participation and self-reflection, and can help individuals to learn beyond what might be possible in independent free play (Skene K et al., 2022, p. 1163). In agreement, Weisberg et al. (2016) describe that although free play is necessary for healthy development in the early years, guided play provides an optimal vehicle for delivering educational content. They agree that enjoyable and engaging formats of guided play give the learner a sense of control and autonomy whilst constraining the activity to facilitate learning. With these ideas in mind, guided play would appear to be the most appropriate approach to the design of STEM interpretation within the bounds of the Power Hall brief.

In relation to play in the context of STEM learning and engagement, Bergen (2009) suggests that play empowers learners to safely test and transmit confident scientific or mathematical ideas to generate stimulating results. Bergen also identifies commonalities between play and science by noting that both concepts require curiosity, observation, logic and discourse. Bergen outlines that children who are accustomed to playful learning will be more likely to be able to draw upon creativity, problem-solving and innovation in later STEM professions using their well-practised playful skills. Neural pathways in children's brains are influenced and advanced through the exploration, thinking skills and language expression that occur during play (Krieg et al., 2023, p. 2).

There are several studies suggesting that play is an observable and measurable construct (e.g. Harris, 1989; Kanhadilok & Watts, 2017; Trevlas et al., 2003). A recent and relevant example is from Henriksen (2020) who developed the 'Dimensions of Play Framework' as a tool for observational, quantitative measurement of play specifically for children's museums. The study involved revising and adapting prior models into a framework concerned with observing three dimensions of play: type, complexity and social level. The study aimed to investigate interrater reliability using a time-sampling method of video recordings of children interacting with a clay exhibit. Henriksen used a complex coding ethogram in a study that claimed to be the first quantitative observational measure to include the dimensions of play type and complexity (Henriksen, 2020, p. 27). Although relevant to the Power Hall study, Henriksen judged this time intensive methodology as not yielding acceptable results (Henriksen, 2020, p. 34) neither does it connect to STEM themes or take into account playful meaning-making. The key combination of play and higher-level STEM skills has been identified by as an area lacking in measured research (Henriksen, 2020, p. 2; Zosh et al., 2017). As the skill or learning content gets more advanced, the harder it becomes to assess the impact of a particular playful learning opportunity. Researchers are known to use before and after assessments of a learner's vocabulary to measure the impact, however, critical thinking skills or innovation are seen as being much harder to quantify (Zosh et al., 2017). This area of weakness opens an opportunity for further exploration within the bounds of this study.

2.3 Intergenerational Engagement

Due to the target audience of the Power Hall interpretation project being family groups with children aged four to eleven years (defined but not limited to), it is important to address the intergenerational nature of this work. Families can be broadly defined as intergenerational groups composed of at least one adult and one child. The adult is very often a parent, but they could also be any adult with an ongoing relationship with the child such as a caregiver, grandparent, or other relative (Povis.K., 2016; Wolf & Wood, 2012).

Mercer (2017) presents that at the foundation of a functional and healthy society are social interactions between young people and adults, an aspect of engagement which is much desired within museum environments. Humans make sense of the world through social interactions with others in a process of 'distributed meaning-making' where understanding can be achieved by gathering information from multiple sources rather than just from one place or person (Falk et al., 2012). With a social lens, it is through discourse that an individual comes to identify themselves as being part of a community or group, often sharing vocabulary, experiences, values and beliefs (Ellenbogen, 2004), these qualities have associations with science capital concepts, far beyond just the shaping of knowledge and understanding. For instance, Archer et al. (2016, p. 3) outline that one of the key dimensions of science capital is "*talking about science in everyday life: how often a young person talks about science out of school with key people in their lives (e.g. friends, siblings, parents, neighbours, community members)*".

In relation to informal learning, the mutual exchange between two or more individuals from different generations provides a natural catalyst for building knowledge and skills as well as the ability to remember, recall and apply thinking (Boger & Mercer, 2017; Haden, 2010). In recent years, researchers have outlined the conditions under which attending experiences together has consequences for human memory, motivation, judgment, emotion, and behaviour (Shteynberg, 2015). Povis (2016) suggests that when two or more people concentrate on the same aspect of their shared environment, be that an object or topic, their joint attention has significant benefits in social learning situations and provides an opportunity to share real-life experiences from both sides of the conversation. Shteynberg (2015, p. 4) explains that through vocalisation and shared attention between individuals the allocation of their cognitive resources is increased, emotional intensity is amplified and in turn, the experience or information is better remembered. From the perspective of a museum environment, joint attention can increase dwell times, promote inquiry at exhibits and lead to increased learning talk and memory outcomes (Povis & Crowley, 2015). These perspectives therefore reiterate the importance of making content appealing and accessible to both children and adults to capture and hold attention long enough to trigger a verbalised response.

A point to emphasise here is that this transference of skills and learning between generations does not travel in only one direction, and the role of *children* as influencers has long been acknowledged (Benckendorff et al., 2018; Istead, 2014). Some researchers (Henson, 2016; Warpas, 2013; Wolf & Wood, 2012) suggest that this can become especially apparent in relation to family engagement with play-based experiences; areas where young people feel particularly comfortable and very often take the lead. Museum studies (Hawkey, 2006; Henson, 2016; Whitebread, 2012) have shown how some parents or adult group members display discomfort in pretend or imaginative play situations and have revealed that these can be obstacles for parent involvement, who sometimes choose to stand back and observe their child or direct them instead of joining in. Adults have a clear view of what they want to learn and they desire to learn it in the most direct way, in comparison, children usually need to be motivated to learn and respond positively to the opportunity to interact in a goal-based environment (Schaller et al., 2002). Henson (2016) states that as well as adults often feeling uncomfortable doing ‘silly things’ in a museum space, they also tend to spend less time interacting with activities that they do not perceive to be of value. Warpas (2013, p. 43) suggests that adults have often lost their ability to play in the true sense of the term (defined in 2.2); children can therefore become the connecting element between adults and the world of imagination and playful exploration.

Wolf and Wood (2012) reinforce that planning for *family* interaction within museums should take much higher priority. To thoroughly support playful learning involving a wide spectrum of age groups, content and activities, interpretation should move through different scaffolding stages, this may range from entry-level concepts and hands-on opportunities working towards understanding and engaging with more complex theories. In the genre of informal learning, scaffolding is concerned with building on concepts and working toward mastery of ideas with the intention of creating rewarding activities which will be suitable for a variety of different learners (Yoon et al., 2013). Scaffolding requires the simplification of ideas or tasks and encouraging the learner to work toward successful experiences and deeper understanding (Wolf & Wood, 2012). Scaffolding consists of advancing levels of activities to support the learner as they are led through an educational experience and is closely related to Vygotsky’s zone of proximal development (Mcleod, 2023b, p. 3), described in the theoretical framework of this study (section 3.2.2). In a museum environment, rather than adding a separate area or activity for children and another mode for adults, designers, curators, educators, exhibition and program developers should work collaboratively to focus features of content or activity that can interest and stimulate various levels of interaction by visitors of different ages (Wolf & Wood, 2012).

These observations and studies have significant importance to both the creative practice and the evaluation methodology of this research. The literature highlights how engagement and the transference of information differ between adults and children, with parents and caregivers tending to use conversations to focus attention, make connections, and impart information (Diamond, 1986; Povis.K., 2016) and children engaging more commonly through on physical actions, imagination and social interaction (Piscitelli & Weier, 2002; Warpas, 2013). Henson (2016) describes that parents most commonly see their role as a learning facilitator in a museum space, searching through certain forms of interpretation to transform the content into more child-friendly or relatable information. Exhibition budgets and limitations on space mean that individual interpretation installations must work smart and hard to successfully satisfy the engagement needs and expectations of a variety of visitor types (Hawkey, 2006). This can be a fine and delicate balance – if the interpretation method looks too *childish* this can put off older children and adults and give a signal to for them to step back and not get involved; too mature and young children are likely to not engage at all (Luke, 2017; Wolf & Wood, 2012).

The literature verifies that engagement opportunities and interpretation installations within an exhibition space need to be made welcoming and comfortable for *both* adults and children. The significance and value of encouraging high-quality intergenerational conversations (Boger & Mercer, 2017) is an aspect which is considered carefully in the design of the creative outputs of this study. Interpretation should provide conversational tools for parents which will enable them to discuss the content easily and confidently with their children (Haden, 2010, p. 63). Scaffolding opportunities, as described by Wolf and Wood (2012), are built into the prototyped design interventions in order to offer multiple entry points to the interaction experience. The variety of child and adult engagement nuances as described above (Benckendorff et al., 2018; Ellenbogen et al., 2007; Istead, 2014) makes successfully designing family-targeted interpretation particularly challenging, but by close attention to these provocations, museums can support true intergenerational engagement through collaboration and building on shared participation (Wolf & Wood, 2012).

2.4 Collaborative Practices and Human-Centred Design

The notion of shared participation and collaboration identified by Wolf and Wood (2012) brings the literature to the topic of collaborative practices in relation to interactive interpretation design. Over recent decades there has been a shift in attitude concerning human-centred design from user-centred processes to that of more participatory and collaborative experiences (Sanders, 2002). The transition is changing the roles of the designer, the researcher and the 'user' and furthermore, changing the landscape of design practice. In turn, these concepts are creating new areas of collective creativity (Sanders & Stappers, 2008).

Human-centred design encompasses a variety of methodologies which all aim to improve the response to the needs, desires and expectations of humans. The multiple human-centred design approaches range significantly in their characteristics and consider humans (in particular users, designers and researchers) to varying degrees (Gall et al., 2021). Sanders and Stappers (2008, p. 6) developed a matrix to demonstrate their own view of human-centred design, plotting 'led by design' vs 'led by research' on one axis, and 'user as subject vs 'user as partner' on the other, as seen Figure 2-2. This diagram helps to add clarity to their divisions and demonstrates the weighting and interplay between designers, researchers and users.

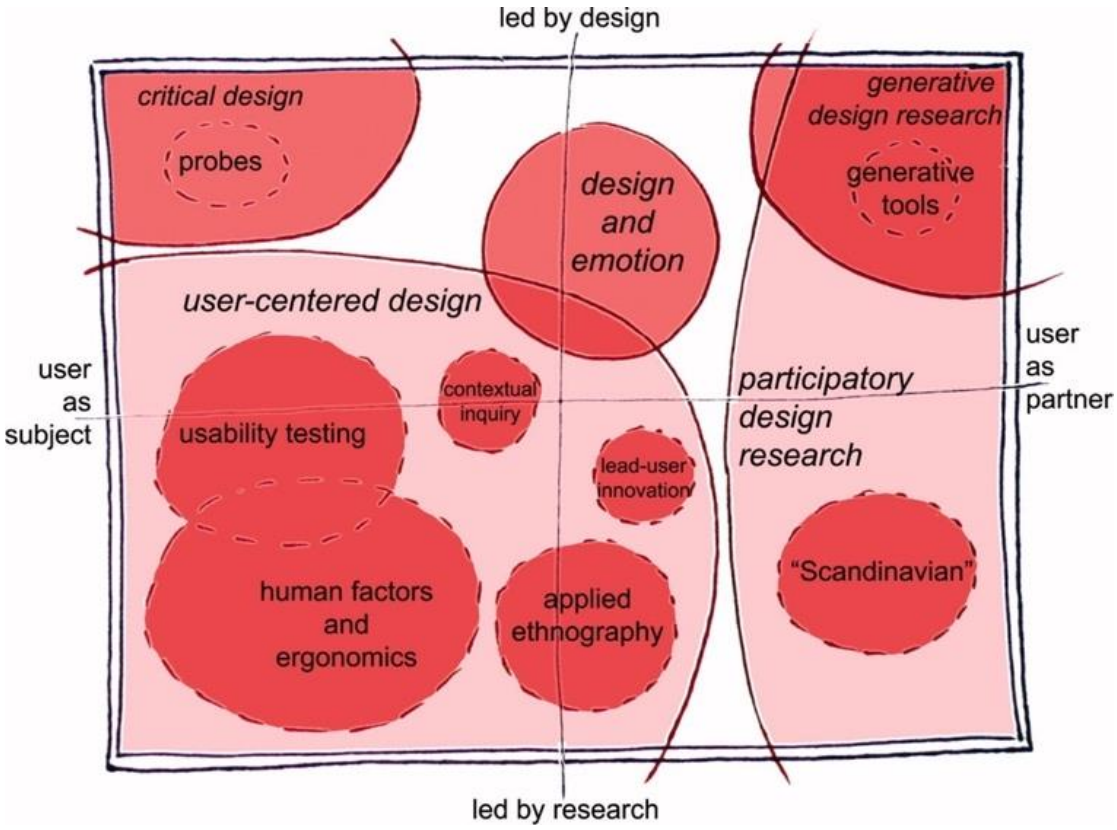


Figure 2-2: Landscape of human-centred design research as practised in the design and development of products and services (Sanders & Stappers, 2008, p. 6)

Users are commonly accepted as a valuable source of knowledge and creativity in the development of new products, services and systems (Buur & Matthews, 2008). In a user-centred design process, the researcher acts as the interface between the user and the designer, their roles are distinct yet interdependent. The focus is on the 'thing' being designed along with ways to ensure that it meets the needs of the user (Sanders, 2002). Gall et al. (2021) explain that user-centred design is an iterative process in which the designer(s) focuses on the users and their needs in each phase of the design process.

As a step further, participatory design moves more toward the user becoming a partner rather than just a subject, it has the goal of working directly with users as well as stakeholders in the design of products and systems (Muller & Kuhn, 1993). van Oorschot et al. (2022) note that research concerned with participatory approaches commonly uses the term 'participation' in one of two ways:

1. participation of those *doing design*; referring to, for example, designers, co-creative innovators and users.

2. participation of those *studying design*; referring more exclusively to researchers.

Sanders (2002) explains that in participatory approaches the roles of the designer and the researcher commonly blur and the user becomes a critical component of the process. This approach appears to be relevant to this particular study due to the intention to engage and consult with museum visitors, collaborate with SIM team members, as well as design and develop creative outputs in the form of interactive interpretation prototypes. Amenably, participatory design invites all stakeholders *(e.g. colleagues, partners, users, consumers)* into the design lifecycle as a means of better understanding, meeting, and sometimes even pre-empting their needs (Dowd & Elizarova, 2017).

In addition, design researchers see participatory design as a popular approach, particularly for complex projects where different practitioners, participants, disciplines and schools of thought can be drawn together to bring the richness necessary to comprehend and unravel compound challenges (van Oorschot et al., 2022). Cipan (2023) also raises the important acknowledgement that participatory design can promote a sense of shared ownership and empowerment by offering users and stakeholders a voice in the design process. By embracing a participatory approach for this CDA museum visitors and stakeholders could be more invested in the final product, increasing user satisfaction and engagement.

2.5 Digital Interpretation Design for Museums and Heritage

Reframing thinking about how users engage with different interactive mediums within a museum setting has the potential to create new interpretation and engagement routes in the form of blended learning opportunities (Donohue, 2017; Hawkey, 2006; Jewitt, 2012). Lee et al. (2021) explain that in the broadest sense, blended learning in the field of museum interpretation involves the integration of two or more delivery mechanisms to improve learning performance and visitor engagement, this might be combining digital outputs with analogue or tactile mediums. They go on to suggest that a blended learning model can expand learning effects by combining a range of factors: goals, interaction methods, time, space, activities and media. Blended learning is suitable for investigation in this CDA because the SIM content team have conveyed interest in digital delivery methods with a 'light touch', meaning that digital techniques are integrated in a tactful and understated way that does not draw away from the exhibition or objects (Donohue, 2017). Researchers suggest that museums that make use of digital resources to supplement objects or exhibits using a more natural, lighter touch can encourage longer dwell times and provide a more engaging and personal learning experience (Donohue, 2017; Hawkey, 2006; Jewitt, 2012).

Connected to the views of the SIM content team, White (2012) raises the point that there may be visitor discomfort concerning technology and digital experiences within a museum environment. Not only may some members of a family or group lack experience or confidence in digital technology, but they may also feel frustrated by children being exposed to more ‘screen time’; an issue that parents/carers may have been working hard to avoid (Goldstein, 2013; Mahroof K., 2018).

However, despite the aforementioned stigmas, digital technology can be a powerful tool to encourage playful learning beyond early childhood (Goldstein, 2013; White, 2012) it also has a vital role in ensuring that museums continue to be relevant and valuable to wider audiences and future generations (Marsh et al., 2020). The traditional form of heritage interpretation is moving away from purely conservational and educational goals to an entertainment and experience-oriented interpretative provision (Reino et al., 2007), technology can open new opportunities for children to actively and playfully explore and experiment (Goldstein, 2013).

As presented by the Department of Digital, Culture, Media and Sport (2018), increasing audience diversity is a high priority for museum and heritage sites and, if used effectively, new technologies can provide museums with a potential hook to reach individuals who may have been previously disengaged or disinterested with gallery content. Using innovative, unexpected and digital approaches can allow an audience to gain exposure to new knowledge and culture in novel or deeper ways which could in turn result in a more lasting impact (Goldstein, 2013). From the perspective of the creative practice within this research, digital approaches may offer alternative ways to engage a variety of family members with steam engine science.

Similarly, from the valuable perspective of accessibility and inclusivity, digital interpretation reveals more avenues and opportunities. Audio and sensory feedback add an essential component to interpretation for visitors, not least those with visual impairments (Vaz, 2018, p. 47). Additionally, the variety of different media formats and digitally enabled opportunities have the potential to make connections with people who may have a wide range of learning styles, interests and preferences. (Department for Digital Culture Media & Sport, 2018; Science Museum Group, 2020; Vaz, 2018). Hawkey (2006, p. 2) notes that digital technology can facilitate more versatility and personalisation within the bounds of museum interpretation, allowing the visitor to be in control and interact with the content in their own way, at their own pace. D'Souza (2018) explains that this sense of empowerment and agency is not just directed at children and teens but also encompasses parents/caregivers. Innovative tools and approaches that encourage whole families to get actively involved with museum experiences help to build trust, confidence and vocabulary, with many museums making a conscious transition from educators to facilitators (D'Souza, 2018).

In a contemporary domain, museums have the potential to be viewed as modern media makers, using a variety of tools to compose and curate how their stories are presented. However, in contrast to the rest of the media world, it is the museum objects and the affording materiality that sets them apart (Kidd, 2014). Museums are responsible for the way that their objects and artefacts are given meaning within their physical and digital space and their communicative processes become even more apparent with a focus on new media and technology (Henning, 2006). The term 'transmedia storytelling' has been used to define a narrative across a variety of platforms, a methodology increasingly adopted by heritage organisations be it through object display, immersive installation, workshops, gallery interactives, AV and more. Using a variety of media platforms under the umbrella of one main objective allows for differing entry points and importantly opens the opportunity for enquiry and play to wider audiences (Henning, 2006; Kidd, 2014; Shneiderman, 1998). Tilden (1977) explains that heritage interpretation is more than just presenting information and encouraging engagement; interpretation should be a revelation or a provocation *based* upon the information and engagement. Tilden goes on to suggest that the purpose of interpretation is to inspire the visitor to find out more, to generate a sense of wonder and to encourage a questioning of exhibition concepts and content.

Powerful examples of museum interpretation are often described as connecting explicitly to the 'big idea' or 'exhibition story', acting as a narrative arc and point of reference throughout the creative process (Popoli & Derda, 2021). Serrell (2015, p. 7) defines that a big idea is usually an active sentence or statement developed by the museum exhibition team in reference to what the exhibition is about. The big idea approach can be applied to an entire exhibition right through to an individual object label and allows an exhibition team to put forward coherent curation with conceptual boundaries. McKew (2022, p. 7) describes the big idea as *"a defining statement, which encompasses the primary message we want to communicate to those engaging with the interpretation. It will provide people with an understanding of the history and what to expect while engaging with interpretation."*

At the point of this research, the big idea currently being developed by the SIM content team for Power Hall interpretation is: *'There is a dynamic relationship between humans and engines'*. It is imperative that this narrative is embraced within the creative outputs of this research. Serrell (2015) explains methodologies of interpretation have the ability to provide clarity, focus and scope to the big idea. Serrell also communicates the importance of all forms of interpretation (including digital) within a specific exhibition, to hold a strong and purposeful position in the ecosystem of the big idea. Hazan (2007), describes that *active* participation can be a catalyst for memorable interpretational experiences and the translation of the big idea. She suggests that we remember substantially more of what we *say* or *do* compared to reading alone. When museum interpretation techniques come together to engage both the hand and the mind, we are able to scaffold and portray the key curatorial message with a lasting visitor impact. Digital strategies have the potential to offer a wealth of opportunities for this 'hands-on, minds-on' approach and with innovative new media techniques we can augment, rather than distract from, the physical object or exhibition mandate (Hazan, 2007).

Parry (2010), nevertheless warns that simply employing the use of digital technologies to enhance engagement or to gain a wider audience appeal is not an assured answer. He suggests that new media regularly suffers from misuse, especially if the digital medium is invested in the same way as the traditional museum logic. Take for example museum labels, which have come under great scrutiny in recent years. In the book *Museums in a Digital Age*, Parry suggests that the typical interpretative dialogue of a museum label is the debated construction of a team of curators and specialists who are forced to make compromises and formulaic standardisation, leading to the concise, institutionalised and undisputable voice which can all too often intimidate and alienate a visitor from the entire gallery experience. Taking similar unassailable content and presenting it in a digital form is certainly not the solution to the problem. A technology-based interactive experience that does not captivate or engage the visitor has failed within its role in the gallery space, it is not enough for it to be purely digital and functional (O 'Brien, 2018). Liu (2020, p. 14) explains that the purpose of interactive interpretation can be best achieved by unifying multi-layered content (both digital and analogue) to actively create valuable cultural, technological and emotional experiences for visitors and inspiring them to resonate with heritage stories and values.

In view of these important points about digital interpretation, including a sense of negativity concerning digital use during a time intended for playful family learning (Goldstein, 2013; Mahroof K., 2018) the creative outputs of this study will endeavour to utilise technology with careful consideration. The use of digital will be sympathetic to the content and environment and should be utilised only when and where necessary.

Nevertheless, the SIM content team, as well as multiple researchers (e.g. Henning, 2006; Lee et al., 2021; Parry, 2010) agree that mindful use of technology can indeed help to engage with hard-to-reach audiences and can provide the visitor with more agency over the interpretation content when compared to a static museum label for example. The use of digital interpretation in the Power Hall should help to spark visitors' interest in the relationship between the steam engines and humans, in line with the exhibition's 'big idea'. The application of digital technology must offer benefits that cannot otherwise be achieved by an analogue, hands-on interactive installation (O 'Brien, 2018). User experience design has a major role to play in the success of digital heritage interpretation, and within this vast field of research, there are many aspects which are particularly relevant to this thesis and the broader sense of digital heritage interpretation.

2.6 User Experience Design

In the book *Designing the User Experience,* Benyon (2019) takes a holistic approach to digital user experience design (UX) which strikes a chord with the analysis of the more modern methodologies used in museum exhibition interpretation. He draws attention to the human-centred approach to designing interactive experiences and states that UX should be understood as enveloping thoughts, feelings and actions whilst being involved in an engagement. The common goal of all UX designers is to make systems that are enjoyable and comfortable to use from a cognitive, ergonomic and emotional perspective (Berni & Borgianni, 2021), and to achieve this they must put humans rather than technology at the heart of the design process of the wider user experience (Norman & Nielsen, 2017).

In their very nature, humans and machines are poles apart; humans are unpredictable, distractible and vague, whereas machines are logical, orderly and precise, it is therefore tempting for designers to take the more straightforward machine-centred approach to UX design (Benyon, 2014). With increasing demand for more immersive and intuitive interactive opportunities, the distinctive line between designer and user is becoming more blurred as UX designers are look towards creating a more universal and ubiquitous interactive experience where users become part of one dynamic design ecosystem (Sande, 2017). It is noted that this methodology connects wholly with the broader science capital approach to engagement; encouraging visitors to feel comfortable, confident, valued and connected.

During the review of the literature, the term *agency* was found to be used frequently in the field of museum interpretation and UX, as well as being defined as a key component of playful experiences. In a user experience or interaction, a sense of agency is a human experience of controlling both one's body and the environment (Limerick et al., 2014). More broadly a sense of agency is conceived as the experience of being the origin of a sensory action consequence (Desantis et al., 2011). Moore (2016) explains that a sense of agency provides individuals with the feeling of being in control in relation to their actions; he warns that a user may risk losing their sense of agency if an interface or experience is too machine-centred, heavily automated or gives little thought to input modalities and sensory involvements. Likewise, museum visitors may become disengaged with exhibition interpretation that does not enable a sense of individual discovery and questioning.

Similarly, the Lego Foundation, in their report about children, technology and play (Marsh et al., 2020) accounts in detail about the significance of user agency and explains that the psychological scaffolding of a playful experience consists of six stages:

1. Non-play: opting out and having no interest in the activity.
2. Passive: a low sense of agency, simply following instructions.
3. Responding and exploring: beginning to form intentions, increase to curiosity and start to interact with the experience.

4. Owning: experience becomes internalised, increased focus and the user is making choices.
5. Recognising: new insight and a sense of accomplishment.
6. Transferring: happens after the experience, the user recalls and reflects on how the experience influences their own life.

New and innovative input modalities have the potential to dramatically enhance and redefine a user's sense of control and agency. Tangible systems in particular have the powerful ability to physically engage participants in active learning by combining the functional benefits of technology with the more intuitive and sensory opportunities of a hands-on experience (Antle, 2007; Limerick et al., 2014). As supported by Vaz (2018, p. 31), making physical engagements with exhibits and artefacts through tangible interfaces has the potential to enhance, develop and complement many aspects of learning that visual content cannot deliver by itself. This notion connects to a constructionist view on learning where meaning is created in the interaction (Antle, 2007, p. 195). In respect of the Power Hall interactive interpretation, such physical or embodied features might include movement and gestures (Skulmowski & Rey, 2018) as well as materiality, friction, freeness and weight, all elements that are particularly important in STEM learning and physics comprehension.

With more experimental and novel systems naturally come greater challenges in interaction design. The realm of HCI has evolved and expanded immensely since its arrival at the beginning of the 1980s as a field of study, and some researchers suggest that it is time to revitalise its position (Bannon, 2011; Carroll, 1997). At its heart, its role continues to seek to support humans interacting with or via technology but through the introduction of a plethora of more ambiguous digitally connected inputs and outputs, technology is no longer just about 'calculating' as it was in the early days of computing (Benyon, 2019). The researcher notes that HCI, play, informal learning and heritage interpretation all have a common and critical goal related to supporting humans in the process of making and building on, their own unique sense of the world. Museums are settings for very personal learning experiences, so by supporting the interactions, engagement and interests of a varied audience, museums will be able to generate more enjoyable and satisfying visits (Falk et al., 2012).

2.7 Prototyping Interactive User Experiences

Prototyping is one of the most critical activities in the development of new products, artefacts, interfaces and more, but the term can mean different things to different industries and applications (Wall et al., 1992). Lauff et al. (2018, p. 10) define a prototype as *"a physical or digital embodiment of critical elements of the intended design, and an iterative tool to enhance communication, enable learning, and inform decision-making at any point in the design process".* They go on to define prototyping as the means through which designers and developers discover, generate, test and refine user experiences. Beaudouin-Lafon and Mackay (2007, p. 52) define a prototype as *"a concrete representation of part or all of an interactive system. A prototype is a tangible artefact, not an abstract description that requires interpretation".* These views make the concept of prototyping vital to the review of literature for this study as the method will become the main vehicle for testing interactive interpretation concepts with real-life museum visitors during the course of this research.

Beaudouin-Lafon and Mackay (2007) claim prototyping has three particular characteristics, each of which connects especially well with this study:

1. They support **creativity**, helping the designer or developer to generate ideas, explore the design space, and uncover relevant information about users.
2. They encourage **communication**, helping the developer, stakeholders, customers, and users to discuss options and interact with each other.
3. They permit **early evaluation** because they can be tested in a variety of ways, including traditional usability studies and informal user feedback, throughout the design process.

Each of these three characteristics are pertinent to the practice of developing creative outputs in response to the Power Hall design problem.

Lauff et al. (2018) describe prototyping as a critical activity in any creative development lifecycle (be that a physically engineered artefact through to a digital experience), to ensure validity, enable communication and inform decision-making. The power lies in its ability to support iterative loops of new knowledge via social interaction and team-based discourse (Lim et al., 2008). Berglund and Leifer (2013) state that how, when and where we use prototypes and prototyping methods depends greatly upon context and relies heavily on situational awareness. Practitioners and researchers often categorise prototypes in terms of *fidelities*, referring to how closely a prototype matches the final product. Low-fidelity prototypes are often cheap and quick to make but bear the least resemblance to the finished artefact. High-fidelity prototypes look more like a finished product but require a greater investment of time, planning and finance (Lauff et al., 2018; Pernice, 2016). Sauer et al. (2008, p. 71) specifically define prototype fidelities as follows:

> *"The degree to which a model of the system resembles the target system refers to the fidelity of the model. The fidelity of the model (or prototype fidelity) may vary considerably, ranging from a low-fidelity simulation of the system (e.g., paper prototype) to a fully operational prototype, which is (almost) identical to the real system."*

In a similar attitude, Beaudouin-Lafon and Mackay (2007) explain that prototypes and prototyping techniques can be analysed within four dimensions:

1. **Representation**: describing the form of the prototype, this might be paper sketches or computer simulations.
2. **Precision**: describing the level of detail at which the prototype is to be evaluated, this might be informal and or highly polished.
3. **Interactivity**: describing the extent to which the user can actually interact with the prototype.
4. **Evolution**: describing the expected life cycle of the prototype (will it be thrown away or iteratively developed).

Ambiguity around prototyping classifications led Lim et al. (2008) to create an anatomic definition of prototypes based on two fundamental dimensions: filters and manifestations. The first dimension suggests that *filter* prototypes are those used to explore a design space and lead to meaningful knowledge about a final artefact. In this sense, prototypes facilitate the discovery of problems and allow the exploration of solutions. Manifest-based prototypes are those that a designer creates to realize an idea through a physical process, externalising a concept and moving it out into the world. A perspective which certainly applies to the prototypes used within this body of work. Although a prototype could be both a filter *and* a manifestation, Lim et al suggests that awareness of this anatomy would enable designers to approach prototyping more intentionally and reflectively giving rise to new knowledge, perception and cognitive operation.

Prototypes can be further distinguished via lifespans, which Beaudouin-Lafon and Mackay (2007) suggest can fall into three categories.

1. **Rapid prototypes** have the shortest lifespan. In the genre of interactive heritage interpretation, rapid prototyping is defined as the creative ideation process of fabricating a preliminary, disposable version of a product or design within a short amount of time and is used to evaluate early design, functionality and tangible interaction scenarios (Mackay, 2021; MuseumNext, 2020; Petrelli et al., 2021; Smithsonian Exhibits, 2019). In the field of interactive user experiences the term encompasses fast prototyping methods including sketches, mock-ups and paper prototypes (Beaudouin-Lafon & Mackay, 2007). Rapid prototyping can be useful in supporting early realisation and communication of ideas in multidisciplinary teams (Collins, 2018, p. 65).
   Although the term 'rapid prototyping' has been adopted by the field of product design, specifically as a way of making a simulations of product concepts using computer-aided 3D modelling (Aldersey-Williams et al., 1999, p. 14), for the purpose of this study it is the definition outlined by Beaudouin-Lafon and Mackay (2007) that will be carried forward.
2. **Iterative prototypes** apply to a design concepts in progress and have the explicit goal of evolving through a sequence of reflections and iterations. Some of the iterations may explore different variations others may systematically increase the precision and finer details of the artefact or interaction (Beaudouin-Lafon & Mackay, 2007, p. 1009).
3. **Evolutionary prototypes** are described as a category of prototype that actually evolves into part or all of the final system, this most commonly only applies to one-off productions or in the development of digital applications. (Beaudouin-Lafon & Mackay, 2007, p. 1009).

As this is an exploratory study, investigating a variety of different approaches, rapid prototypes (sketches and mock-ups) and iterative prototypes will be created.

Blomkvist and Homlid (2011) recognise a further form of classification in this field of research which can be described as “what prototypes prototype”. Houde and Hill (1997, p. 3) propose that prototypes are used to address three specific dimensions; *role*, *look and feel*, and *implementation*. Each dimension alludes to questions that are pertinent to the design of the artefact or system. To expand, *role* refers to questions about the function of the proposed artefact in a user’s life. *Look and feel* refers to the sensory experience of the artefact (what the user will see, feel and hear whilst using it). Implementation refers to questions about how the artefact works, including the techniques and components through which the artefact performs its function. Houde and Hill (1997) explain that a prototype may address questions or design options in one, two or all three dimensions of this representative model. These dimensions will each be given careful consideration in the development of the prototypes embedded within this study.

Of particular interest to this CDA is the mixture of views surrounding prototyping lifecycles and frameworks. One significant and influential example is the work of De la Rosa (2017). Put simply, their study looks at how a framework for prototyping need not necessarily take a simple funnelling approach but instead act as an exploratory probe which supports deviations and new embodied knowledge. Their framework for prototyping avoids the common concept of iterations aiming for the ideal solution and instead looks toward the periphery of a design problem in an attempt to draw out new knowledge and a new understanding of the challenge itself. Figure 2-3 demonstrates De la Rosa’s proposed model for design research which attempts to show how prototypes can be used as a negotiation tool between stakeholders within a project lifecycle and how expectations of stakeholder changes and expands with each stage of iteration.

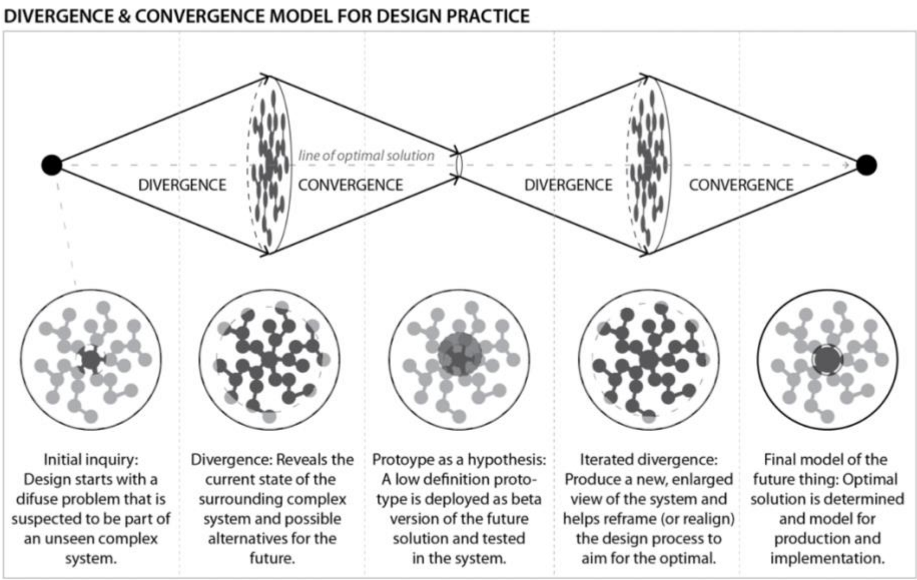


Figure 2-3: De la Rosa's representation of the intention of the use of iterative divergence and convergence on the design practice process (De la Rosa, 2017, p. 9)

This alternative perspective is particularly relevant because it demonstrates how prototypes can be used to widen the field of investigation rather than narrow it down. In agreement with De la Rosa (2017), the researcher is looking for an opportunity to explore and test a variety of options for interactive interpretation concepts which will involve looking broadly at the field of steam engine science.

Drawing on this literature, the practice research of this CDA aims to experiment with a nuanced application of prototyping which fulfils the roles of playful manifestation and the communication of ideas. Based on the categories outlined above, this study will utilise low-fidelity, rapid prototypes for early-stage communication and user feedback it will then move on to the user of high-fidelity, iterative prototypes for the later stages of user testing and 'proto-scoping'.

2.8 Evaluating User Experiences in Museums and Heritage Sites

One of the most significant and valuable assets of prototyping is that it permits the opportunity for early forms of evaluation and stakeholder communication (e.g. Blomkvist & Homlid, 2011; Petrelli et al., 2021), particularly pertinent for not only this study but also from a wider, audience-driven, exhibitions perspective. This final portion of the literature review endeavours to connect the earlier discussions of prototyping, UX design, informal learning and playfulness by looking at how these themes are currently evaluated and assessed in the context of a museum environment.

From a very broad perspective, the discipline of 'visitor studies' aims to study the visitors or audiences who attend museums. The field covers everything from the behaviour of visitors to their imagination (Jones, 2015). It occupies an increasingly significant area of museum practice and theory, particularly for educational goals, marketing, and exhibition evaluation (Davidson, 2015). Evaluation can affect museum content and delivery by helping practitioners to be more effective and efficient. It has the potential to shine a light on which elements are working well and importantly, where and how to focus valuable and often limited resources (Adams, 2012). As a generalised approach, evaluation is often broken into a cycle of 3 phases: front-end evaluation (a planning stage to assess visitor needs and wants), formative evaluation (testing prototypes and mock-ups during the development stage), and summative evaluation (assessing the impact of the finished product) (Grey et al., 2006, p. 75). Because this CDA is positioned distinctly within the realm of design exploration and prototyping, formative evaluation will be the focus of the practice.

In an outcomes-driven climate, culture and heritage organisations see evaluation as a way to demonstrate accountability and impact with educational value being of particular interest. Hooper-Greenhill (2004) cites that in March 2003 a conceptual framework for measuring learning was developed through the Learning Impact and Research project, this framework is utilised throughout SMG and SIM. Five thematic 'Generic Learning Outcomes' (GLOs) are outlined in order for museums, libraries and archives to identify, measure and describe dimensions of learning. Each GLO category is concerned with a different kind of impact on the visitor. They are deemed to be all equally important and regularly overlap. The five categories for organising outcomes and evaluation are given below:

1. Knowledge and Understanding
2. Skills
3. Attitudes and Values
4. Enjoyment, Inspiration, Creativity
5. Activity, Behaviour, Progression

Hooper-Greenhill goes on to acknowledge that the GLO framework does not simply recognise the traditional scholarly perspective of thinking about learning but, perhaps more importantly, makes headway for a more contemporary approach to learning; the multi-dimensional view that facts and information are deeply connected to feelings, values, actions and enjoyment. Within these GLOs the researcher identifies connections with science capital themes related to *attitudes and engagement* as well as the informal characteristics of play and exploration.

In contrast to Hooper-Greenhill's positive views however, Brown (2007) suggests that GLOs are not a guaranteed method of evaluation as they focus on factors indirectly associated with learning such as enjoyment and inspiration. Brown also argues that GLOs are weighted towards predictive learning outcomes rather than emergent, open-ended measures.

> "*Thus, while they have considerable value as overall institutional performance measures, they do not get to the heart of measuring actual learning and they cannot be used predictively to assess the likely learning effectiveness of any given learning activity*."(Brown, 2007, p. 29)

For these reasons, Brown suggests that the GLO thematic framework is mostly suited to summative evaluation processes rather than to prototype learning activities in the early phases of a project. Similarly, Falk et al. (2012) and Serrell (1997) describe how studies used by museums most commonly employ methods of visitor tracking, timing studies and detailed exit questionnaires to measure visitor engagement, however such tools are not ideally suited for prototype evaluation and comparison, furthermore they are not always useful for measuring real-time engagement with interactive interpretation concepts and artefacts (Sutcliffe & Kim, 2014).

Davis (2007) explains that when evaluating interactive interpretation prototypes, there are three key themes which should remain in focus: Motivation, usability and content. In other words, are participants/visitors motivated to use the interactive and do they enjoy it? Do participants/visitors understand how to use it? And do participants/visitors understand what the interpretation is trying to tell them? Davis also reinforces that planning should be made for three iterations of the same prototype to ensure changes are successful. However, Davis states that it is important that when testing these iterations, researchers should stay focused on the changes made rather than gathering more data. Adams (2012) reiterates that it is hugely important to think carefully about the questions we are asking participants during interpretation assessments. Evaluation takes investment and visitors are giving up their valuable time to take part, therefore researchers must think about how the results of the questioning or evaluation influence, grow or change the practice. Preskill (2011) also votes for a more strategic approach to evaluation and warns of not treating the process as solely a 'problem-solving' activity, they state that evaluating interpretation concepts and prototypes is an important opportunity to be vulnerable and exposed to brave conversations with visitors.

In relation specifically to the aspect of digitally enhanced heritage experiences connected to this study, Liu (2020) developed an evaluation framework specifically targeting the visitor digital experience at a heritage site. This employed a field study methodology involving a self-administered questionnaire as the main research method to gather quantitative data on visitors' experiences, along with the support of interviews. This involved open and close-ended questions proposed to heritage visitors during pre-visit (to assess prior knowledge and motivations), on-site visit (to assess visceral-level, behavioural-level and reflective-level experience), and post-visit (general evaluation and satisfaction gains) periods. The on-site visit modes of evaluation were connected to the work of Norman (2005) who distinguishes between three aspects/levels of the emotional system concerned with user experiences: visceral (concerned with appearances), behavioural (concerned with the pleasure and effectiveness of use) and reflective (concerned with the rationalization and intellectualisation of a product). These three levels are valuable aspects for consideration in both the generation and the evaluation of the creative outputs although they do not emphasise the social aspects of heritage user experiences that are particularly important to this research.

In another relevant heritage interpretation study, Warpas (2013) used a more varied, mixed methods approach to the evaluation of museum user experiences. This study was concerned with a design concept for a digitally enhanced exhibition space developed according to a new human-object engagement model labelled as the *Social Dream Spaces Model*. Warpas's model defines social dream spaces as:

> *"the dream spaces of individuals, which, through communication of engagements and responses, influence and are influenced by one another, resulting in a social union created between visitors with museum objects at its heart." (Warpas, 2013, p. 63)*

Warpas (2013) explains that social dream spaces are characterised by contact and engagement with an object and occur on two response levels: personal and social. To evaluate such complex, communal and spontaneous engagement, Warpas used a mix of methods based on ethnographically-informed field studies, which included observations, participation, child generated images, usage of cameras, interviews and field notes. These were applied before and after the design interventions at Bantock House Museum, (Wolverhampton, UK) using an action research approach. The main focus of the evaluation was interaction, this included elements such as the occurrence of particular feelings and behaviours and the identification of favourite objects *(Warpas, 2013, p. 84).*

Although Warpas's research is concerned with a broader spectrum of museum experience and not a particular STEM focussed concept for interactive interpretation, it does provide further acknowledgment of the value of studying more naturalistic and social responses to museum content. This aspect of evaluation for authentic visitor discourse and interaction relates closely to the study for the Power Hall exhibition.

In an effort to explore the role of museum types, Silverman (1990) investigated the content and consequences of 'visitor pair talk' at The National Museum of American History and The National Gallery of Art. Silverman employed the method of tape-recording visitors' own conversations while viewing a target exhibit, along with follow-up interviews and questionnaires. The interviews followed a schedule of eight topics and was designed to ascertain visitors' own thoughts and descriptions of social aspects of the exhibit experience as well as attitudes about the notion of 'meaning'. The three-page questionnaire was designed to solicit demographic information as well as thoughts about the influence of their companion (Silverman, 1990, p. 57). Silverman scored visitor talk using five basic categories of response:

1. Establishment (*to name, recognize, and/or identify from exhibit label, an object, its title, its creator, its subject matter, its date of creation, or, to refer to the exhibit theme.* P.95)
2. Evaluation (*to express a preference, judgement, desire to own, or interpretation regarding an object at hand.* p.99)
3. Absolute object description (*to discuss or describe aspects of the object at hand without explicit reference to outside information, particularly those relating to four*

distinct points - perceptual aspects, physical aspects, function and subject matter. p.104)

4. Relating to special knowledge (*to bring specialized knowledge to bear upon the object at hand, including facts, and background information.* p.109)
5. Relating personal experience (*to bring personal experience to bear upon the object at hand, including memories of and references to people, places, objects and events in one's life. p.111)*

The ‘interpretive acts’ were defined by Silverman in retrospect; after all the recordings had been gathered and listened through, he then identified themes and created the five categories through which he was then able to organise the data.

Silverman surmised that through interaction with one’s companion in a museum or cultural arts setting, intertextual resources are maximised and shared. He further suggests that his five response categories (“*interpretive acts*”) constitute the verbal building blocks with which visitor pairs socially construct meaning (Silverman, 1990, p. 90). Silverman’s study (although focussed only on adults) provides further support for the perspective that visitors *make* meaning, rather than *receive* it. His work connects with the literature on intergenerational conversations discussed earlier in this review of literature (e.g. Boger & Mercer, 2017; Haden, 2010). Silverman’s research provides further evidence for the value of visitor talk in promoting and sharing individual knowledge, experiences and perspectives.

> “Thus meaning is socially constructed. While not all meaning making occurs verbally, talk itself constitutes part of the process.” (Silverman, 1990, p. 92)

Although the exhibition message is important to some visitors, value appears to be embedded in to be associating personal experiences and recognising things they know, sharing attention and expressing their taste and identity (Silverman, 1990, p. 269).

Concerning the Power Hall research of this study, Silverman has offered an interesting and associated take on visitor evaluation and data collection. Although his study focussed on adult visiting pairs, not families, and the comprehensive and lengthy nature of his data collection methods was not deemed suitable for a prototype evaluation with young participants, his work heavily informed the methodology of this study, particularly the clear definition of the interpretive acts.

Building on the learnings from Silverman, a final evaluation study to mention here is the work of education researcher and exhibit evaluator Sue Allen (Allen, 2002), and concerns an evaluation of the *Frogs* exhibition at the Exploratorium in San Francisco. In a diverse exhibition space containing hands-on interactive elements, terrariums of live animals, cases of cultural artifacts and two-dimensional elements of interpretation, Allen employed the use of discourse analysis evaluation to make comparisons about the kinds of learning experiences visitors have with different types of exhibition elements (Allen, 2002, p. 2). Microphones were used to record conversations of 30 participant dyads who were followed by a ‘tracker’ who was also recording conversations and making discreet notes about their movement around the exhibition space. In her conversation coding scheme, Allen used a socio-cultural approach using verbal expressions of noticing, thinking, feeling and acting as evidence that learning was taking place. This was supplemented by cognitive concepts including memory, inference and metacognition. From this position, a complex matrix of five main categories and sixteen subcategories of learning talk were defined (please see Figure 2-4).

Perceptual	Conceptual	Connecting
Identification	Simple	Life-connection
Naming	Complex	Knowledge-connection
Feature	Prediction	Inter-exhibit connection
Quotation	Metacognition	

Strategic	Affective
Use	Pleasure
Metaperformance	Displeasure
	Intrigue / Surprise

Figure 2-4: Coding Scheme used by education researcher Sue Allen (Allen, 2002).

By analysis of visitor conversations using this coding scheme above, Allen and her team were able to decipher which types of exhibition content (such as live animals or hands-on elements) were most successful at eliciting certain types of learning talk (such as perceptual, affective or conceptual).

This method of data collection and analysis was reported as being very fertile. Its strength was found to be in bringing the researcher into the heart of the learning action and emphasising learning as a process rather than an outcome (Allen, 2002, p. 55).

Allen did experience several problems concerning the data collection of the study including acoustic issues from the myriad of sounds in the exhibition space making it difficult to hear conversations, the movement of people around the space causing issues with microphones, difficulty in deciphering and making sense of the audio recording without visual references or video recordings, and finally, transcription was expensive and time-consuming (Allen, 2002, p. 8). In consideration of these issues described by Allen, it was decided that discourse analysis would be a more suitable fit for the Power Hall study because the evaluation would be occurring in a controlled space, on a more observational level in real-time, and focussed on one element of interpretation at a time. For this reason, it was important to make sure the coding scheme was prepared before the evaluation sessions take place so that the tally could be kept as the discourse were taking place.

In light of this literature, the specific evaluation of the Power Hall/All Shapes and Sizes interactive interpretation concepts draws upon a variety of existing strategies already in use in the field of museum audience research and user testing. By combining a mix of approaches (including those informed by SMG and SIM), the researcher aims to create a bespoke evaluation framework to achieve optimal outcomes and usability both for the researcher and the participant.

2.9 Literature Review Summary

This chapter has outlined the key concepts regarding the design and development of playful, STEM-focused, exhibition interpretation for a family audience. The literature review has been used to synthesise existing research and scholarly publications based on the themes of informal STEM learning, playful engagement, user experience design and prototyping in the context of a science museum setting. It has drawn commonalities across these themes and has facilitated the capacity to create a theoretical and conceptual framework for the study (3.2.2).

Of note is the emphasis on the human-centred approach in all genres, as well as the importance of encouraging a sense of agency and connection for the visitor. A worthy consideration, and feeding into the design interventions, is the evidence that adults and children engage and interact in different ways within an exhibition space and with interactive interpretation, but in doing so, they bring positive, relational value to the experience (e.g. Schaller et al., 2002). As described in more detail in the theoretical framework (3.2.2) the researcher considers this to be a strong connection to a social constructivist ideology where knowledge results from social engagement and language use and puts emphasis on the process of learning in social settings (Wertsch, 1985). In turn, this also has connections to the science capital approach adopted by SMG and discussed in both the literature review (2.1) and the theoretical framework (3.2.2).

Moving forward, the researcher seeks to utilise these significant connecting theories through the development of family-friendly interactive interpretation. She looks to advance the field of STEM interactive interpretation development by exploring a new structure for comparative prototyping (proto-scoping) and a strategy for evaluation that is especially illuminating from both the perspective of adult and child engagement and informal learning. The literature has identified a need for a strategy for the impact analysis of playful, family-friendly engagement concerning complex concepts and high-level skills within an informal museum environment. These distinctions involve the inspection of elements such as critical thinking, meaning-making, building connections, and reflection. Much of the work so far in this field (particularly from significant academics such as Archer (2018) Marsh et al. (2020) and Zosh et al. (2017)), states that the development of science capital and complex STEM skills through play are difficult to evaluate and measure. Through this review of literature, the researcher has come to recognise the need for a more effective, creative, and coherent approach to addressing the subtle nuances of family-focused informal learning. It has highlighted that for an interactive interpretation concept to be truly 'family-friendly', it must confidently present educational value to parents and caregivers, providing them with tools to impart knowledge, whilst at the same time demonstrating a strong degree of playfulness and physical action and/or imagination in order to appeal and connect to a younger target audience.

Chapter 3: Methodology

This chapter outlines the rationale for the design and research methodology of this study. It features methods and tools used in the main phases of the design and evaluation process for a collection of interactive interpretation prototypes for the Science and Industry Museum. Due to the nature of this multifaceted project (including collaborative partner consultation, the integration of a specific design brief, audience participation, designing and developing creative outputs, data collection and output analysis), the methodology of the research is broken down into three key phases, some of which overlap throughout the development lifecycle. The methodological choices are intrinsically linked to the dynamic journey of the practice research and project modifications, however, for the clarity of this thesis, the methodology is extracted and described in this chapter as a linear format.

1. Discovery (design research and project scoping)
2. Development (practice research)
    a. Preliminary prototype development (creative ideation and low-fidelity prototyping)
    b. Pilot study (informal user testing and consultation)
    c. Advanced prototype development (creative ideation and high-fidelity prototyping)
3. Formal Evaluation (data collection)

3.1 Framing the Problem

The practical and real-world aim of this research was to explore, investigate and create concept ideas for digitally enhanced, playful, interactive interpretation prototypes which could be used to engage families and children with steam engine science. The work was directed and overseen by the collaborative partner (the Science and Industry Museum), but the creative outputs, proposed design and evaluation framework and resulting outcomes have been generated by the researcher. The study synthesised a combination of theoretical investigation, practice research and participatory design via a mixed methods and pragmatist approach, in order to answer the main research question and two subsidiary questions (outlined in section 1.3 and concluded in section 6.1).

A significant detail to note is that two pathways were navigated during the timeline of the CDA which added to the complexity of the research process. These parallel pathways were connected by action and interplay, which led to the outputs and contributions of this work.

The fundamental avenue of research was the design and development of creative outputs (prototypes) in response to the design problem and 'client' brief. This was addressed through the process of theoretical research, ethnographical fieldwork, creative ideation, participatory design and practice research. The creative outputs enabled the researcher to explore a variety of interactive interpretation concepts in answer to the main research question.

The second pathway of research focused on the development of a new framework to guide the direction of audience-centred interactive interpretation design for a science museum setting. The framework integrated comparative prototyping and a bespoke discourse analysis system mapped to science capital themes (a process labelled by the researcher as proto-scoping). The literature review, fieldwork and personal reflections on the practice research identified the need for the new framework. The pathway enabled the researcher to address the two emergent subsidiary questions through a mixed methods approach with the creative outputs as the subject matter of evaluation. The two research pathways are visualised in Figure 3-1 below.

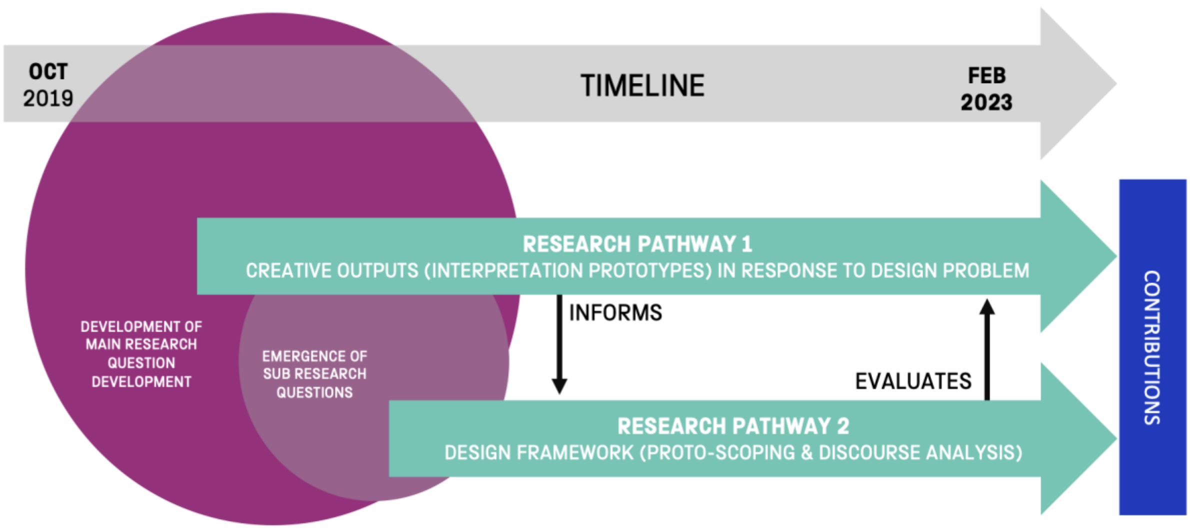


Figure 3-1 Visualisation of the research pathways addressed during the timeline of this study.

The researcher held the position of the designer and the developer of both the prototype outputs and the design framework created during this CDA, this provided a critical and holistic perspective to the study enabling a close and comprehensive analysis of all stages of the design lifecycle. However, despite this being a useful standpoint, the researcher acknowledged that there was an important need to be self-reflective and have an understanding of personal biases (Hoadley, 2004, p. 204) to support generalisable and rigorous findings. With guidance from academic literature (e.g. Guba, 1981; Lincoln & Guba, 1986; Nowell et al., 2017), the researcher considered four key points with an aim to promote trustworthiness and rigour within the study:

1. Confidence should be established regarding the **truth** of the findings (truth value)
2. The degree to which the findings are **applicable** in other contexts
3. The degree to which the findings can be **consistently** repeated in the same context
4. The researcher should ensure a **neutral** position to ensure the findings are a function solely of the respondents.

To address these points the researcher took a range actions and approaches. Firstly, the study has been directed and driven by the collaborative partner, the Science and Industry Museum. This wealth of professional guidance has not only informed the study but has also meant that the researcher has been accountable for actions, process and results. The data collection sessions were supervised by museum staff and the researcher kept the content team regularly debriefed regarding the project progression and findings. Secondly, as described in section 3.2.3, a mixed methods approach to research ensured that findings did not rely on one form of evaluation. By combining a variety of strategic research approaches and procedures the researcher was able to broaden her understanding and evaluation of the design problem and in turn, augment the consistency, validity and reliability of the data (Zohrabi, 2013). Other steps, which are described in more detail in the methodological strategy (section 3.2) were designed to ensure that the data collection processes and the techniques for prototype development were easy to replicate in a variety of contexts.

3.2 Methodological Strategy and Theory Development

3.2.1 Philosophical Stance

The selection of a philosophical paradigm is an important step in academic research because it provides a conceptual and practical toolkit with which to solve a specific research challenge (Abbott, 2004, p. 42). A research philosophy is a system of beliefs and assumptions about the development of new knowledge in a particular field (Saunders et al., 2019, p. 130). From a holistic perspective, the research methodology for this thesis fundamentally lies within the paradigm of pragmatism, a philosophy that brings focus to the practical consequences of knowledge and encourages a flexible and real-world problem-solving approach (Creswell, 2014; Goldkuhl, 2012). This is a relevant characteristic for this study as exploratory research and creative practice were used to inform design decisions and concept direction for the reinterpretation of the Power Hall exhibition at the Science and Industry Museum.

Adding depth to this philosophy choice is the view that pragmatism is concerned with action and change and the interplay between knowledge and action (Goldkuhl, 2012, p. 136). As described in the framing section above (3.1), the action and interplay between the two research pathways were underpinned by the pragmatism paradigm as the researcher looked toward the relationships between the explored creative outputs and the proposed design framework to inform and reveal new knowledge and understanding. The process of iterative prototyping described in this thesis is inspired by a supplementary strategy of action research (as described in section 3.2.4.3), which builds upon a process of planning, acting, observing and reflecting, leading to the development of contributions and outputs within this study.

In line with this concept, according to Morgan (2014), in the pragmatist paradigm, knowledge is not about an abstract relationship between the knower and the known, it is instead an active process of enquiry, creating a reciprocating movement between beliefs and actions. This statement leads comfortably to the method of prototyping and the reflexive and reflective nature of creative practice. Pragmatism is renowned for its emphasis on the 'what works' approach while abstaining from the use of hard metaphysical concepts such as 'truth' and 'reality' (Goles & Hirschheim, 2000). It is not tied to a particular methodology but instead focuses more strongly on understanding the problem and investigating it from various perspectives, depending on the purpose or objective of the inquiry (Dillon et al., 2000). Although the methodologies used in this study were mainly qualitative, quantitative research has also been employed to deliver the capacity to compare prototype concepts and analyse results with enhanced efficiency. Pragmatism has supported this adaptive perspective and was a suitable choice of paradigm because it embraces a plurality of methods (Maxcy, 2003) and a mixed-methods approach to research (Creswell & Clark, 2017).

3.2.2 Theoretical and Conceptual Framework

Due to the variety of motivating aspects of the research, including direction from the industry partner, literature analysis and design problem exploration, it is necessary to define the underpinning theories that are deemed relevant to address the research questions and to provide a foundational lens by which the study is developed.

Firstly, the researcher wishes to report the significance of the science capital approach used to embrace the stakeholder requirements and to influence the development of the creative outputs and modalities of evaluation. From a theoretical perspective, the science capital approach builds on the work of French sociologist Pierre Bourdieu (1990). Bourdieu described the notion of *cultural* capital which relates to the impact of social and cultural experiences upon an individual's ability to 'get ahead'. In a similar format, *science* capital is concerned with the science-related experiences, knowledge, relationships and attitudes that a person builds up throughout their life. It is designed to expose why certain social groups are underrepresented in science careers and post-16 science education (Archer et al., 2016, p. 2). Research suggests that the implication of high science capital levels brings skills, connections and awareness, and therefore increasing the currency of science capital in a society (Archer et al., 2015).

The science capital approach has gained increased popularity in the formal education sector, and as described in the previous review of literature, is being increasingly adopted by informal educational settings to help more diverse audiences engage with science. With steer from SMG, SIM is keen to develop exhibition interpretation that encourages diverse groups of visitors to have a positive and connected experience with science during their visit

(Science Museum Group, 2021a). They recognise that by creating content that is widely accessible, participatory, and intrinsically welcoming, visitors are more likely to feel valued, connected and empowered. SMG states that equity and social justice are integral to the concept of science capital and it is through this approach that visitors can be empowered and supported to access the opportunities and wonders of STEM (Science Museum Group, 2021c, p. 4).

The researcher agrees that exposure to science-related resources can be associated with the production of social aspects of equity, advantage/disadvantage (Archer et al., 2015, p. 5); however, Jensen and Wright (2015, p. 1144), argue that Bourdieu's account of cultural capital did not specifically exclude scientific aspects of culture, therefore, science capital should not be viewed as separate from cultural capital but be encompassed within it. Similarly, they explain that the proliferation of such labels could obscure the similar underpinnings of cultural exclusion in other domains; the notions of the measure of one's experience and exposure could stretch to a huge variety of topics from horticulture to home economics. The researcher concurs that the more associations we have with *any* type of topic, ethos, hobby or discipline, the more likely we are to feel a growing sense of comfort and confidence in that area of focus, and the more likely we are to continue and extend those interests into adulthood or even as a career. Although Archer et al. (2015, p. 21) state that their work is driven by a commitment to equity, Jensen and Wright (2015, p. 1144) argue that the increased focus on a science capital approach could in fact risk reifying the topic of science and scientific institutions as even more exclusionary.

Despite these criticisms, the science capital approach is important to this study because it has supported essential reflection and scrutiny of the interactive interpretation content and encouraged the researcher to think more carefully and creatively about how science information is delivered to a diverse, family audience. Furthermore, due to the directive of SIM and SMG it has been a fundamental and required consideration in all aspects of design, development and evaluation. It has increased the value and impact of the practice research and making steam engine science more accessible and joyful to a wider audience was viewed only as a positive by the researcher.

A second element of the theoretical foundation of this study and uniting all major characteristics of this research including informal learning, intergenerational interaction, playful engagement and science capital is the significance of social constructivism. Of particular note, are the key notions of active, social participation and the influence of prior knowledge and cultural experiences.

The social constructivism doctrine stems from the work of Lev Vygotsky (1896–1934) whose ideas link learning to social interaction. Vygotsky believed that community plays a central role in the process of making-meaning and that cognitive development is a socially mediated process in which children acquire cultural values, beliefs, and problem-solving strategies through collaborative dialogues (Mcleod, 2023a). A principal idea of social constructivism is that new learning is built upon a foundation of previous knowledge, it is focused on learners and active participation (Hausfather, 1996). The constructivist learning theory is suitable for a variety of settings and is being adopted by museums in their approach to sharing content with visitors. For example, Henson (2016) states that:

“Visitors need a solid background to slot more detailed information into; otherwise it just becomes an exhausting sea of disparate facts.”

These observations make the learning theory a worthy fit for the intergenerational, human-centred and science capital approach of the study.

Furthermore, according to the social constructivist ideology, knowledge results from social engagement and language use; it puts emphasis on the process of learning in social settings rather than the passive transmission of information (Wertsch, 1985). In Vygotsky’s theory of learning and development, the Zone of Proximal Development (ZPD) focuses on collaboration and relationships in the learning process. Vygotsky identified that we learn through dialogic interaction with others and that the level of potential development and learning increases through the process of collaborative communication, particularly with more capable peers or adults. His research around ZPD highlights utterance-to-utterance relationships and interaction as the cornerstone of informal learning (Billings & Walqui, 2017). Vygotsky used the ZPD concept to criticise more common psychometric testing methods which only measured a learner’s current abilities, not potential for development. Importantly, Vygotsky argued that educational assessment should be collaborative to reveal emerging skills (Mcleod, 2023b). In reference to the Power Hall study, social constructivism has helped to highlight the suitability of the discourse analysis method as a way of measuring prototype success and potential.

Also of note, is the Vygotskyian thinking around higher mental processes which are especially pertinent in the interpretation of steam engine science and engineering concepts to a family audience. Mediated learning tools such as language, signs, and symbols are viewed as key components during interpersonal discourse resulting in deeper learning processes and the transition from 'elementary' to 'higher' mental functions (Kozulin, 2003; Wertsch, 1985). The researcher considered that the concept also links with Bergen (2009) who values play as a facilitator for higher-level thinking and informal learning as described in the review of literature (see section 2.1). Museums are social, dialogical settings with visitors mostly attending in pairs, families and groups (Falk et al., 2012), this affords huge opportunities for interpretation experiences and knowledge development. It supports a departure from 'spoon feeding' the visitor audience with text-heavy content, perceived in the previous interpretation of the Power Hall, and instead provides the foundations to embrace and promote active participation, engagement and meaning-making between children and adults.

The conceptual framework below (Figure 3-2) demonstrates the connections and relationships between the main components of the engagement experience and establishes where the theories of science capital development and social constructivism (Vygotsky's ZPD) fit into this strategy. It also addresses the variety of differing motivations experienced by adults and children when engaging with exhibition interpretation (described in section 2.3 of the literature review). Finally, it outlines the main design direction components which inform the decisions made regarding the ideation and development of the interactive interpretation concepts and prototypes.

These considerations, alongside theoretical and ethnographical research, have been implemented and ingrained throughout the practice research. This conceptual framework has also informed the development of the proposed discourse analysis evaluation strategy described in the methodology and the development framework (including proto-scoping) described in the discussion chapter.

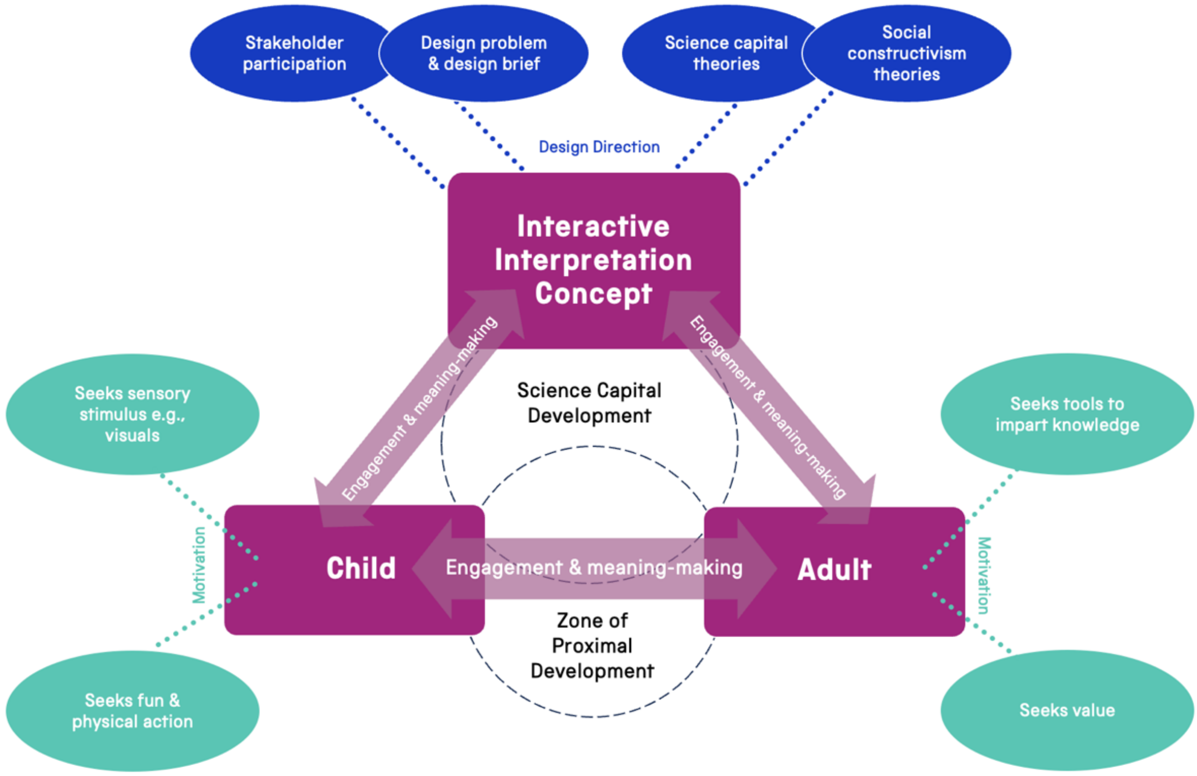


Figure 3-2: Conceptual framework of proposed engagement experience connected to the interactive interpretation prototypes.

3.2.3 Methodological Approach

The complexity and sociocultural nature of creative research often requires an eclectic approach to method (Collins, 2018, p. 8). This study draws upon a range of informing components and investigative approaches with a particular focus on reflexive design, encompassed by a pragmatist and mixed methods approach to research. The review of the literature and the identification of a theoretical framework helped to synthesise the topics and open avenues for investigation. The growing theoretical and ethnographical foundation, participatory design and practice research provided the three key elements of the methodological approach used to explore the research problem. Supplementing these strategies was the process of action research which was utilised throughout to support reflection and adjustment as the research adapted and aligned to the changing demands of this real-world project. Borrowing and modifying the ‘Research Onion’ (cited in Saunders et al. (2019, p. 130)) as a basis for visualisation, the researcher presents an overview of her methodological choices (Figure 3-3). These interconnected factors and closely linked strategies were instrumental to the decision-making process and channelled a procedure to answer the research questions.

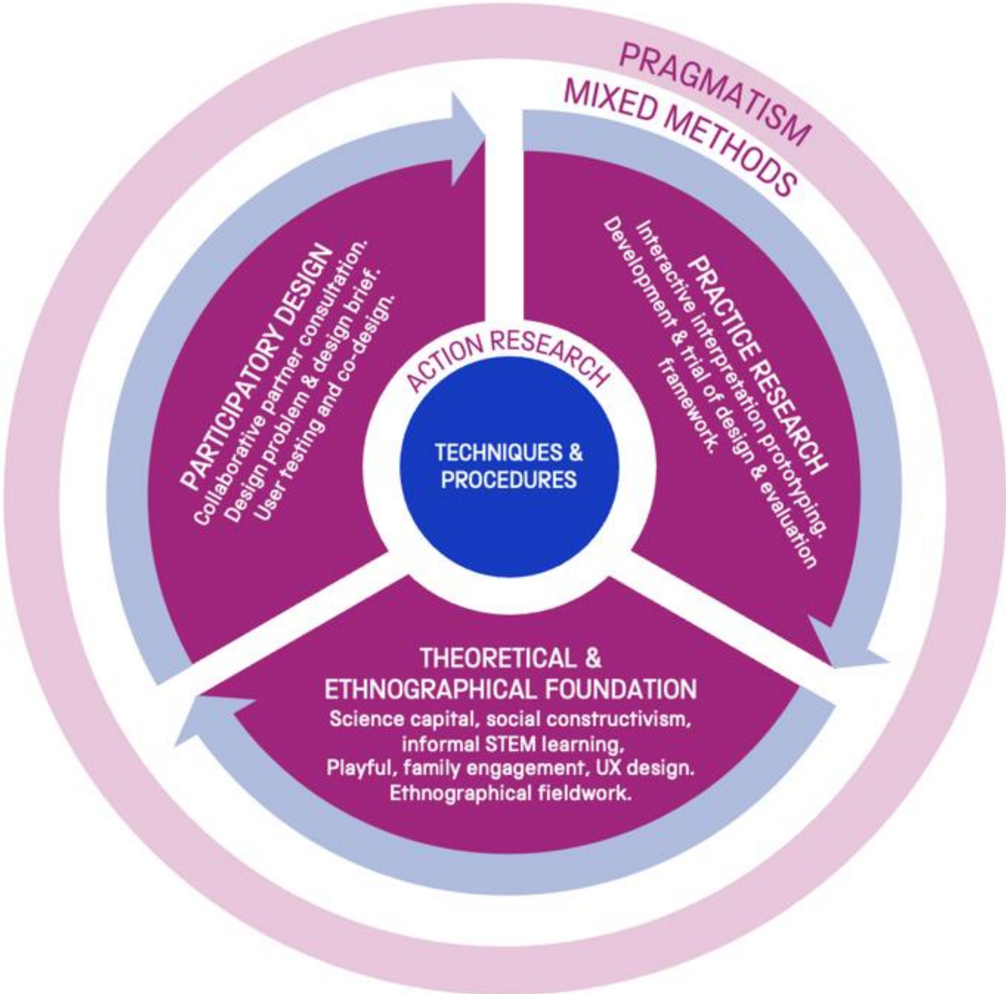


Figure 3-3: Overview of the methodological approach to the study.

The exploration of the main research question combined with the data-driven goals of the subsidiary questions necessitated a mixed methods approach to research. In brief, mixed methods refers to the collection and analysis of data which integrates qualitative and quantitative elements into a single study or inquiry (Tashakkori & Creswell, 2007, p. 4). Used in their singular form, qualitative research and quantitative research provide different perspectives and each has its limitations. Mixed methods research, on the other hand, has the potential to offer a more rounded and complete understanding of the research problem (Creswell & Clark, 2017).

Mixed methods research is generally regarded as a good partnership with a pragmatist philosophical approach (e.g. Denscombe, 2008, p. 273). As described in section 3.2.1, pragmatism is focused on understanding the problem and investigating it from various perspectives (Dillon et al., 2000) hence forming further support for its selection.

In respect of this study, the experimental, exploratory and participatory nature of the creative practice was viewed by the researcher to be particularly suited to a qualitative research approach. User feedback was obtained through methods of observation and open-ended questionnaires with results that were rich, diverse and informative. This approach is useful for investigating 'why and how' questions (Hennink et al., 2020), making this ideal for addressing the main research question. However, through theoretical investigation, and practice reflection the researcher became more aware of the value of family discourse and its relationship to meaning-making, user engagement and science capital development. There was also the emergent perspective related to the need to be able to efficiently compare the success of one interactive interpretation prototype to another in relation to intergenerational engagement and science capital; a feature that was difficult to achieve quickly and easily with only a qualitative approach. This led to the development a of mixed methods evaluation system, focussing on discourse analysis and facilitating the ability to give a qualitative score to the engagement experience (see section 3.3.3).

3.2.4 Research Strategies

3.2.4.1 Practice as Research

Firstly, as an umbrella strategy, this study has taken a practice as research (PaR) approach, a type of research that offers an opportunity for inquiry and exploration through doing and making (Bulley & Şahin, 2021), leveraging the collaboration and innovation required for the creative work. In contrast to more traditional methods of study, PaR helps to enable more affective and imaginative routes to propagate methods of knowing (Leˆ & Schmid, 2020). With a similar view, the Arts Humanities and Research Council states that PaR is the generation of knowledge through practical means and is a process that values 'knowing' through 'doing'. They also define that within the realm of PaR, the researcher is positioned as a creator who is engaged in an exploratory process to investigate the research problem (AHRC, 2023, p. 16), a perspective that is agreeable with the positioning of this study.

Using the nuances of terminology set out by Bulley and Şahin (2021) and Candy (2006), the research, practice and evaluation found within this work could be characterised as a combination of both practice-based and practice-led. Unique and creative artefacts have been produced to explore and provide solutions for a novel interpretation problem, alluding to the *practice-based* element of the research. Correspondingly, a *practice-led* approach has been embraced through the nature of the project progression; research strategies and questions have emerged from the practice itself, which in turn have been used to test ideas, gather data and provide direction.

3.2.4.2 Participatory Design

As introduced in the literature review discussing collaborative practices (see section 2.4), participatory design (PD) is a key element of the research strategy, promoting and highlighting the direct involvement and consultation of users and stakeholders in the co-design and problem-solving process (Robertson & Simonsen, 2013; Sanders, 2002). This methodology has lent itself well to the nature of this research as it allowed for the crossing of boundaries between the designer, developer, researcher and stakeholder, to generate design solutions which fit more appropriately to the needs of the user and client (Robertson & Simonsen, 2013). 'Stakeholder' is a term commonly used in PD which not only encompasses the end user but anyone who is involved in or impacted by the project (Collins, 2018; Dowd & Elizarova, 2017; Robertson & Simonsen, 2013). Through a co-creation process, people (stakeholders) are supported to identify hidden opportunities and design issues, and participants are valued as subject matter experts in their own field (Dowd & Elizarova, 2017). Importantly, through the process of PD, stakeholders are empowered with a sense of ownership in the generated outcomes (Sanders & Stappers, 2008). The sense of empowerment and ownership is a point of interest for this study as it connects with the values of the science capital approach (Archer, 2018; Godec, 2017) and playful learning characteristics (e.g. D'Souza, 2018; Mardell et al., 2016) as described in the literature view (section 2.1 and 2.2).

PD is embraced in the development of the creative outputs (within pathway 1, Figure 3-1) where SIM stakeholders are consulted and involved in the phases of the prototype design lifecycle. In the development framework and proto-scoping strategy (pathway 2, Figure 3-1), participation is promoted as an ideology, demonstrating how users can be involved in scoping concept ideas using comparative prototyping and discourse analysis as an efficient method for evaluation and reflection. The investigated framework is designed with the intention of making the interactive interpretation prototyping process more efficient and illuminating using evaluation of family discourse through a science capital lens.

Besides the author taking on the role of researcher, designer and developer, other stakeholders include:

- Museum visitor target audience and user testing participants
- Industry supervisor and SIM interpretation manager
- Power Hall exhibition curator
- SIM Power Hall content team
- SIM visitor engagement team
- SMG audience research team
- SIM senior management

A rich and meaningful stakeholder involvement ensures that this study embraces and acknowledges a broader range of views and perspectives. It also has positive implications on the issue of the research validity and credibility. Participatory and collaborative modes of research are viewed as being useful for strengthening research findings and interpretation, arriving at evaluation conclusions as a result of a consensus among persons and perspectives (Zohrabi, 2013, p. 259). The researcher was answerable and accountable to the museum stakeholders and the work was closely monitored by the Power Hall Content Team and industry supervisor. As well as in-depth discussions and team meetings the researcher gave regular presentations and updates to SIM colleagues about how the prototype ideas were progressing and what results were being seen, this was an opportunity for further collaboration and reflection. The user testing and data collection sessions were supervised by museum staff and where necessary, assisted by technical support teams.

Finally, the focus of PD was a good fit for this study because of the involvement of children as participants and to a degree, co-designers. Enabling children to participate in the design and evaluation process provided the designer/researcher with valuable insight into unique child-focused issues that may not have been considered through an adult lens (Kellett, 2009). It also offered the chance for children to not only be seen as informant mechanisms for the project development but to explicitly add value in the opposite direction, providing children with the potential to develop new problem-solving skills and design-thinking techniques (Paracha et al., 2019).

3.2.4.3 Action Research

Action research (AR) is simply described as a combination of action and research which provokes change (Foth & Axup, 2006, p. 94). For the purpose of this study, AR was used as a complementary approach within the strategy of PD because it offered an opportunity to examine the social phenomena of stakeholder engagement through a process of introducing interventions or 'actions' and observing the outcomes of those actions (Bhattacherjee, 2012). This notion was considered by the researcher to be especially pertinent to prototype ideation. AR is often distinguished by its collaborative nature because the process usually goes beyond traditional research paradigms by emphasising the involvement of stakeholders and effecting positive change (Stewart, 2023).

Noakes (2010) states that a widely accepted definition of AR can be found via Carr and Kemmis (1986, pp. 165-166) who claim that the approach has three clear characteristics:

1. The subject matter is a social practice susceptible to improvement.
2. The project proceeds through a spiral of cycles which feature periods of planning, acting, observing and reflecting.
3. The project involves people who are responsible for the practice, widening participation.

On reflection of this three-point definition, AR connects to this study because:

1. The subject matter of research is the intergenerational engagement of visitors (in particular families) with steam engine concepts in a public science museum setting. It is concerned with supporting individuals to build upon their science capital through positive, digitally enhanced, interpretation experiences. Furthermore, the practice proposes and tests a new strategy for supporting a more audience-driven approach to scoping exhibition interpretation ideas. The ambition of the framework is to inform design decisions for a final interpretation output that has a strong potential for supporting family engagement and playful STEM learning.

2. The research works through a series of cycles that feature investigation and preparation (planning), design and development (acting), consultation and user testing (observing), prototype ideation and framework development (reflecting).
3. The project involves a wide range of people (stakeholders) who are integrated into the progression of the study, particularly the researcher acting as the designer/developer, the Power Hall exhibition content team and user testing participants.

Although AR is often linked with service delivery (Lingard et al., 2008, p. 460) the researcher saw this as a useful, complementary strategy with both PaR and PD due to the cyclical and iterative nature of all of the approaches. In reference to PaR the AHRC state:

> "There is an **iterative** cycle involved, where the research informs knowledge and the knowledge informs doing. Picking, testing and contesting theoretical ideas along the way. Often artistic concerns lead the research rather than questions around impact" (AHRC, 2023, p. 16)

Similarly, in reference to PD, Cipan (2023) states that this approach follows an iterative process that allows for continuous improvement and refinement based on user feedback and insights.

Due to the strong weighting towards qualitative research found within this study, AR is further deemed as a suitable approach to facilitate this characteristic. Although AR is not necessarily defined by the use of qualitative or participatory methods, it usually benefits from ethnographically-informed techniques to address human-based problems (Foth & Axup, 2006).

AR is commonly visualised as a spiral or cycle showing the four key elements of plan, act, observe, and reflect (e.g. Kemmis & McTaggart, 2007, p. 278). Based on these existing diagrams the researcher presents her own visualisation to demonstrate the key cycles that took place during the research as seen in Figure 3-4.

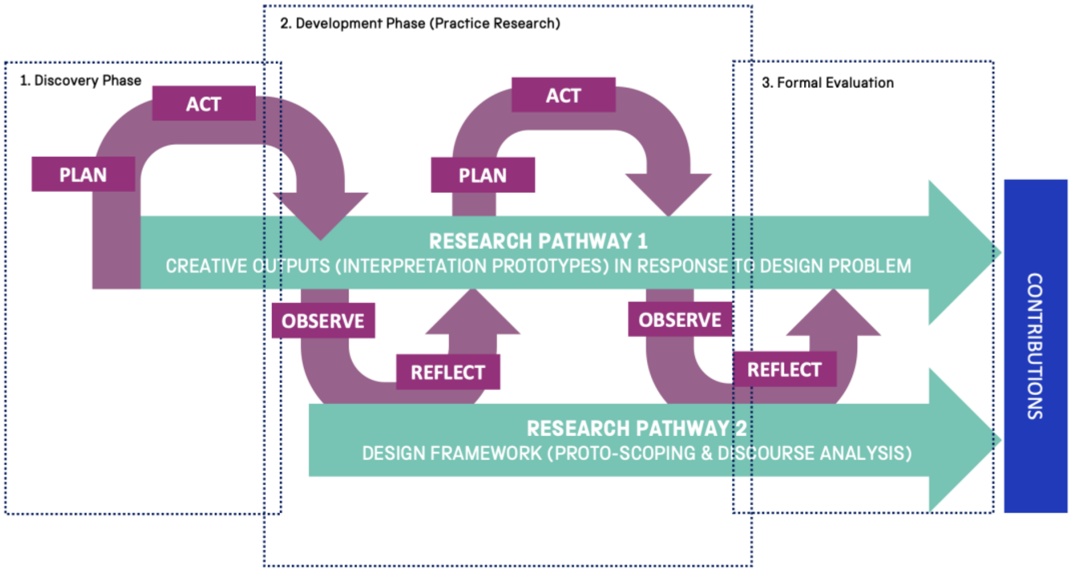


Figure 3-4: Visualisation of action research in relation to the research pathways.

3.3 Research Plan – Techniques and Procedures

3.3.1 Discovery Phase (Design Research and Project Scoping)

3.3.1.1 Ethnographic Fieldwork

Building on the literature review (conducted to synthesise the topics of informal STEM learning, playful engagement, user experience design and prototyping situated in the field of science museum exhibition interpretation), site specific, empirical and secondary research were first undertaken to identify the researcher's position within the Power Hall project and to reflect upon opportunities for creating original contributions to knowledge. This was achieved through an ethnographical approach, with the researcher becoming embedded within the Power Hall design team, attending weekly content team meetings at SIM and joining as many related events as possible including museum workshops, conferences and study days (dates and a brief overview of discovery phase events are listed in Appendix F). The Power Hall Content Team consisted of SIM Interpretation Manager (and collaborative industry supervisor to this CDA) – Kate Chatfield; Gallery Project Manager – Sallyann Browning; Curator of Engineering – Sarah Baines; Associate Curator – Abi Wilson; Schools and Families Manager – Rebecca Gazey-Mcgaughey; Historic Working Machinery Operating Technician – Pippi Carty-Hornsby and Learning and Participation Manager – Ruth Murray. This experienced, multi-disciplined and talented team were instrumental to the ideation process and offered an opportunity to both witness and become deeply embedded in the preliminary stages of exhibition planning. Furthermore, the researcher also conducted informal investigative talks with members of the SMG Audience Research Team and the SIM Explainer Team with the objective of revealing information about current interactive interpretation prototyping techniques/processes and refining the specific research questions. These ethnographic activities are in line with the view of Banks et al. (2014, p. 71) who state that ethnographic fieldwork should:

- Develop close relationships with the research community.
- Involve the acquisition of local language and terminologies.
- Render high degree of reflexivity.
- Utilise a range of methods including observation, surveys and fieldnotes.

This early period of the research project is identified as a valued and important step in the development of any user experience problem, known commonly as the 'discovery phase' (Grey et al., 2006) in the field of UX and museum experience design. Grey states that by obtaining baseline information, organisations, developers and designers can achieve solid underpinnings from which to build upon in the later phases of development and implementation. From the broader perspective of UX design, Rosala (2020) explains that the discovery phase involves researching the 'problem space' and gathering evidence and initial direction with regard to what to do next. It involves obtaining an understanding of who the users are and what they need/value from the solution. It should investigate the problem to be solved and the opportunities for the organisation, and finally, it should achieve an appreciation of the shared stakeholder vision including objectives and desired outcomes.

During the ethnographic fieldwork within the discovery phase, secondary data and SMG directives were gathered to provide a growing foundation of knowledge regarding:

1. The specifics of the SIM and SMG audience profiles.
2. Definitions of common but specific SMG terminology.
3. The techniques through which SMG encourages the employment of a science capital approach in their STEM interactive interpretation.

This fieldwork can be seen described in the section 4.1 and was a source of essential detail and direction for the creative outputs.

3.3.1.2 User Personas

Once the researcher had obtained a thorough and accurate understanding of the target user, the method of creating *user personas* was employed using a basis of existing audience segment data and inspired by informal gallery observations. Personas are generally used in the field of user experience (UX) design to create representational portraits of key audience segments and are based on both qualitative and quantitative audience research (Abrams, 2019; Bruton, 2022). It was an interesting step in this study as it allowed the researcher to consider children's actions and behaviours which may differ from the already well-studied parental/adult motivations and visitor behaviour. Four child-based user personas were created ranging from four to eleven years, these tools helped the researcher to visualise, validate and scope the design requirements of the later proposed interactive interpretation approaches (see section 4.1.5 and Appendix G).

3.3.1.3 Sketches

During the discovery phase, whilst gathering an appreciation of the Power Hall and the SIM visitor audience, the researcher also used the method of sketching to generate a collection of initial ideas for Power Hall interactive interpretation concepts. In UX design, sketches are created in the first exploratory/discovery stages of a design process. They help designers to propose, explore and communicate design ideas in a fast, cheap and easy-to-iterate format (Rosala, 2020). The generated sketches provided a tool to discuss preliminary ideas and project direction with the industry supervisor and SIM stakeholders (see section 4.1.9). These first concepts explored the themes of 'tinkering', 'peopling' and 'everyday relevance' (key SIM terminology is explained in section 4.1.1), and the dialogue created around these preliminary notions played an important role in the progression and direction of the work. The wide variety of approaches and content themes such as a technician's tinker table and digitally enhanced role-play spaces revealed for need for a more specific brief to refine the key learning objectives and provide a clearer direction for the project.

To summarise, the discovery phase of the study enabled the researcher to achieve a thorough understanding of the Power Hall environment and to draw out assignment objectives. Using both secondary data and empirical research, knowledge was gathered about existing museum processes, audience requirements, project intentions and SIM design guidelines and brand toolkit (Appendix H). Additional methods included user personas and sketching, all as a foundation for developing a design brief and a set of initial ideas for a range of interactive interpretation prototypes.

3.3.2 Development Phase (Practice Research)

3.3.2.1 Design Brief

After five months of early fieldwork, and influenced by the exploratory research and the discovery phase, the SIM industry supervisor was able to provide the researcher with a design brief (Appendix A) to bring more focus to the generation of interactive interpretation concepts. In design practice, a design brief outlines the aims, objectives, issues, audience, and other considerations (such as budget, site, resources, or constraints) that a new design must take into account (Burdick, 2015). In addition, the SIM design brief acted as a guiding agreement about the outcome of the process, defining that which constitutes success. It was also seen as a way to bring together and interpret the research that preceded it.

3.3.2.2 PACT Analysis and Product Requirements

Becoming familiar with the project environment and problem space set the foundations for the prototype design decisions and interventions in the subsequent prototyping phase of the project. Using this data, a review of audience and project requirements was undertaken in order to scrutinize the design problem and to conserve the authenticity of this real-world challenge grounded in the Power Hall reinterpretation project. This led the researcher to the method of developing a People, Activities, Contexts, Technologies (PACT) analysis to further envisage the target audience and context of the Power Hall interpretation. PACT is widely used for the development of design thinking in relation to an interactive system and provides a good starting point for exploring the requirements of the practical work outlined in this report. Benyon (2019) supports the PACT analysis framework as a method to foresee future solutions and opportunities for a design problem, making it an admirable fit for this project. The main idea of a PACT analysis is to think about the requirements of a system or application in four parts: People, Activities, Contexts, and Technologies (see 4.1.10).

In a similar nature to the PACT analysis, it is commonly recognised in design practice and product development, that a product requirements document (PRD) should be created to provide a vision of the end product and clarify user needs (Benyon, 2019). It is useful as a communication tool between the design team and the client/stakeholders to elucidate the project features, functionality and goals (Ritika, 2020).

3.3.2.3 Ideation and Low-fidelity Prototyping

After the finalisation of the design brief, a more targeted concept direction was taken, focussing on the 'All Shapes and Sizes' compound within the Power Hall (Appendix A), with specific attention to five engine parts that are a common feature on the engines located within the compound. This resulted in concept ideation, wireframe diagrams and low-fidelity prototypes in the form of paper mock-ups (see 4.1.9). Wireframing is a process of generating simple overviews of interactive products to establish the structure and flow of potential design solutions. They can be used to help teams and stakeholders ideate toward optimal, user-focused prototypes and products and have a focus on functionality, structure hierarchy and navigation (IxDF., 2016). Paper mock-ups are a commonly used form of low-fidelity prototyping in the field of UX, as they are useful to visualise and discuss active functionality (Sauer et al., 2008, p. 72). Paper prototypes are one of the fastest and most cost-effective of the so-called rapid-prototyping genre (Rettig, 1994, p. 22) and the process enabled the researcher to explore and demonstrate interaction behaviour and informally test and convey the ideas with SIM stakeholders. Low-fidelity prototyping was chosen as the practice research method because this gave the freedom and flexibility to explore ideas without extensive investment of time and resources. Secondly, the researcher was interested to see what emergent knowledge this process would bring to bear on the discipline of interactive interpretation and whether this was a viable and realistic approach for the museum to carry forward for the scoping out of future interactive interpretation projects. Finally, this process was used to test whether this was a successful method of making science museum interpretation more visitor-centred and more attuned to science capital development concepts in line with the theoretical framework (see 3.2.2).

An important point to record at this stage in the methodology chapter is the impact of the COVID pandemic lockdowns on the prototype developments and the participatory, co-creation intentions of the project. During this time an adjusted methodological approach had to be taken as the researcher was forced to work in a more solitary format from March 2020 through to August 2020 and again from November 2020 to April 2021 due to the museum closure and government guidance. As a result, opportunities for consultation and co-creation with genuine museum visitors became diminished. The direction of the interactive interpretation ideas took a different path as the researcher considered options to develop an entirely online approach and investigated modes of ‘pandemic-proof play’. This included interactive interpretation concepts that could be accessed from the ‘visitor’s’ own home or in a contact-free format, as well as managing the consideration that the researcher needed to be able to develop the prototype concept single-handedly from her own home, without the need for specialist resources, support or equipment.

The weekly SIM content team meetings were moved online (via Microsoft Teams) allowing for the maintenance of SIM stakeholder participation, however, early consultation with visitors had to take place in the much smaller window of time, between the first two national lockdowns, once the museum was open again to the public. Considerations and plans were made for investigating a pathway of user consultation online however this would have necessitated an application for a new ethics approval (with significant time implications) along with the recruitment of online participants, which the researcher and SIM stakeholders believed would impact the credibility of the data. Further details of the impact of the pandemic can be seen in the challenges section of this thesis (see 6.5)

Although four interactive interpretation prototype concepts were initially created beyond the phase of the early sketches, they were not all selected to move forward to further development, high-fidelity prototyping and user testing. The pandemic and a collection of wider Power Hall redevelopment disruptions had a large impact on the prototype approaches. It was vital to the authenticity of the CDA that the work should be relevant and of value to the SIM Content Team and therefore it was crucial for the researcher to be reflexive by adapting concept approaches to suit the project climate. The two main factors being:

1. The playfulness should have the potential to be ‘pandemic proof’ and support low-contact, hygienic situations.
2. Funding and budget allocation uncertainties could potentially dictate limited budgets for the realised interactive interpretation concepts, therefore development costs must be kept to a minimum.

For these reasons, a concept for an animated interactive projection panel (see 4.2.1.3) and an augmented reality-enhanced multimodal trail (see 4.2.1.4) were progressed into the first informal user testing and pilot evaluation phase, based on their strengths in the above areas (minimum contact and low production costs).

3.3.2.4 Informal User Testing and Pilot Evaluation

Once the museum opened after the lockdown period, the researcher was able to conduct informal, qualitative user testing and visitor feedback opportunities. The method for this early user testing consisted of sharing two prototype concepts with museum visitors, discussing ideas, making fieldnotes and, for the final two sessions, conducting a short, pilot questionnaire developed with guidance from the SMG Audience Research Team. Because the target audience for the research was families with children aged four to eleven years, these sessions were conducted on weekends and school holidays.

The initial testing area was located in the 'Conversation Space' at the Science and Industry Museum which is a large public area at the end of a ramp that leads down from the Textiles Gallery. Here the researcher was able to spot families coming down the ramp and invite them over to participate. For these formative sessions, groups of two or more people containing at least one adult and one child, between the estimated age of four to eleven years were visually identified. This sample was chosen to fit with the identified audience segment of 'engaged community drivers' (see 4.1.3) (Science Museum Group, 2019c). Participants were already partway through their visit to the museum when invited to take part in the evaluation exercise. The researcher and the SIM Content Team agreed that it was important to test the prototypes with a genuine museum audience to enhance the rigour and authenticity of this exercise, rather than a convenience sampling approach.

Three initial formative sessions (each lasted one to two hours) were conducted with a total of thirty-two families participating.

- Session One: An **informal** consultation session gaining initial visitor responses to 'everyday relevance' imagery (see 4.2.2), alongside casual discussions of the initial approach to prototype three (using a 'proof-of-concept' system of laminated sheets showing how the animated interactive engine projection could work). Twelve families were involved in these informal discussions with the goal of conducting short co-creation opportunities.

- Session Two: A **pilot** user evaluation of the proposed interface for the animated interactive projection panel (prototype three). This took the form of a digital interface demonstrated on an iPad, replicating the visuals and functionality of the proposed concept. Ten families participated by trying the interactive interface and answering the short pilot questionnaire as a family at the end of the session. A small
- Session Three: A **pilot** user evaluation of the augmented reality-enhanced multimodal trail (prototype four) in its premature form. Again, ten families participated by trying the interactive interpretation concept and answering the short pilot questionnaire as a family at the end of the session.

Each of the three informal user testing sessions took place three weeks apart and tested the two different prototypes at a variety of premature stages. During each session, observations and notes of discourse and significant statements from the participants were quickly recorded by hand in the form of fieldnotes. This allowed for reflection after the sessions were complete and helped to identify any common patterns or themes that could further feed the design process.

To produce continuity across sessions two and three, the same five questions were used at the end of each sample and the same number of participants took part (ten for each).

The questions consisted of:

1. How does this experience make you feel about steam engines?
2. Do you think this information is connected to your life? Why do you think that?
3. Is there anything you particularly liked about it?
4. Is there anything you disliked about it?
5. Do the engines make you think of anything or anyone that you are familiar with today? If so, what?

The questions were written in line with guidance and examples from the SMG Audience Research Team and developed using the theoretical underpinnings of science capital and a constructivist approach (see 3.2.2). They were designed to draw out signs of a sense of connection with the content and to identify if the visitors were engaged and comfortable with the information presented. The questions also looked to identify if the participants were associating the engine parts with their everyday lives, an important characteristic to support the development of science capital (Archer et al., 2016, p. 3). In addition, because there were numerous COVID-19 restrictions and controls in place, including social distancing and facemasks, the researcher felt it was important to keep questions to a minimum, restricting the number five felt more comfortable for the situation without creating a sense of uneasiness. They were delivered in a conversational manner to make participants feel as relaxed as possible.

The questions were pitched in a child-friendly way, using short sentences and age-relevant terms (Bell, 2007, p. 463). Gathering views from children in this informal stage was considered an important part of the participatory design approach. Kellett (2009, p. 53), explains that children have a unique insider perspective that adults are unable to offer. They are party to the 'elusive subculture of childhood' which can provide a critical perspective on the design of concepts and productions, generating valuable opportunities for data collection and analysis. The pilot sessions allowed the researcher to observe and reflect on the field notes and how the questionnaire worked with children and families, with a focus on the quality of their responses and the robustness of the questions, a necessary step before moving forward to the next evaluation stage (Bell, 2007, p. 468).

The method of sharing low-fidelity prototype ideas with museum visitors was intended as an evaluation and co-creation springboard enabling families to use these early concepts as a basis for identifying solutions, potential stumbling blocks and even new ideas altogether. It was considered that without this basis, children in particular might find it difficult to quickly get a grasp of the project and make appropriate contributions. The low-fidelity prototypes were designed as a discussion starter and a target for critique, and the method was used as a tool to quickly present and communicate ideas to participants (Rudd et al., 1996, p. 84).

To summarise, the key goals of these formative sessions were to gain any general feedback on the prototypes, with a view to further iterations and amendments, and to also make notes about significant comments and conversations that were occurring. The researcher recorded data by making brief transcripts during engagement and completing a short questionnaire sheet with each participant group. During this phase, the process of action research was employed by planning, observing, reflecting and acting on the feedback obtained from these informal, pilot sessions. In turn, the prototypes were iteratively adjusted and developed to form high-fidelity prototypes which functioned in a similar way to a finished product. Action research was also used in combination with practice research to reflect on the user-testing and evaluation process.

3.3.2.5 High-Fidelity Prototyping

Progressing and building upon the informal user testing of the low-fidelity prototypes, two high-fidelity prototypes were developed to further explore and refine the digital interactive interpretation concepts. These consisted of the final prototype for an animated interactive projection panel (see 4.2.1.3) and an augmented reality-enhanced multimodal trail (see 4.2.1.4).

Unlike low-fidelity prototypes, high-fidelity prototypes demonstrate near-to-complete functionality and the actions of the prototype user more closely resemble the 'real-life' users of the product (Rudd et al., 1996). The method of high-fidelity prototyping was again solely undertaken by the researcher as a PaR approach, the majority of which had to be conducted during a further lockdown period with limited resources. High-fidelity prototypes are known to be time-consuming to produce (Rudd et al., 1996; Sauer et al., 2008) however the lockdown period gave the researcher the fortuitous opportunity to complete the interactive interpretation prototypes to an advanced standard, ready to proceed to the formal user testing.

The design of the high-fidelity prototypes was built upon the preliminary interactive interpretation research but became more refined in terms of both content and functionality and informed by feedback and field notes of the pilot evaluation and informal user testing sessions. Careful attention was paid to the aesthetical nature of the prototypes as it was important for the interactive interpretation to be visually in line with the SIM and SMG branding and it was also viewed to be important for the user to be able to use the prototypes in a relatively unassisted format in order to mimic the final product. Full details of the production process can be found in section 4.2 of this report.

3.3.3 Formal Evaluation Phase (Data Collection)

Whilst further preparing for the formal evaluation phase of this study, empirical research and conversations with the Audience Research Team revealed that existing evaluation strategies used by SMG rely heavily on the method of audience surveys and questionnaires. On reflection by the researcher, these lean more upon the feedback from the adults within a visiting group and struggle to capture the raw and authentic responses within the active moments of user engagement. Questionnaires and surveys are also not ideal for sampling data from young children, particularly those under seven years of age (Bell, 2007, p. 469).

The prevailing, SMG qualitative survey method makes it difficult to compare two opposing interactive approaches in terms of science capital development, meaning-making and intergenerational engagement. Conversations with the SMG Audience Research Team matched with the literature view suggesting that qualitative data gathering can be time-consuming and challenging, both in terms of collection and analysis (e.g. Anderson, 2010; Banks et al., 2014, p. 75; Creswell, 2014). Furthermore, evaluation systems at SIM were not usually standardised, different surveys were used for each individual project depending on exhibition objectives. The researcher was interested in exploring a process that would be more efficient and more illuminating from a family-focused, science capital perspective as well as being less problematic and cumbersome for the Audience Research Team. In turn, this may lead to a pathway of earlier visitor participation and co-creation. The researcher labelled this element of the practice research as 'proto-scoping' because high-fidelity prototypes (which each answer the same brief) were scoped using a method of family-friendly evaluation to reveal which approach was most successful at eliciting science capital-themed discourse.

3.3.3.1 Mixed Methods and Discourse Analysis (Proto-scoping)

For the evaluation of the high-fidelity prototypes, a mixed methods approach was utilised, ensuring a breadth of data to enrich understanding and add rigour (Banks et al., 2014, p. 66). The approach to evaluation consisted of four elements:

1. A discourse analysis scoring system focused on science capital-themed utterances.
2. A visitor graded 'experience score' with a supporting visual reference.

3. A measure (in seconds) of how long the participants spend engaging with the prototype (dwell time).
4. A short survey featuring just two qualitative questions to facilitate further iteration.

As an overview, besides the objective of efficiently gathering meaningful data, the motivation behind this newly developed system of methods was guided by a variety of informing factors including the following:

- The researcher identified a lack of clear, user-friendly evaluation guidance specifically mapped to science capital themes and family-focused, informal STEM learning.
- Due to empirical research and conversational feedback from SMG Audience Research Teams, the researcher was keen to investigate a more streamlined and easy-to-use process that would allow for efficient data collection and expedient analysis compared to the more commonly used qualitative visitor surveys.
- Scoping multiple options of interactive interpretation approaches called for the ability to efficiently compare the STEM engagement success of one prototype to another. In the case of this study, the success of a prototype was primarily judged by its ability to elicit intergenerational discourse centred on science capital themes. This was acknowledged and driven by the theoretical underpinnings (3.2.2) and the direction from SMG (Science Museum Group, 2016, 2020) and the wider informal learning sector regarding the connection between intergenerational conversations and meaning-making (Allen, 2002; Leinhardt & Knutson, 2010; Povis, 2016; Silverman, 1995).
- The researcher and SIM Content Team were keen to use a naturalistic sample of genuine museum visitors to add to the authenticity of the research. It was considered that the chosen evaluation methods were suitable for family participants who would have been interrupted during their museum visit and were giving up their valuable family time to take part in the study. It was important to be aware and sympathetic to this situation by using a streamlined system that was enjoyable and comfortable to take part in.
- Following the previous pilot evaluation and informal user testing sessions, the researcher became aware of ‘passing’ visitor dialogue which provided valuable

engagement evidence; yet details could be easily missed in evaluation strategies that rely heavily on surveys or questionnaires. The researcher also became aware of a lack of authenticity experienced in the low-fidelity prototyping evaluation phase via the method of questionnaires. These points were particularly prevalent with young participants where it was observed by the researcher that previously energetic and chatty children were inclined to clam-up. A further reflection of the informal user testing and pilot evaluation can be found in section 4.2.2 of the chapter 'Presentation of Research'.

In reference to the formal evaluation phase, it is first necessary to define what is meant by the term discourse analysis due to its broad and varied use across a range of disciplines. The literature describes discourse analysis as a social study, understood through analysis of language in its widest sense including face-to-face talk, non-verbal interaction, images and symbols (Cheek, 2004; Gee, 2005; Shaw & Bailey, 2009). In this study, the researcher utilises discourse analysis as a socio-cognitive approach to help to quantify and record evidence of science-talk and meaning-making during observed periods of engagement with science museum interpretation. It includes analysis of questioning and conversations between family dyads (one adult and one child), as well as standalone utterances and remarks. The goal of the devised discourse analysis scoring scheme described in this study was to progress the development of a viable tool that could be used to measure family engagement through conversations and to compare different interpretation solutions with a science capital lens.

Choosing discourse analysis as the primary method for scoping out different interpretation approaches was a carefully considered decision and has its foundations in the theoretical framework described in section 3.2.2. The methodology draws upon the work of researchers such as Allen (2002), Ash (2003) Leinhardt and Knutson (2010) and Silverman (1995) who recognise that learning talk and visitor conversations are strong indicators of meaning-making in a museum environment. This knowledge is subsequently connected with the extensive work on science capital already undertaken by Archer (2018) and promoted by the Science Museum Group. Of further note, the devised discourse analysis scoring scheme is connected to Vygotsky's sociocultural theory of 'Zone of Proximal Development' which puts emphasis on learning through dialogic interaction with others (Billings & Walqui, 2017; Mcleod, 2023b). In addition, the linguist James Gee (2005) presents the idea that human language forms two clearly linked purposes: to support the implementation of social activities and to develop and sustain human links within cultures and social groups. A positive relationship was identified between these views and those of the science capital theories that had been closely researched. Discourse analysis allows the opportunity for examination of immediate, moment by moment dialogue and expression, in a casual and often spontaneous situation. Due to its 'on the fly' nature, the researcher considered it to have the potential to capture more raw and honest reactions when compared with other methodologies, such as exit questionnaires and focus groups.

The literature revealed that the benefits of family-focused learning identified by the museum sector have led to the adoption of a diverse range of methodologies for monitoring and evaluating, with intergenerational conversations and discussions being high on the agenda (Ellenbogen et al., 2007). Analysis of dialogue and visitor conversations is an accepted evaluation tool for assessing learning in an informal environment such as a science museum, where baseline assessments and post-visit tests can often prove less enlightening (Allen, 2002). However, empirical research and experience at SIM did not reveal strong evidence of SMG using such methodologies. As stated above, their current systems rely most commonly on qualitative observations (which do include some notetaking of key statements), questionnaires and exit surveys.

The scoring scheme employed for the discourse analysis used in the proto-scoping phase of this practice research has its foundation in the work of educational researcher, Sue Allen. As explained briefly in the literature review, Allen used a coding system to identify utterances of 'learning talk' from pairs of visitors at the Exploratorium *Frogs* exhibition. The coding system is demonstrated in detail in the chapter '*Looking for Learning in Visitor Talk'* (Allen, 2002). Allen's coding scheme follows a sociocultural slant by taking vocal expressions of *noticing*, *thinking* and *feeling* as evidence of informal learning, supplemented by cognitive concepts including *memory*, *inference* and *metacognition*. The five main categories and sixteen subcategories of her coding system can be seen in Figure 2-4 in the literature review.

It is important to note that Allen's system was designed for a summative evaluation of a completed exhibition space with visitors being recorded, tracked and observed moving around approximately 4,000 square feet of museum floor space (Allen, 2002, p. 6) Allen's coding scheme was also designed to cover all types of learning talk between two companion visitors.

It was identified that Allen's system could be reformed and augmented, to a more flexible and less complex scheme that would be quicker and easier to use in a fast-moving prototype testing situation. The researcher was also looking to develop a method which mapped specifically to science capital theories, and importantly, to provide a quantitative outcome that could be used to easily compare the success of one form of interpretation to another in relation to vocalised family engagement and science capital contributions. Through this evaluation, the researcher was looking to identify if the interactive techniques were eliciting meaning-making themes such as a sense of connection, linking to existing knowledge/experiences, reflection, and deeper engagement. Figure 3-5Figure 3-5 shows the devised discourse analysis scoring scheme used with each prototype engagement experience. It was designed by the researcher to give each experience a numerical score of family science engagement making it then possible to easily compare the discourse success of one prototype to another. It was also considered that the scoring scheme could potentially be used for all forms of science-based interpretation including hands-on activities and screen based, digital interactions.

Enjoyment or surprise expression (e.g. "Wow, aha, ooo")	**Reading text aloud**	**Strategic talk** (e.g. "You have to scan this code here")	**Connection and linking**			**Positive cognitive/ perceptual talk** (e.g. "So that's what a crank is!")	**Grand Total**
			Activity or event (e.g. "I remember when we went to…")	**People or place** (e.g. "your Grandad used to work with engines")	**Object, action or skill** (e.g. "That looks like …" "It moves like my bike")		
SC principle = Change in mindset, indication of engagement. Feeling comfortable 'this place is for me'.	SC principle = Indication that the parent/carer or participant feels the language is accessible. Indication of sharing.	SC principle = building confidence and ownership. Developing skills.	SC principle = Extending the reach of the experience. Making connection with their own life.	SC principle = Helping people to recognise that they know people who use science + how science is shaped by everyone in society.	SC principle = Linking to everyday life. Building on existing knowledge. Meeting people 'where there are'.	SC principle = Building confidence. Promoting science talk. Evidence of meaning-making.	
			x 2	x 2	x 2	X 2	

Figure 3-5: Science capital focused discourse analysis scoring scheme used to compare STEM interpretation prototypes.

Although the scoring system has been purposely kept as logical and straightforward as possible, some forms of discourse are rated higher than others. Visitor talk that reveals instances of connection and linking (falling within the categories of ‘activity or event’, ‘people or place’ and ‘object action or skill’) such as “Can you remember that red spinning top you used to have?” or “we saw something like this at the mill we went too” has a weighted score of double points, as does talk that is cognitive or perceptual, such as “look how the piston attaches to the crank”. This is because these elements were deemed to be most significant in building science capital and provide strong evidence of meaning-making and therefore, of a higher priority value. Further explanation of each category is described below. This describes how the coding strategy links to SMG guidance on science engagement (Science Museum Group, 2020) and researched science capital recommendations (Archer et al., 2016):

Enjoyment or surprise expression: This may simply take the form of instances of positive affective expressions such as “ooooh” or “wow” or could be more detailed such as “I’ve never seen anything like this before!”. This correlates with the ‘affective’ category used by Allen (2002) but does not include scoring for displeasure. An expression of enjoyment and surprise could indicate that participants are having a positive engagement experience and building a sensation that ‘this content/this place is for me’.

Reading text aloud: An instance of quoting the text would be a suggestion that participants are eliciting information from the experience and sharing it with other group members. It may suggest that the language is accessible and interesting enough to read aloud. Reading the text aloud could also be an indicator of joint attention which helps to increase cognition, emotional intensity and memorability (Shteynberg, 2015, p. 4). It may also provide an impetus for more valuable and noteworthy learning talk between visitors (Povis & Crowley, 2015, p. 179). This thematic discourse correlates with the ‘perceptual talk’ category used by Allen who states that this is evidence of learning because it is an ‘act of identifying and sharing what is significant in a complex environment’ Allen (2002, p. 21).

Strategic talk: This may take the form of phrases such as “You have to connect it like this” or “press this button here”. As in Allen’s category of the same name, strategic talk was identified as an explicit discussion between the participant dyads of what to do or how to use the prototype. Strategic talk could be an indication of confidence building and could suggest evidence of science-based understanding and knowledge construction.

Activity or event (weighting x 2): For example, “I remember when we went on that bike ride by the canal”. Referring to a past activity or event may be a suggestion that the participant is extending the reach of the experience and that they are making connections and links with their own lives. Allen (2002, p. 22) explains that discourse of this nature shows that visitors are using the interpretation as a stimulus to share a personal story or previously learned information that was not directly linked to what they were looking at. These connections are highly valuable to meaning-making but as they may be perceived as not directly associated with the science content, they could easily be disregarded in traditional modes of evaluation like observation.

People or place (weighting x 2): In a similar way to talking about an activity or event, this relates to a sign that participants may be recognising people they already know who use science and that science is shaped by people in society. For example, “Dad had to put the chain back on his bike last week didn’t he?”. Participant discourse of this nature may help users recognise that they know people who have science-related skills or jobs. This connects to points six to eight in the ‘Key Dimensions of Science Capital’ (Archer et al., 2016, p. 3) quoted below:

> 6. Family science skills, knowledge and qualifications: the extent to which a young person’s family have science-related skills, qualifications, jobs and interests.
>
> 7. Knowing people in science-related roles: the people a young person knows (in a meaningful way) in their family, friends, peer, and community circles who work in science-related roles.
>
> 8. Talking about science in everyday life: how often a young person talks about science out of school with key people in their lives (e.g. friends, siblings, parents, neighbours, community members) and the extent to which a young person is encouraged to continue with science by key people in their lives.

Object, action or skill (weighting x 2): Talking about an object, action or skill could again be an indication that the participants are building on their existing knowledge and making personal connections with STEM experiences. It may suggest that the interpretation is working well to 'meet people where they are' and building a stepping stone for further learning and connection. For example "Can you spin your body around like a governor?". This category is similar to the 'Conceptual talk' category used by Allen (2002, p. 21) where participant utterances about an object, action or skill may indicate a process of cognitive interpretation.

Positive cognitive/perceptual talk (weighting x 2): This type of talk or statement may suggest that the participant is building confidence during the experience and that the interpretation is promoting science talk. It may also suggest that meaning-making is taking place. Examples of this type of talk include "So the piston is inside the cylinder" or "The belt is what makes all the other machines move". In relation to the **'**Key Dimensions of Science Capital' (Archer et al., 2016, p. 3) this may indicate that the participant is demonstrating confident use of science literacy.

A tally system was used to complete a discourse score for each prototype engagement experience. As an example of how the total is formed for each dyad engagement, a completed scoring scheme is shown below in Figure 3-6.

Enjoyment or surprise expression (e.g. "Wow, aha, ooo")	**Reading text aloud**	**Strategic talk** (e.g. "You have to scan this code here")	**Connection and linking**			**Positive cognitive/ perceptual talk** (e.g. "So that's what a crank is!")	**Grand Total**
			Activity or event (e.g. "I remember when we went to…")	**People or place** (e.g. "your Grandad used to work with engines")	**Object, action or skill** (e.g. "That looks like …" "It moves like my bike")		
SC principle = Change in mindset, indication of engagement. Feeling comfortable 'this place is for me'.	SC principle = Indication that the parent/carer or participant feels the language is accessible. Indication of sharing.	SC principle = building confidence and ownership. Developing skills.	SC principle = Extending the reach of the experience. Making connection with their own life.	SC principle = Helping people to recognise that they know people who use science + how science is shaped by everyone in society.	SC principle = Linking to everyday life. Building on existing knowledge. Meeting people 'where there are'.	SC principle = Building confidence. Promoting science talk. Evidence of meaning-making.	
|	|||		|			||	10
			x 2 2	x 2	x 2	X 2 4	

Figure 3-6: An example of the discourse analysis scoring system showing how the discourse score is calculated for each engagement sample.

For clarification, in an intergenerational question-and-answer situation, or a statement and response on the same topic, this was only counted as one instance. For consistency, it was decided that the participants for the discourse analysis data gathering sessions should be family dyads consisting of one adult and one child (four to eleven years of age). As with the pilot testing of the low-fidelity prototypes, the formal testing of the high-fidelity prototypes was conducted with real museum visitors in a method of purposive sampling. It was decided that, for the authenticity of the results, visitors already in the museum on a general visit should be invited to take part. It was considered important to keep to two participants per sample, rather than families of varying sizes. The reason behind this was firstly to make the discourse analysis a fair and controlled data sample. Using only two family members meant that the proto-scoping could take place at different times if required whilst still retaining an element of regulation over the analysis. If larger groups were able to take part this may have resulted in generally more vocalised instances and interaction and therefore could create unfair comparisons. Secondly, the moment-by-moment analysis of discourse between two people is easier to manage and log rather than that of a large group. By asking for just two people per sample the evaluation experience could be kept calm and organised.

After each prototype engagement, the visitors were asked to give an experience score from one to five. The experience score question was supported by a laminated visual reference (Figure 3-7) to encourage children in the group to take the lead in this part of the evaluation. The chart was shown to children at the end of each prototype engagement, and they were asked: “How many stars would you give this experience?”.

Figure 3-7: Visual reference to prompt visitors to provide an experience score between one and five.

The methodological thinking behind the experience score was not only to simply compare the success of one prototype to another but also because the researcher was interested to discover if there was any correlation between the discourse analysis total and the level of the visitors' perceived enjoyment. In other words, could the amount of elicited family discourse be an indication of experience enjoyment/interpretation success?

When comparing the two prototypes for each dyad sample, the research was able to analyse if the prototype which scored highest in the discourse analysis is also perceived to be the most enjoyable. If this hypothesis was found to be the case, this could contribute to further evidence of the importance of promoting and provoking science talk between families using interpretative tools such as visual aids, embodied cognition (Skulmowski & Rey, 2018) and more accessible content.

To add a further dimension to the data, the length of time that the participants spent engaged with the interactive interpretation prototype (dwell time) was also registered. Some studies (e.g. Jambor et al., 2020, p. 6) suggest that a longer dwell time may be an indicator of deeper visitor engagement. The researcher was interested to see whether any patterns could be identified between the dwell time, the discourse analysis score and/or the experience score.

Finally, as a prototype development opportunity, the participants were then asked just two qualitative questions:

1. What was your favourite thing about it?
2. What do you think could be better?

This simple and efficient process meant that any 'after engagement questioning' could be kept to a minimum to reduce family discomfort, however, the questions were designed to succinctly identify positive and negative features of the interactive interpretation prototype to facilitate further iteration.

3.3.3.2 Baseline Test and Pilot Study

As an initial attempt to trial the previously outlined evaluation system, it was decided by the researcher that the set of data collection methods should first be applied to an assessment of the previous Power Hall interpretation signage (as seen in Figure 3-8).

As well as briefly testing the new evaluation process, the researcher was looking to gain some baseline data which she could compare to the evaluation results of the newly designed high-fidelity interpretation prototypes in the final phase of data collection.

The pilot study was conducted within a new testing area located in the 'MyDen' space, which is a restricted area at the side of the museum's Textiles Gallery. Dyads were identified (containing one adult and one child between the approximate ages of four to eleven years) and invited over to take part in the study.

Using laminated copies of the interpretation signage, a small sample of analysis was conducted involving seven visitor dyads. It should be noted that existing evaluation of the old Power Hall interpretation had already taken place before the Power Hall closure by the Science Museum based Audience Research and Advocacy team which helped to inform the prototype idea generation stage.

Figure 3-8: Example of old Power Hall interpretation signage for four steam engines in the 'All Shapes and Sizes' compound

Printed and laminated copies of four old interpretation signs for the 'All Shapes and Sizes' compound were laid out on a table. Parent/caregivers were invited to look at the signage with their child. The researcher completed a data collection sheet for each dyad engagement session as seen in Appendix I. The researcher used a stopwatch to monitor the length of time that dyad was engaged with the interpretation sample, this provided a measure of dwell time. Relevant STEM discourse from each dyad engagement was tallied, participants were asked to give the experience a score out of five (supported by the star chart shown in Figure 3-7) and the two evaluation questions were asked. The results of this baseline test and pilot study are described in section 4.3.2.

3.3.3.3 Formal Data Collection

Once the baseline test had been completed and prototype three (the animated interactive projection panel) and prototype four (the augmented reality-enhanced multimodal trail) were developed to a good level of maturity, the researcher was ready to move forward to comparative prototype evaluation and the formal data collection phase. The process would form a substantial trial of the proposed discourse analysis, proto-scoping technique and provide a methodology to address the research questions. The researcher was aware that for this approach to be successful the prototypes would need to be functioning to a realistic standard in order for visitors to use them unaided with minimum intervention. Figure 3-9 and Figure 3-10 show the two interactive interpretation prototypes set up in the MyDen testing area.

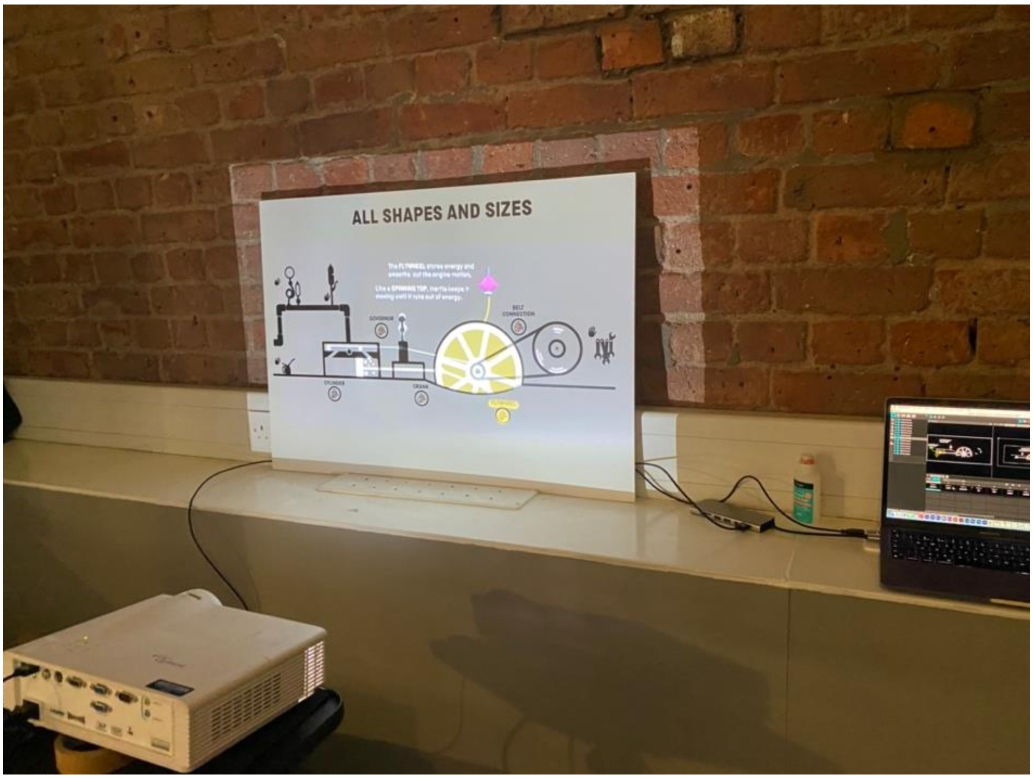


Figure 3-9: Photograph of the interactive projection panel prototype set-up in the SIM 'MyDen' area.

Figure 3-10: Photograph of the multimodal trail prototype set-up in the SIM 'MyDen' area.

As with the pilot test, the formal data collection sessions were conducted within the 'MyDen' area, this space gave more control over who was able to enter the area and allowed the focus to be on one sample session at a time. Dyads were identified (containing one adult and one child between the approximate age of four to eleven years) and invited over to try out the interpretation experiences. During each sample session, independent use of the prototypes was encouraged, and users were allowed their own time to work out what to do, this created a more independent and naturalistic engagement experience with the intention of eliciting more candid visitor responses. The researcher took an observational stance, standing back and using the scoring system to keep a tally of conversational statements and references that were occurring during the interaction.

The formal evaluation of the high-fidelity prototypes featured a total of 26 unique data collection instances using the previously outlined mixed methods evaluation system.

Each family dyad was asked to look at the two interpretation prototypes in turn: the animated interactive projection panel and the augmented reality-enhanced multimodal trail, which resulted in 52 sets of data (26 for each prototype). The order in which the prototypes were presented to the visitors was alternated to avoid any bias due to participant fatigue. A data collection sheet was completed for each prototype engagement as seen in Appendix I, the relevant discourse from each sample was tallied in the discourse scoring chart and the dwell time was recorded. Following each prototype engagement, participant dyads were asked to give the prototype an experience score out of five (supported by the star chart Figure 3-7) and asked the two evaluation questions.

The results of this formal data collection can been see described in section 4.3.

3.4 Research Ethics

The study and data collection involved members of the public on a visit to the museum and all of the participant groups contained children, therefore a number of ethical considerations were required. The research was conducted in a public exhibition space under observation from museum staff, and children were always accompanied by a parent or caregiver meaning that a disclosure check was not required.
Prior to the study, formal ethical approval was sought from the University of Salford Research Ethics Committee (See Appendix D) and a risk assessment was undertaken before each data collection session. It was agreed that no photographs or recordings would be taken of the participants and no personal data would be taken or stored. When visitors were invited to participate in the user testing, they were provided with a participant information sheet (Appendix B) providing an overview of the research and parents/caregivers were asked to sign a consent form allowing the researcher to conduct engagement observations and to make notes (Appendix C). Participants were assured that they could leave the study at any time.

3.5 Methodology Summary

In summary, this chapter has provided the overarching methodological approach to this creative, exploratory and reflexive study. It has presented the philosophical stance, methodological choices, research strategies, ethical considerations, data collection methods and overall research structure. The methodology, based on practice research and participatory design, has facilitated the creation of a collection of interactive interpretation ideas and prototypes. Emerging from this process, was the creation of a new framework for a more audience-driven approach to the development and analysis of family-friendly interactive interpretation design concepts for science museum settings.

The next chapter presents the main body of research. It firstly collates the key findings from the discovery phase before moving onto a description of the practice research in detail.

Chapter 4: Presentation of Research

This chapter describes the three main phases of research that took place during the CDA. The **discovery phase** provided the important foundation of design research which included ethnographic fieldwork and project scoping. The **development phase** was used to generate a collection of interactive interpretation prototypes in answer to the design brief. It was also a time to plan a strategy and framework for the comparison of one prototype to another through the lens of STEM-focused intergenerational conversations. The **formal evaluation phase** was used to assess the success of the concepts created during the development stage; this was an essential period of forming conclusions in answer to the emergent research questions. There was a degree of overlap between phases, especially concerning the discovery phase and the development phase but for the purpose of this thesis they described in a linear manor.

4.1 Discovery Phase (Design Research and Fieldwork)

As described in the methodology (section 3.3.1), the discovery phase was necessary for scoping and establishing the direction of the project, as well as becoming accustomed to the nuances of the collaborative partner. In this chapter section, the researcher explains a collection of ethnographical findings regarding specific SMG terminologies, the SMG approach to science capital, secondary data gathering regarding the interpretation target audience, project requirements and initial methods of ideation, all of which provide an important foundation for the practice research.

4.1.1 Familiarisation with SMG Terminology

Acquiring a strong handle on the specific terminology and language used by the exhibitions and interpretation team at SIM and the wider SMG was an essential element to the validity of the practice research and resulting contributions. Becoming familiar with this discourse and dialogue helped to form a much clearer definition of the larger project ambitions, as well as scaffolding a greater sense of continuity and 'fit for purpose' in the developing prototypes.

The following explanations have been achieved through secondary, empirical and ethnographic research. They proved to be vital clarifications as the research progressed and will provide the reader with a greater sense of the nuances woven deeply into this praxis.

Interpretation Plan: This is a dynamic and strategic document collaboratively developed by the Power Hall Exhibition Content Team to define the interpretative themes within the gallery space. The document is used to communicate progression and projection to the senior members of the museum as well as to provide a 'go-to' document for stakeholders, external partners or contractors.

User Agency: The Science Museum Group colleagues frequently use the term to describe a visitor's sense of control whilst being engaged with the exhibition or installation. Within this setting, a sense of agency is a human experience of controlling both one's body and the environment (Limerick et al., 2014). Facilitating user agency requires interpretation and design with layered content so that the visitors can decide on their own level of interactive engagement or how much they want to gain from the experience.

Tinkering: The Science Museum Group defines the term tinkering as an open-ended, tactile, playful opportunity which, in relation to a gallery interactive, will have a variety of outcomes and no set structure. A tinkering interactive should ideally be suitable for more than one person and lead to longer dwell times and deeper engagement.

Everyday Relevance: The Science Museum Group have a robust agenda for incorporating everyday relevance into their exhibition interpretation (Science Museum Group, 2021b). They state that a visitors' engagement with science can be measured and observed by the meaningful connections a visitor makes with the content and how links are formed with what they already know and have experienced in their everyday life. The theme of everyday relevance is explored by Silverman (1995) who states that relevance is attributed to human meaning-making and is inherent to forming meaningful museum experiences. The SIM Content Team expressed that the previous Power Hall interpretation did not connect with the lives of modern visitors. Emphasising how steam engine science is relevant to contemporary visitors is a challenging yet significant element of the Power Hall reinterpretation plan.

Peopling: Similarly, evaluation of the previous Power Hall exhibition suggested that visitors wanted to see more evidence of human stories and relatable content in the gallery. SIM intends to use the technique of 'peopling' the gallery by adding more audio and visual content of people, and social stories to demonstrate more of the human-engine relationship. The SIM Content Team also refer to the employment of 'people stories' which is connected to the use of on-gallery storytelling techniques. This helps to bring often unexpected human-centred narratives to the exhibition space. The intention of 'peopling' and 'people stories' is to create a greater sense of connection between the visitor and the exhibition content.

Intergenerational Conversations: SIM are keen to support and elicit conversations between young visitors and their parents/carers and they value interactive interpretation as a tool to facilitate this. Researchers including Ellenbogen et al. (2007) describe how exchanges and interactions within a visiting group can enrich personal experiences, support meaning-making and shape perceptions. This notion is intrinsically linked with the previously discussed theoretical framework theory of social constructivism and in particular Vygotsky's 'Zone of Proximal Development' (see section 3.2.2) and became an essential component of creative practice and data collection.

4.1.2 The SMG Approach to Science Capital

The SMG approach to science capital embraces the eight key dimensions suggested to be most important to STEM-related influences (Archer et al., 2016), these can be seen illustrated below in Figure 4-1.

Figure 4-1: Eight dimensions of science capital (Science Museum Group, 2016)

The eight dimensions have been reflected upon by SMG and used as a guide to inform the development of their visitor experiences and resources. Many of these dimensions, where applicable, have played a significant part in the playful and creative design thinking of the interpretation prototypes created by the researcher and discussed in this study. These dimensions have been summarised below (Science Museum Group, 2016):

1. Scientific Literacy: Building confidence to apply science experiences and understanding to everyday life and the world around them. Achieved by encouraging visitors to recognise existing knowledge and building upon it.
2. Science-related Attitudes and Values: Enable visitors to see that science has a value and is something they can do. Achieved by helping visitors to make personal connections to the content and using accessible language and personal pronouns.
3. Knowledge about Transferability of Science: Raise awareness of how science-based skills are useful for any job and many real-life situations. Achieved by showing skills that visitors already have and use in everyday life.
4. Consumption of Science-related Media: Increase exposure to science via other activities. Achieved by providing the visitor with opportunities to extend the experience through accessible digital content or takeaways.
5. Participation in Out-of-School Learning Activities: Enable visitors to see how science can extend from the school environment through to home and the local community. Achieved by providing consistent visual appeal and enhanced accessibility via different modes of delivery.
6. Family Science Skills, Knowledge and Qualifications: Provide opportunities for families to talk during and after their visit where they can share existing knowledge and experiences. Achieved by providing parents with conversation tools such as friendly visuals and accessible text to support engagement and build confidence.
7. Knowing People in Science-related Positions: Helping visitors to recognise people and jobs they already know of that are related to science. Achieved by providing content about everyday science skills that connect to their family and community.
8. Talking to Others About Science in Everyday Life: Promoting science-talk during their visit to the museum and sustaining this after they leave. Achieved through building

confidence, asking questions, making provocations and showing connections to day-to-day objects.

The eight key dimensions have been embedded into the design thinking of both the creative outputs and the evaluation strategy sand are referenced at necessary points in this thesis.

4.1.3 Identifying Audience Requirements

The Power Hall and The Science and Industry Museum Audience

The Science Museum Group (SMG) consists of five leading UK museums across the UK (Science Museum, National Railway Museum, National Science and Media Museum and Locomotion), all of which use the same, well-established audience segmentation model. This labelling system ascertains that visitors fall into one of eight categories according to their motivations, cultural attitudes and visiting behaviours (Science Museum Group, 2019c). The motivation-based model is grounded in the work of Morris Hargreaves McIntyre (empirically deemed to be sector-leaders in audience segmentation) and has also been implemented by other national museums beyond SMG (Science Museum Group, 2018).

According to SMG audience research, a large proportion of visitors to SIM (50% in 2018/19) fall into a category labelled as Engaged Community Drivers (ECDs), as shown in Figure 4-2.

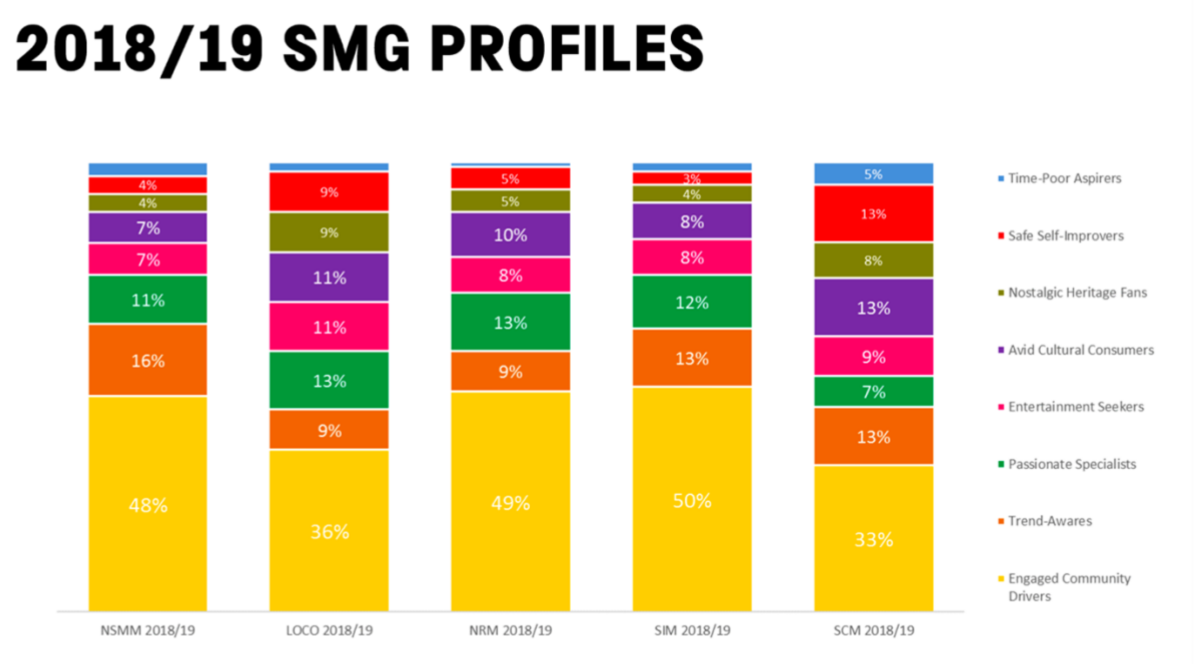


Figure 4-2: SMG visitor segment profiles for 2018/2019 (Science Museum Group, 2019b)

As a summary, these visitors are viewed to have several common characteristics:

- ECDs are on a general visit rather than looking to find a specific topic or object type.
- Mostly, ECDs visit as a family and 1 in 3 ECDs have a child aged 4 or under with them.
- They dislike elitism and exclusivity.
- They enjoy experiencing (and sharing) a range of experiences and enjoy being active and involved.
- Specifically related to SIM, approximately 50% of visitors in this category are from the Manchester area.
- A third of ECDs are on a repeat visit to the museum.
- 15% of ECDs are classified as Black, Asian and minority ethnic.

Following the wider organisational direction, the SIM Content Team have defined **families within the EDC segment** as the target audience of the proposed interactive interpretation concepts for the Power Hall, and therefore the audience of the prototypes developed in this practice research. This focus on families is also in line with the team's verbalised interest in intergenerational engagement and opportunities to encourage dialogue between adults and children. This information was highlighted during numerous ideation sessions and meetings with the SIM content team throughout the initial months of the project and connects to the theoretical framework of science capital and social constructivism outlined in section 3.2.2.

ECDs are clearly a broad demographic to target with few boundaries or ethnographic eliminations. This blanket grouping integrates children of all ages who of course have a wide degree of developmental disparities. For methodological alignment, the research and SIM Content Team defined family groups that contain primary school-aged children (**four to eleven years)** as the specific focus of our research and interpretation work. The researcher felt that this distinction was necessary in order to funnel the content delivery, tone of voice and user experience but still provide enough breadth to achieve the greatest value, accessibility and outreach from a single interpretation opportunity within an 'open for all' gallery. Exhibition budgets and limitations on space mean that individual interpretation installations must work 'smart and hard' to successfully satisfy the engagement needs and expectations of a variety of visitor types (Hawkey, 2006). As discussed in the review of literature, this can be a fine and delicate balance – if the interpretation method looks too childish this can put off older children and give a signal to adults to step back and not get involved; too mature and children are likely to not engage at all (Luke, 2017; Wolf & Wood, 2012). The prototype ideas described in this report attempt to meet these accessibility challenges through scaffolding opportunities, layered content, and widely appealing interactions.

An important goal of SIM's principal reinterpretation work for the Power Hall exhibition space is to promote an inclusive and accessible environment. By finding a catchment compromise between the broad EDC demographic and a less flexible, age-specific target audience, for example, the more traditional category of 'Key Stage Two, seven to eleven year-olds', the researcher proposes the engagement of a wider number of families, and to support those who may be visiting with children of varying ages and educational requirements. Research supports that families need flexibility to accommodate their variety of needs (Falk et al., 2012) this makes designing for public spaces particularly challenging. Equally, the researcher also wanted to make sure that interpretation solutions do not exclude or alienate visitors without children. During this period of audience definition, the researcher and the SIM Content Team compiled a set of defined objectives related to accessible UX design to support family engagement. This was theoretically and conceptually informed not only by the researcher's commercial practitioner experience but also by SMG brand toolkit (Appendix H) and further research into the museum visitor experience (e.g. Falk et al., 2012; Hawkey, 2006; Henson, 2016; Luke, 2017; Wolf & Wood, 2012). The collection of key design objectives used as a starting point for the design interventions are outlined below:

- The text should be used only where necessary. Any text that is deemed necessary should be carefully considered and should be written in child-friendly, accessible language that does not need to be 'translated' by an adult (Henson, 2016; Science Museum Group, 2022b).
- The interpretation should be intuitive to use and not require the user to read detailed instructions prior to taking part. Through an easy-to-use interface the installation should support different levels of engagement (Hornecker & Stifter, 2006, p. 141)
- Friendly visuals should be used to help convey information and promote joint attention and shared cognitive engagement (Povis & Crowley, 2015, p. 168). This

may act either in support of, as a substitute for, text copy. Graphics and illustrations should not be overly childish for adults to feel comfortable engaging with the interpretation concept. Equally, they should also not be too serious or mature (e.g. Henson, 2016; Schaller et al., 2002).

- Visuals and colours should be bold and eye-catching but not paramount to functionality. They should also adhere to the SMG brand guidelines (sample pages seen in Appendix H).
- Physical features of the interpretation should be accessible by individuals of varying heights, dexterities and physical abilities (e.g. McKew, 2022, p. 9).
- Consider short attention spans and busy visit schedules, families are often pressed for time (Henson, 2016).
- Use audio to enhance content and to augment interaction, however background noise needs to be considered and duration must be less than two minutes (McKew, 2022, p. 10)
- Allow for agency and enable visitors to work at their own pace. Interpretation concepts should be designed with layered content so that the visitors can decide on their own level of interactive engagement or how much they want to gain from the experience (Limerick et al., 2014).

The Science and Industry Museum works hard to enhance experiences for all its visitors in the hope of creating happy and satisfied individuals who will come back again for a return visit or at least share their good experience with others. Consideration for the visitor experience has been written into the heart of the 'Gallery Interpretation Plan' which was collaboratively developed by the SIM content team throughout the duration of the researcher's first year. Below are the key extracts from this active document (Chatfield et al., 2020), which are particularly pertinent to the digital interactive installation and feed directly into the prototype ideas and developments:

> The Power Hall will deliver a fully accessible experience, both intellectually and physically. The text will be written and presented in a clear, accessible, and non-technical way. (p. 3)
>
> The sensory nature of the gallery, with its atmospheric noises and many tactile opportunities will capture the imagination of all visitors but lends itself well to an

especially rich experience for visitors with visual impairments. Creating a social space where intergenerational conversation is encouraged and facilitated will make this a comfortable gallery for a broad range of visitors to spend time. (p. 3)

We inspire futures by:

Creative exploration of science, technological innovation and industry, and how they made and sustain modern society.

Building a scientifically literate society, using the history, present and future of science, technology, medicine, transport and media to grow science capital.

Inspiring the next generations of scientists, inventors, engineers and technicians. (p. 4)

All gallery interpretation will be open for all, guided by the concept of science capital. This approach will help visitors feel science and engineering is for them and that they are welcome. (p. 6)

Since the creation of this document (and other thinking around the interpretation of the gallery), elements have changed with regard to the wider museum direction due to numerous uncertainties around funding, budget allocation, team restructures and gallery opening delays. Despite this ambiguity, the target audience and the interpretation goals of the Power Hall have remained resilient and have enabled an exploratory and experimental approach to research and ideas.

4.1.4 Generic Learning Outcomes

Generic Learning Outcomes (GLOs) are widely recognised as a way to plan and measure the types of learning that takes place across museums and the cultural heritage sector (Hooper-Greenhill, 2004). During the research time spent at SIM, the content team were developing and fine-tuning a defined set of visitors' learning outcomes concerning the Power Hall and more specifically the 'Making More'[1] area of the exhibition. A GLO document developed by the content team can be seen in Appendix J and have been summarised below.

Making More will facilitate visitors to:

- Be amazed by the scale and variety of engines made in Manchester.
- Use their senses and skills to actively engage with the phenomena on display.
- Achieve an understanding of how engines work.
- Develop their understanding of how engines affect people's lives.

The Generic Learning Outcomes for the Power Hall have been designed to fit the five categories of learning:

- Knowledge and Understanding
- Skills
- Attitudes and Values
- Enjoyment, Inspiration and Creativity
- Activity, Behaviour, Progression

This clearly defined list will be used by the museum team in the future to measure impact and help identify the benefits that visitors may experience whilst participating in the gallery experiences.

4.1.5 Personas

As outlined in the methodology (3.3.1.2), based on the wealth of existing knowledge regarding SIM visitors and SMG audience segments, the method of creating user personas was utilised to support and sustain a human-centred approach to interactive interpretation design. It was an especially valuable step in this study as it allowed the researcher to consider children's actions and behaviours which may differ from the already well-studied parental/adult motivations and visitor behaviour. The researcher undertook a period of observation 'on gallery' (lasting one hour) where she took inspiration from real-life visitors

[1] The 'All shapes and Sizes' compound of engines is a sub-category of the 'Making More' section. It is expected that some of these learning outcomes should be addressed by the prototyped solutions.

who matched the SIM audience segment. A collection of four child-based personas were created ranging from four to eleven years and included details of their visiting group dynamics. These tools helped the researcher to visualise, validate and scope the design requirements of the later proposed interactive interpretation approaches. They were used to visualise and acknowledge user expectations from the perspective of the target audience. An example of one of the representational personas used to envisage user engagement is provided below in Table 4.1 (three others can be found in Appendix G).

Table 4.1: Example persona information

Persona 1			
Age:	11	School Year:	Year 6
Gender:	Male		
Personality:	Quiet in public, loves model building and crafting. Interested in history and objects. Enjoys computer games, Lego and Star Wars.		
Motivations for visit:	Family trip out for half-term, looking to be entertained.		
Experience with technology:	Digital native. Quite tech savvy, has an iPad and a PlayStation which he regularly plays. Enjoys browsing eBay and Lego sites. Often uses multiple screens/devices at the same time (TV and iPad).		
Relationship to science:	Interested in science and has good understanding for his age but does not directly see anyone he knows as a scientist or engineer.		
Museum visit group:	With mum and sister.		
Profile:	Noah is eleven years old and lives with his parents and sister in South Manchester. He loves technology and devices and is comfortable with technology. He likes to watch TV and browse on the iPad looking at		

	sites like eBay, brick link and Lego. He watches 'how to' videos on You Tube and likes to craft and create models. He enjoys creating costumes and researching ideas for accessories. He is not sporty or allowed to play out alone so does spend a lot of time indoors. Weekends usually involve family dog walks and visiting grandparents and aunts. He likes to experiment with making music on garage band and creating home videos.
Goals and Pain Points:	Wants to be entertained, to do hands on activities, to have fun. Does not like spaces that are too busy and overcrowded. Anything that could be considered a bit scary like loud noises. Does not like to read information or labels. Does not want join in large group sessions.

The personas were used to visualise and discuss how the individuals might engage with the concept ideas. For example, what would their attention span be like? Would they dive into the interaction or use it more tentatively? What elements of the design might capture their interest?

4.1.6 External Research

Despite the COVID-19 pandemic and the sudden closure of museums (and much of the world), most of the research into existing steam engine science interpretation was forced online. However, several particularly influential museum visits did manage to take place such as to the Etruria Industrial Museum where the famous Princess engine was seen 'in steam' and their collection of steam engine interpretation was explored. The researcher also joined an educational session at Middleport Pottery to see the Duchess steam engine in action and to observe how the mechanics and processes were explained to young visitors. However, it was an inspiring visit to the Thinktank (part of Birmingham Museums) that had the most significant impact on the practice of this study. An overview of the fieldtrip is summarised in Appendix K.

In summary, the researcher perceived the Thinktank' 'Power Up' exhibition as a vibrant and interactive space that managed large volumes of people and audience flow particularly well. The exhibition featured a wide range of interactives many of which contained digital components. Of particular interest were the interactives which combined the use of digital and physical elements.

The researcher's key insights that helped to inform the practice of this study were:

- Any written guidance should be seamlessly embedded as part of the interactive rather than a label on the side, which is too easily ignored.
- User interfaces need to be incredibly robust in order to withstand the vigorous and intense usage of a public exhibition.
- Related to considerations of scale, it was observed that when engaged with an especially large interactive interpretation installation, visitors might not make complete logical connections with the content that is out of view. A more compact approach might work better so that all aspects of the interactive are in sight of the user.
- Engagement feedback needs to be obvious and immediate to support positive user interaction.

This was an extremely influential and helpful visit but most importantly it reinforced the need for more emphasis on human connections within STEM interactive interpretation prototypes. The researcher considered that this would make engineering processes more relatable to real life and to people not at all familiar with steam engine science. It also emphasised the necessity of bringing forth the consequence of user engagement and interactions for valuable feedback purposes.

4.1.7 Collaborative Partner Observation – Ethnographical Reflection

Despite extensive visitor statistics and existing knowledge to draw upon which provided the foundations of the design project, there were several unknowns related specifically to the Power Hall reinterpretation. As the researcher attempted to move forward with the design problem and the formulation of ideas for interactive interpretation, there were many project-based elements still undefined throughout the course of the practice research. Grey et al. (2006), in their ‘Saying it Differently’ handbook for museums refreshing their displays, explain that gathering baseline information should be supported by ‘discovery questions’ which help the team to agree on parameters from the onset. They suggest some example primary questions to be:

> What is the scope of your project?
>
> What is your known budget?
>
> What is the timescale for delivery?

Due to unforeseen circumstances during the time of this CDA (including a Power Hall ‘exhibition development pause’, budget uncertainties, COVID-19 disruptions and changes to SIM leadership structures), the answers to these fundamental questions remained unresolved. For this reason, most of the considered ideas were generated with a degree of caution, specifically where costs were concerned. In addition, there were several other significant unknowns applicable to the specific nuances of the project such as:

- How many engines will be running in the compound and the exhibition, if any? This not only affects the visitor experience and the requirement for animated simulations of working engines but will also impact noise levels within the exhibition space.
- What other forms of interpretation will there be in the Power Hall? The researcher was keen to establish this information in order to create more variety in the exhibition space.

Nevertheless, these uncertainties did not hamper the design process considerably. Budget constraints encouraged more creative thinking and resourcefulness around the themes of materials and technology, and the lack of existing plans for other interpretation allowed content ideas to have more freedom and flex. This contemplation around the distinctions, limitations and challenges of the project can be seen in more detail Chapter 6: of this report.

An element worthy of further critique at this point is the observations made about the influencing groups and bodies currently (at the time of research) shaping the pathway of the Power Hall reinterpretation project. Throughout the twelve to eighteen months of working alongside the content team at SIM, numerous potential interpretation ideas were discussed and grappled with. This highly formative process had many moving targets stemming from a mixture of influential steers from higher up in the organisation. Efforts and adjustments were made to regulate the fundamental research questions in response to themes and debate from the ongoing development of the content teams' interpretation plan, workshop sessions and discussions. It was considered vitally important for the authenticity of the CDA that the practice research aligned and responded to the demands of this real-life, industry-based inquiry. A diagram was created by the researcher (as seen in Figure 4-3) to visually describe the significant influences on the SIM gallery interpretation installations, from the starting point of 'interpretation ideation', moving through to 'prototyping and testing' and concluding with 'concept realisation'. It has been designed to demonstrate the complexity of this present project ecosystem and shows the many steering factors and influential components impacting on interpretation themes, approaches and installations.

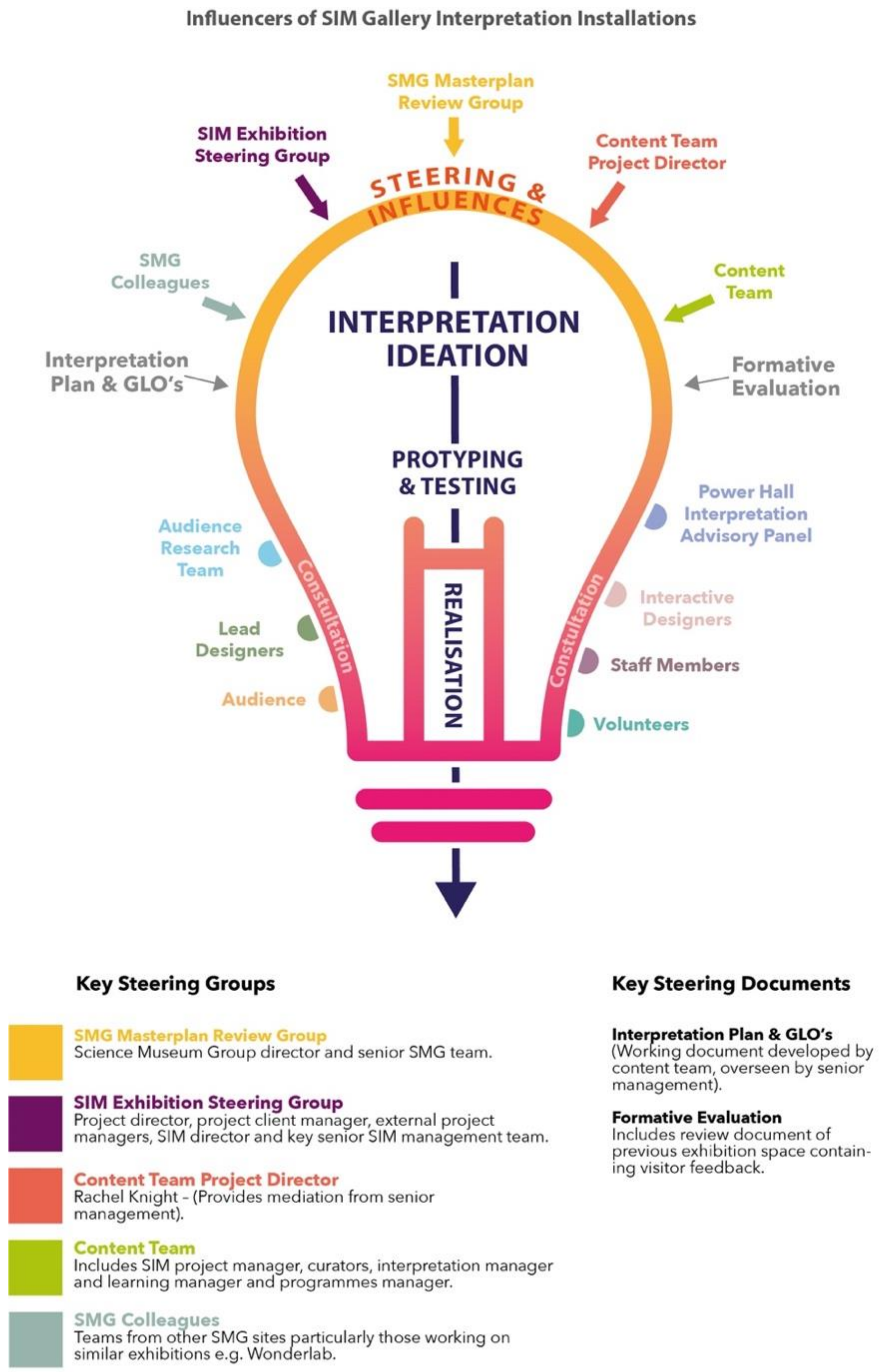


Figure 4-3: Influencers of SIM gallery interpretation installations (infographic created by Christina Buckingham)

Figure 4-3 was formed and populated by the researcher to describe the lived experience and empirical research during the year of the CDA. Being immersed within the museum environment, it became apparent to the researcher that besides relatively small focus groups, visitors were not usually involved in the creative process until a firm interactive interpretation idea had been generated by the interpretation team and a designer/developer had been contracted. Then, in a traditional SMG workflow, the agreed external supplier would work with the museum audience research team to prototype and rigorously test functionality and usability. Appendix L shows a recent interpretation workflow diagram created by a SIM research academic which was used to develop a new installation for the Textiles Gallery. This provides a demonstration of the current lifecycle of interactive interpretation development. As an alternative approach, the researcher was keen for the workflow tactic of this project to be more playful, exploratory and collaborative, and the researcher was eager to involve the target audience at the earliest opportunity using prototyping techniques to compare multiple interpretation approaches and technologies in answer to a single brief.

4.1.8 The SMG Approach to Prototyping – Ethnographical Reflection

To add further detail to the findings of 4.1.7, the discovery phase was continued by becoming familiar with the specific SIM and SMG approach to interactive interpretation prototyping and user testing. Informal discussions were held with the Senior Audience Researcher, Bethan Ross at SIM and five online discussions between April 2021 and September 2021 were held with Dafni Konstantinidi Sofrona, a member of the audience research team at the London Science Museum, to gather information and advice about interactive interpretation prototyping and user testing, and to report on this current project's developments. This was an important step to not only gather information about existing strategies but to also ensure the validity and rigour of the developing approach of this study. The audience research team members were highly experienced, knowledgeable and thankfully, willing to share details of their techniques and practices. It was discovered that SMG and SIM do not strictly have a standardised procedure for user testing. Audience researchers expressed that tailored solutions were generally created according to the demands, requirements and learning outcomes of the project. Information was shared in the form of PowerPoint presentations that had been produced for previous dissemination within the SMG organisation. According to the audience researchers, methods of evaluation and data collection currently consist of semi-structured observations and interviews. These are undertaken in small numbers and in-depth, until they see trends and find out why they are happening. The SIM and SMG audience researchers reported evaluation as time-consuming and analysis of detailed qualitative data, whilst informative, can be very cumbersome and difficult to decipher. As outlined in 4.1.7, an important finding from the SIM audience research team was that prototyping and target audience participation commonly takes place after a period of input and influence from SMG review groups, exhibition steering groups, exhibition content teams and interpretation advisory panels. A design brief is then defined, and the exhibit design team is commissioned. Usually, this is followed by the production of three iterative prototypes each produced two weeks apart by the commissioned exhibit design team which are then tested with the target audience at the museum site by the audience research team. Feedback is provided to the exhibit design team ready for the next iterative phase of user testing. This can be seen visualised in the presentation slide screenshot below (Figure 4-4) which the audience research team shared to demonstrate the usual proceedings.

Figure 4-4: Screen grab from Science and Industry Museum audience research dissemination presentation entitled "Introduction to Prototyping"

The SIM Senior Audience Researcher explained that the first prototype falls into the category of low-fidelity prototyping usually consisting of a string and paper mock-up. The second and third are more advanced iterative prototypes focussed on evaluating aims and objectives with scope for changes built into the development process.

On reflection of these perspectives, the researcher of this study saw an opportunity to investigate a more creative process of comparative prototyping and a method of supporting participatory design and early user consultation. In turn, the researcher also became interested in whether discourse analysis targeting science capital-based utterances and conversations between users could be used as an effective and efficient prototype evaluation method compared to semi-structured observations and interviews.

4.1.9 Sketches and Preliminary Ideas

Also positioned during the discovery phase was an ongoing series of sketches and preliminary ideas created to communicate the researcher's early thoughts on the wider design problem. Initial ideas first took the form of simple sketches to communicate and brainstorm interactive interpretation concept ideas to the SIM Content Team, promote stakeholder discourse and explore potential avenues of development. This took place before the production of a firm design brief, the PACT analysis (4.1.10) and the product requirements document (4.1.11) but it is useful to share a few of these ideas here to demonstrate the initial starting points of the practice research.

Preliminary Example One – Technician's Tinker Table

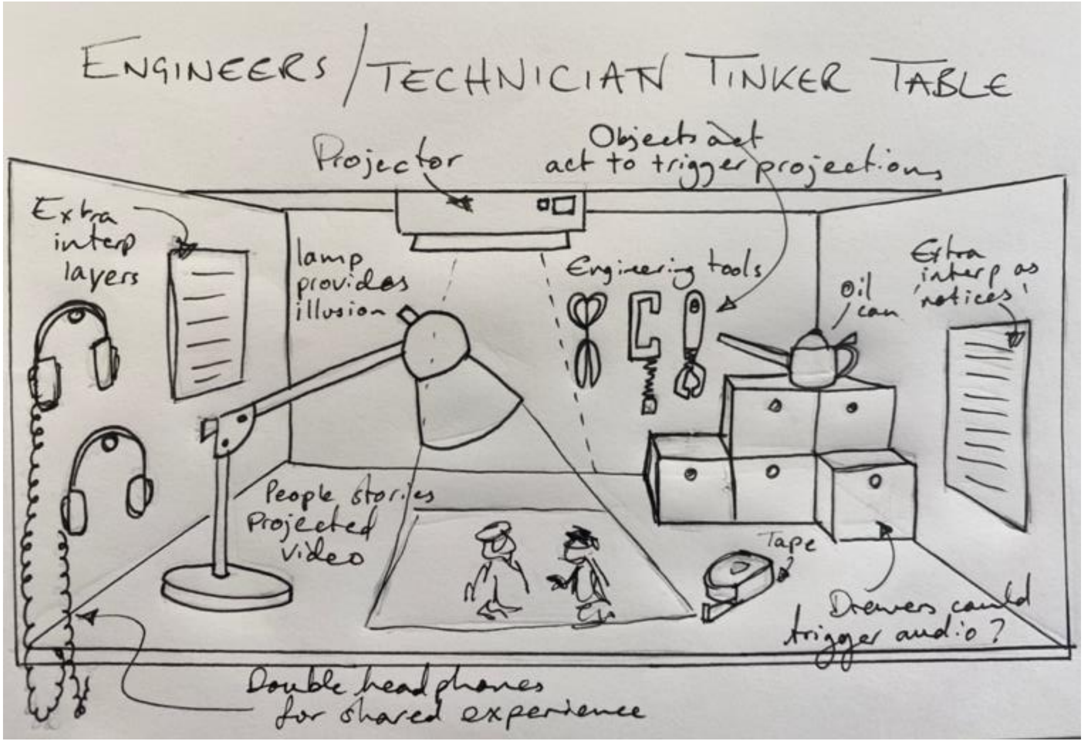


Figure 4-5: Sketch of preliminary idea one – Technician's Tinker Table (sketch created by Christina Buckingham)

Overview: An initial idea for a technician's tinker table involving tactile objects as digital triggers for projected video footage of engineers and sounds of the Power Hall environment. This was created as a response to direction from the SIM Content Team who were interested in ways to raising the profile of transferable, technical tinkering skills and sharing authentic stories.

Concept: Visitors could sit at the tinker table, put on the headphones and become immersed in the environment of a steam engine technician. A selection of 'tools' from the hanging display could be placed on the trigger point to deploy (using RFID tags and readers) projected video footage of engineers and technicians sharing their stories or information about their job roles. Playful, exploratory options would encourage visitors to lead their own interpretation journey about human stories in the Power Hall.

Preliminary Example Two – Interactive Engine Roleplay

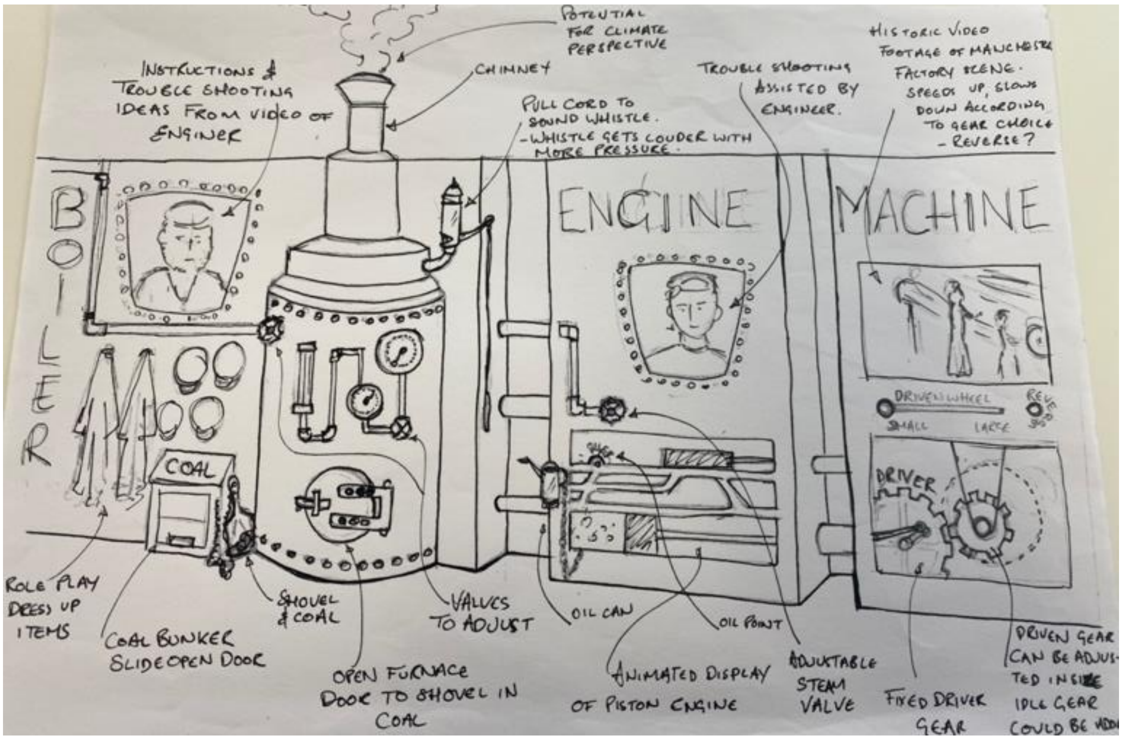


Figure 4-6: Sketch of preliminary idea two – Interactive Engine Roleplay (sketch created by Christina Buckingham)

Overview: An initial idea for an interactive steam engine wall involving hands on role-play with RFID tags to instigate animated features on embedded screens. This was created as response to SIM Content Team discussions of how the exhibition might inspire skills such as problem solving, critical thinking, clarifying and checking.

Concept: Visitors could pretend to shovel coal into the furnace to trigger the engine system into action. They could 'problem-solve' errors by listening to the technician on screen and use the oil can and valve to trouble shoot issues and set the piston moving again. Animations could show the flow of steam around the cylinder. Playful features could be included like pulling the chain for the whistle, spinning dials and gauges, dressing up in an engineer's costume/hat or sliding a lever along to change the size of the belt connection wheels which in turn would make video footage of people working in factories go faster or slower.

Preliminary Example Three – Interactive Gears and Belts

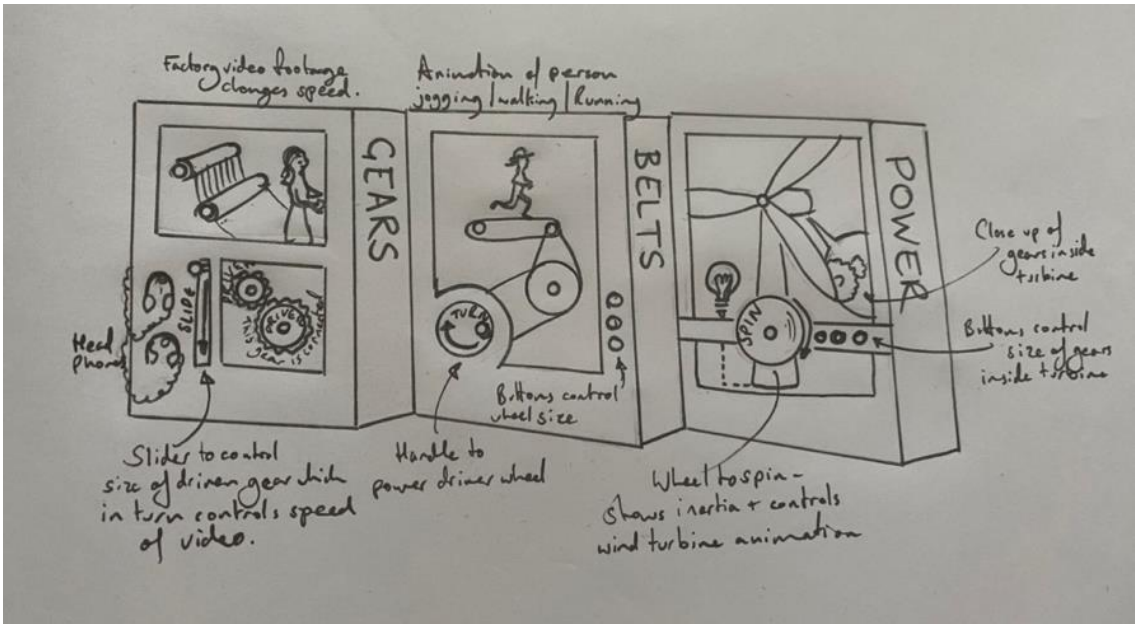


Figure 4-7: Sketch of preliminary idea three – Interactive Gears and Belts (sketch created by Christina Buckingham)

Overview: A large freestanding panel broken into three sections. Users experiment with dials, buttons and levers to change the size of driven gears which in turn has resulting effects on videos, animations and music.

Concept: On the first 'Gears' panel visitors slide the lever up and down to change the size of the driven gear, this then effects the speed of the factory video footage and music. On the 'Belts' panel visitors wind the handle to turn the belt on the treadmill. Buttons can be pressed to change the size of the belt wheel which will make the person walk, jog or run accordingly. On the third 'Power' panel visitors spin the dial to set the turbine spinning. Buttons can be used to tinker with the size of the gears inside the turbine. This in turn impact the brightness of the lightbulb.

The preliminary ideas and sketches shown above were an initial step, used to examine, discuss and explore ideas. Some of the sketches were used in combination with the user personas (4.1.5) to begin to visualise how different users might engage with the concept ideas through the process of descriptive 'user scenarios'. This creative strategy helped the researcher to visualise how the concepts might be interacted with by different users. An example of one of the scenarios for the ‘Noah’ persona described in section 4.1.5 is provided in Appendix M.

4.1.10 PACT Analysis

After the early fieldwork and influenced by the exploratory research taking place at SIM, the industry supervisor was able to provide the researcher with a design brief (see Appendix A) to bring more focus to the generation of interactive interpretation concepts. This briefing document helped to hone the direction and objectives of the practical work and gave much more focus to the broader theme of the Power Hall. It gave the researcher the capacity to develop a People, Activities, Contexts, Technologies (PACT) analysis to further envisage the target audience and context of the Power Hall interpretation.

PACT Analysis: People

The Science Museum Group have identified that the majority of visitors to SIM fall into the category labelled as Engaged Community Drivers. The Power Hall exhibition team would like to encourage a particular group within ECDs; families with young people/children. The team aspire to make families feel welcome, excited and engaged with the exhibition content and gallery objects using enhanced interpretation and hands-on STEM opportunities.

As well as visitors to the exhibition, other people to consider in the project development are exhibition stakeholders and sponsors, exhibition designers, gallery maintenance teams, museum volunteers, and visitor engagement team members.

It should also be noted that visitors to SIM could be tourists whose first language is not English, it is therefore particularly important that the interface is intuitive without heavily relying on text instructions. The basic analysis for Power Hall PACT is as follows:

> **Physically**
>
> The digital interpretation should be suitable for the widest possible range of ergonomic measurements ranging from four years to adult. As supported by Kennedy and Prager (2008), it is critical that environments and experiences are suitable for adults and children alike. All members of a family should feel comfortable taking active roles in participation. They also reiterate that where

possible modalities of interaction and control should err on the side of moderate scale and simplicity. Small pieces and loose parts should be avoided, moving parts and mechanisms must be carefully considered and any floor-based elements must be carefully planned to avoid stumbling hazards or impediments for wheelchair users.

The prototype solutions should ideally have multiple sensory inputs/outputs, making them more accessible for use by visitors who may have visual, hearing or sensory impairments, or physical disabilities. The interface must be easy to use by visitors who may be in a wheelchair or have mobility restrictions and it would be an advantage if the installation could be used by, or engage, more than one user at a time.

Psychologically

The target audience of the Power Hall is deemed as being generally interested in history, science and technology, it is likely that they will be motivated and will be in the mood to learn and engage. However, from an opposing perspective, the science-based content must be delivered at level that is accessible to a variety of audience ages, backgrounds and experiences. It should not be required that visitors should use interpretation installations in any specific order or have any prior knowledge or understanding of steam engine science. Families with small children will have come to SIM for a fun and educational day out; children may be excited and an effort should be made to hold attention and increase dwell time. Visitors may jump quickly from one form of engagement to another, and the installation should support the delivery of small snippets of learning opportunities without requiring visitors to dwell for more than two minutes at a time.

Socially

SIM has identified the Power Hall exhibition as an opportunity to significantly improve their family offer, broaden equity and diversity and encourage intergenerational activity and conversations. SIM would like to, where possible, demonstrate the dynamic relationship between human and engines and have suggested that the engine interpretation should ideally feature a human figure to emphasise this. It could also help to place the engine in its 'real-life' setting.

SIM has identified that their target audience profile is typically confident, sociable energetic and expressive. They like to get involved and enjoy hands-on interactive experiences. If they have an enjoyable time, they are likely to make return visits and may choose to share their experience through social media or talk about it with friends.

In connection with science capital, the exhibition approach should be designed so that visitors are likely to feel that engineering is for them and that they are welcome and comfortable in the gallery space. It should be an opportunity for visitors to identify themselves in the gallery interpretation and show how engineering is connected to their own lives. Together the interpretation opportunities should strive to shape attitudes towards STEM.

PACT Analysis: Activities

During the course of the data gathering process, the researcher and collaborative team have identified the following activity requirements for the proposed interpretation.

- The interpretation should illuminate five key mechanical aspects of an engine, how they are connected and how they function. The mechanisms/parts at the centre of this design task are the cylinder, crank, flywheel, governor and belt connection.
- Visitors should be encouraged to observe the physical engines on display and identify the five key parts of the engines within the compound and throughout the exhibition.
- The interpretation should give visitors an opportunity to physically engage with the interpretation in order to make deeper and more meaningful connections with the STEM/engineering processes.
- Considerations must be made for minimal contact opportunities or hygiene-friendly interactions that can be easily cleaned.
- The interactive should be inherently playful with scaffolded opportunities for engagement suitable for a wide range of age groups.
- The interactive interface should display clear user feedback at all times.

- The STEM approach and activities should build on a visitors' prior knowledge or experience and will help to reduce a possible perceived intellectual distance between themselves and the engine objects.

PACT Analysis: Contexts

The interpretation needs to be developed for the 'All Shapes and Sizes' compound of five engines which is centrally situated in the 'Making More' area of the exhibition. The space allocated for the interactive installation is very restricted therefore the proposed solution(s) can take up little/no floor space. Visitor flow and movement around this compound should be prioritised for peak times to avoid people traffic congestion. The opportunity to create an immersive, full-body experience in the given area is very limited and effort will need to be made to make the interactive installation compact. Figure 4-8 shows a map of the gallery space and the location of the 'Making More' and 'All Shapes and Sizes' compound (indicated by the blue box label).

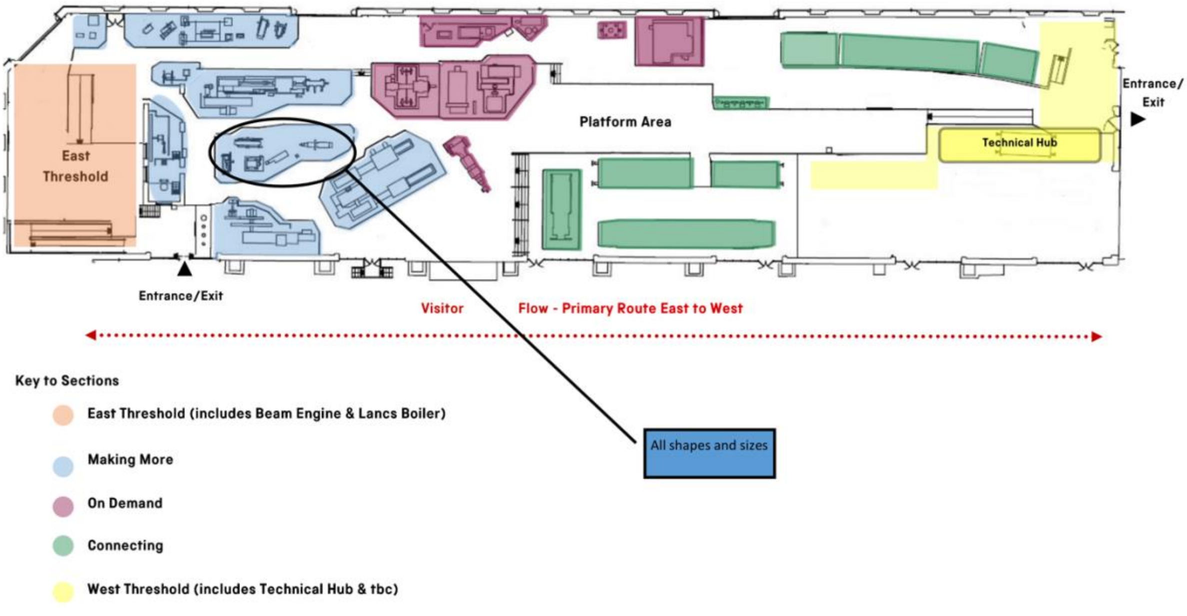


Figure 4-8: Visitor Journey Diagram; Adapted from the 'Power Hall Interpretation Plan' with permission from Kate Chatfield (SIM Interpretation Manager)

There is currently no dedicated wall space to hang or display screens or large interactive elements, and vistas across the gallery need to be maintained. However, the content team would like the interactive to be a visual attraction to draw visitors towards the compound.

Railings surround the engine compound and therefore could offer the opportunity to attach fixtures or build in panels if required.

Light levels in the exhibition space can be unpredictable but it is mostly a reasonably bright space due to the large expanse of windows, for this reason, projected displays should be supported by high-quality short-throw projectors. Humidity levels in the space may also form a challenge as there are plans for at least one steam engine in the exhibition to be running at all times. In addition, working steam engines can be incredibly loud therefore the interpretation interface should only use audio to enhance the user experience and not rely heavily upon it.

Often, especially during the holidays, the museum spaces can get extremely busy and the interactive should cater for intense usage. It should be robust enough to withstand heavy-handed, repetitive play.

PACT Analysis: Technologies

As a SIM content team preference and supported by research (Parry, 2010), technology (in particular screens) should only be used with careful consideration. Digital interactives must offer clear advantages over other alternatives. The Power Hall project management and interpretation team have not provided any preference or specific lead with regard to the type of technology they would like to use, however, it must be accessible and inclusive to the widest possible range of audiences. The Power Hall will be staffed, but in most instances, the visitor should be able to use the interpretation installation independently without assistance and the technology must be able to withstand intensive and rough play.

The gallery will have a ten to fifteen-year lifespan and consideration should be made about whether the technology or the interactive will need to be updated. Although a budget for the project has not yet been outlined and are still under review, keeping project costs low is a key consideration.

4.1.11 Product Requirements Document

As described in section 3.3.2.2 this live and dynamic document has been used to define the value and purpose of interpretative productions and to improve communication with SMG stakeholders and the Power Hall Content Team. The content of this document (created shortly after the delivery of the brief) can be seen below and provides a key point of reference for the generation of further design ideas.

Product Requirements Document

Product goals and objectives

- To recognise that engineering and tinkering is something a visitor can do... Encourage an 'I can do that' attitude.
- To emphasise the relationship between engines and humans.
- Encourage intergenerational conversations and dialogue between visitors and allow for a group to gather around or engage with the installation or interactive.
- To facilitate reflection about the cultural and environmental impact of the human-engine relationship.
- To express the logical and problem-solving skills that are important for the upkeep of engines.
- To encourage visitors to the Power Hall to use their senses and bodies to interact with machines and gain a deeper understanding of the skills required to run the mill engines.
- To make the theme of steam engines fun and accessible to reluctant learners and people with no prior interest.
- To enable visitors to understand the connection between water boiler, engine and machine but also value that they each are separate entities with different roles to play.

Target users

The Science and Industry Museum label its target visitor group as: Engaged community drivers. This is a segment that enjoys shared communal experiences. They have an appreciation of science and how it affects their lives, and they recognise that scientific understanding is important for themselves and their children. Engaged community drivers are looking for in-depth engagement through visually stimulating and immersive experiences. Their free time is highly valued and they try to squeeze lots in to make the most of it. They often visit museums with family and friends and expect everyone to be welcomed.

Research by SMG outlines that this segment of visitors is the most likely to be accompanied by children on their visit to a museum above all other groups. This emphasises the importance of digital curation to be targeted at families.

It has been identified that the main learning style of this group is visual and spatial, creating and interpreting through visual images and models.

Product features and functions

- The product must run in a standalone format without the need for assistance from gallery support.
- The UX must be intuitive and not require the user to read too many instructions.
- The product must be able to be reset easily or allow the new user to continue where the previous user left off without causing confusion or requiring prior knowledge.
- The product should allow for multiple users to enjoy the UX, sometimes as a family or with other general visitors during busy periods.
- The product should utilise as many senses as possible to emphasise the sensory experience of the engines.
- The digital curation interface should enhance accessibility by allowing for multiple information outputs such as sight, sound and touch.
- The interpretation should make it explicit that parts of the engine can be used to change the speed of a machine or the direction of force.
- The interpretation should show the key engine parts: The cylinder, the crank, the flywheel, the governor and the belt connection.
- The product should not rely solely on screen-based interaction.
- The product needs to be very robust and be able to withstand rough use.

Although the PRD changed somewhat during the course of the study, many of the key points held firm and both the PACT analysis and PRD proved vital to keep ideas on track and aid internal conversations with SIM.

4.1.12 Summary of the Discovery Phase

In summary, this section of the 'Presentation of Research' chapter has described the discovery phase which provided the important foundation of design research including ethnographic fieldwork, secondary data gathering and the creation series of project development documents. Several preliminary sketches were made in order to scope possible research pathways and to communicate thoughts and ideas with stakeholders. These essential elements of the design process laid significant groundwork for the forthcoming development and practice research phase by informing and enlightening the design thinking and in turn adding further validity to the creative outputs.

4.2 Development Phase (Practice Research)

This section aims to portray the practical approach to addressing the main research question concerning the development of interactive interpretation techniques to encourage playful engagement with steam engine science specifically in answer to the SIM design brief. The concepts described in this section are delivered in chronological order to expose the evolution and nuances of this dynamic and industry-grounded practice research.

Spending the initial months of the project embedded within the museum environment, gaining industry and audience knowledge (via the discovery phase), provided the necessary foundation for early interactive interpretation ideation. The design intervention starting points were initially provided by the literature research, stakeholder discussions, in-house workshops and existing interpretation inspiration. Subsequently the design brief, the PACT analysis and PRD provided a more assured course for the interactive interpretation concepts.

Unfortunately, a large proportion of the developed ideation and prototype creation phase was spent in lockdown due to the COVID-19 pandemic. The museum was closed to both the public and staff, with weekly team meetings had to be maintained online. Much of this period of practical development was conducted from the researcher's own home and, as the pandemic continued, led to experimenting only with prototyping techniques that could be created singlehandedly, in a limited resource/equipment environment. The advantage of this situation was that prototyping techniques could be presented as being realistic for a museum team to produce inhouse before the costly and restrictive stage of commissioning contractors.

4.2.1 Prototype Development

4.2.1.1 Prototype One: Hands-on Play Panel with Digital Enhancement

The first prototype developed as an initial response to the finalised brief was a hands-on play panel consisting of five moving components. It was designed to represent a tangible user interface of the five engine parts commonly found on steam engines throughout the exhibition: cylinder, crank, flywheel, governor and belt connection. The main objective of the installation was to encourage users to identify the parts on the historical engines and to understand how the different elements work in a tactile and visceral format. The idea for this design intervention was that visitors would interact with a 'playable' panel of colourful and moveable parts:

1. A large red valve to turn – representing the release of steam into the cylinder and starting the engine in motion (or stopping it).
2. A sliding bar to move in a linear action – representing the reciprocal movement of the piston.
3. A governor arm to spin – demonstrating the speed control of the steam engine.
4. A flywheel to spin – demonstrating the energy conversion to rotary motion.
5. A dial to turn – demonstrating the belt connecting the engine to the machines

Engaging with the playful elements on the physical play panel would in turn trigger a second level of information on a suspended AV display as the initial sketch in Figure 4-9 below demonstrates.

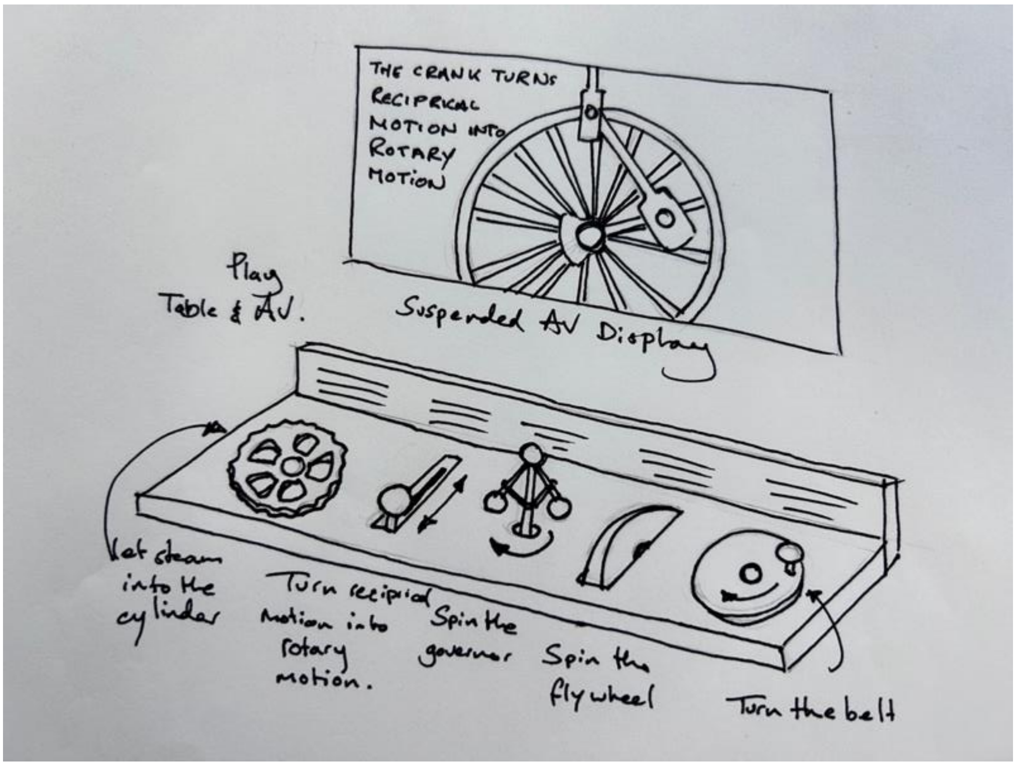


Figure 4-9: Initial Concept Sketch for the Hands-on Play Panel with Digital Enhancement

The researcher and SIM Content Team agreed that the playful, hands-on triggers for the 'All shapes and Sizes' interactive installation would be the central focus of the engagement. One of the biggest challenges in the interface design was dealing with the fact that each part is dependent on the other – an engine functions in a cyclic process and separating the parts out into their own entities proved particularly difficult but necessary. To promote the realism of the engine parts the researcher and the SIM Content Team discussed the following important points concerning the tangible triggers:

- They should be simple to use and fit with the visitors' mental model.
- They should look similar to the 'real-life' engine parts.
- The materiality and texture should be as authentic as possible.
- The nature of the engine part should be felt, such as the looseness of the free-spinning flywheel.

Adding to the layers of learning opportunities, spotlights could also be triggered by the play panel to indicate the 'real' engine part. These scaffolding opportunities offer multiple entry points to the interaction experience and help to increase the breadth of audience engagement especially for younger visitors (Wolf & Wood, 2012).

The researcher also explored some initial ideas for 'everyday relevance' examples related to the engine parts such as bicycle pedals and a fairground swing. These design ideas and approaches (which apply to all the prototypes created in this study) were informed by the theoretical underpinning of the literature review and the theoretical framework. Everyday relevance was utilised to support human meaning-making and discourse providing a catalyst for forming knowledge and meaningful museum experiences (Boger & Mercer, 2017; Haden, 2010). Silverman (1995, p. 165) states that through reference to familiar and relevant concepts, visitors can make personal connections. That connection itself can constitute as a meaningful experience, however, very often the connection lays the important groundwork for the visitors' learning process.

A preliminary wireframe document was created to flesh out thoughts and ideas around meaning-making and everyday relevance as seen in Figure 4-10 below.

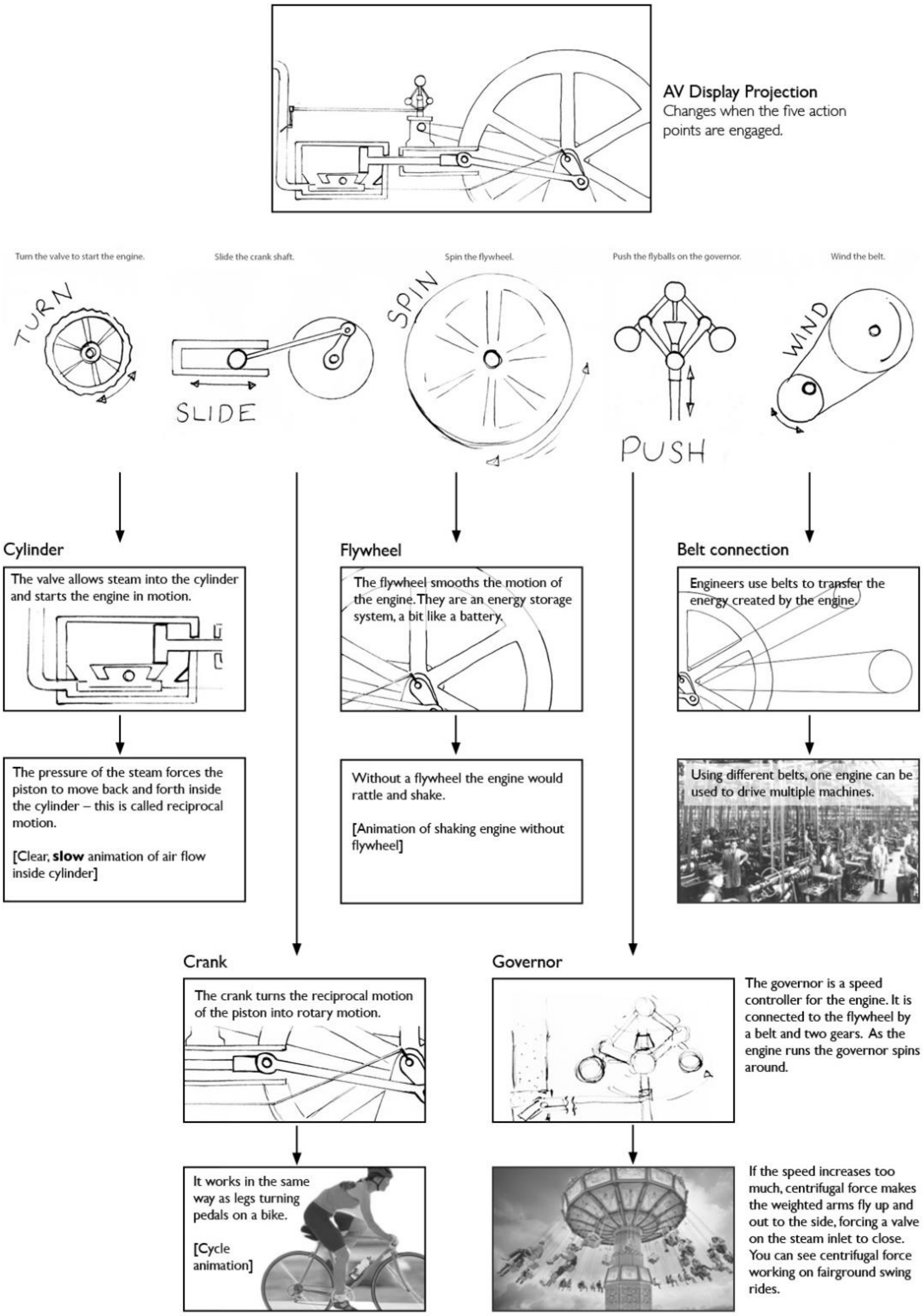


Figure 4-10: Illustrated wireframe document to support a discussion of AV ideas (created by the researcher)

Initial sketches progressed into paper mock-ups (Figure 4-11) and later, a more developed low-fidelity prototype created from mountboard for stability and split pins to explore movement and functionality (Figure 4-12).

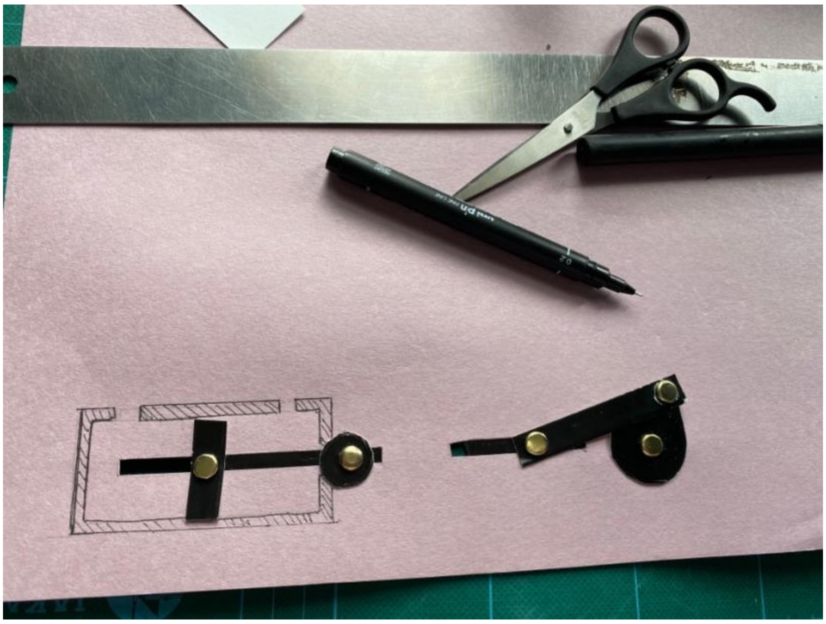


Figure 4-11: Play panel paper prototype in development

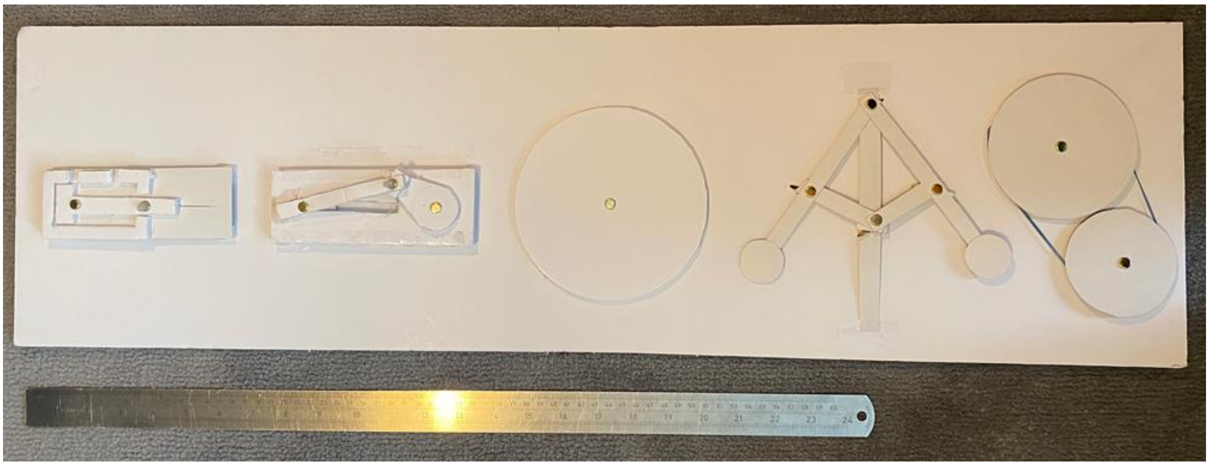


Figure 4-12: Developed larger working prototype for the tangible user interface (made from mountboard and split pins)

The prototype gave the researcher the opportunity to present and discuss design considerations with the SIM Content Team like scale and proportional sizing. Using split-pins, card and mountboard the researcher was able to demonstrate and discuss the movement and mechanisms involved in each part. The Learning Manager, Ruth Murray, was interested in how these moving parts could offer visitors the opportunity to experiment with the materiality and physicality of each part such as feeling the 'looseness' of spinning the flywheel compared to the laboured friction of turning the belt connection.

Using the low-fidelity prototype and the illustrated wireframe document, we were able to discuss important design elements such as:

- Where will the handle be? – Each of the five parts will need a clear call to action.
- What will they be made from? – Authenticity should be represented in the material choice.
- What AV will they trigger? – Each part will trigger an animated AV version with associations.
- Will more than one visitor be able to interact? – The AV display could split into sections depending on what part is being played with.

Using this proof-of-concept, an engagement diagram was used to plot the user journey and demonstrate the different levels of success within the interactive as can be seen in Figure 4-13 below.

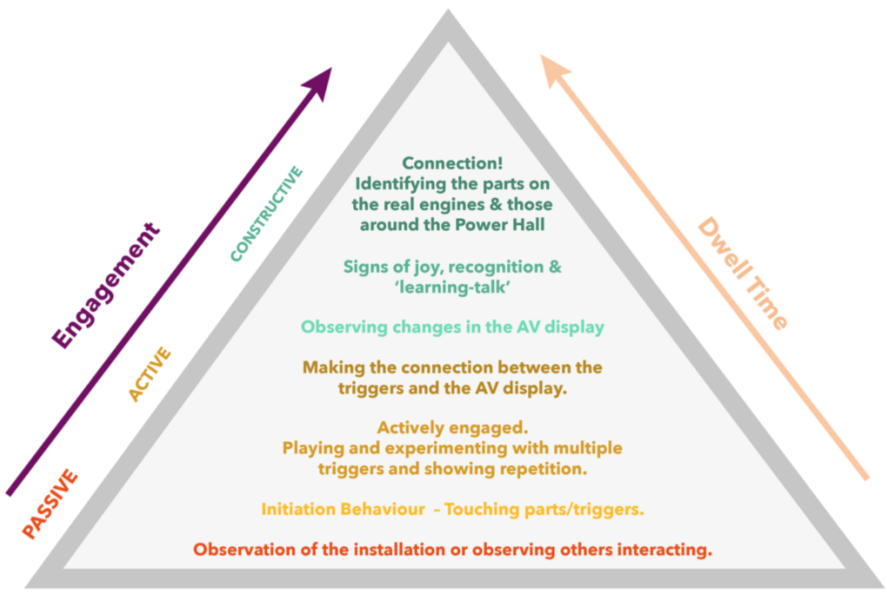


Figure 4-13: User engagement diagram for the 'All Shapes and Sizes' play panel proof-of-concept (infographic created by Christina Buckingham)

Also, as a proof-of-concept, the hands-on prototype was wired up with a Bare Conductive Touch Board, a power pack and speaker to demonstrate that, by interacting with the elements on the play panel, visitors could potentially trigger digital media. In the first instance, the interaction triggered a short audio piece explaining what the part was and its function (as seen in Figure 4-14). It was envisaged that this would progress to digital triggers for projection onto a display area or even onto the engines themselves.

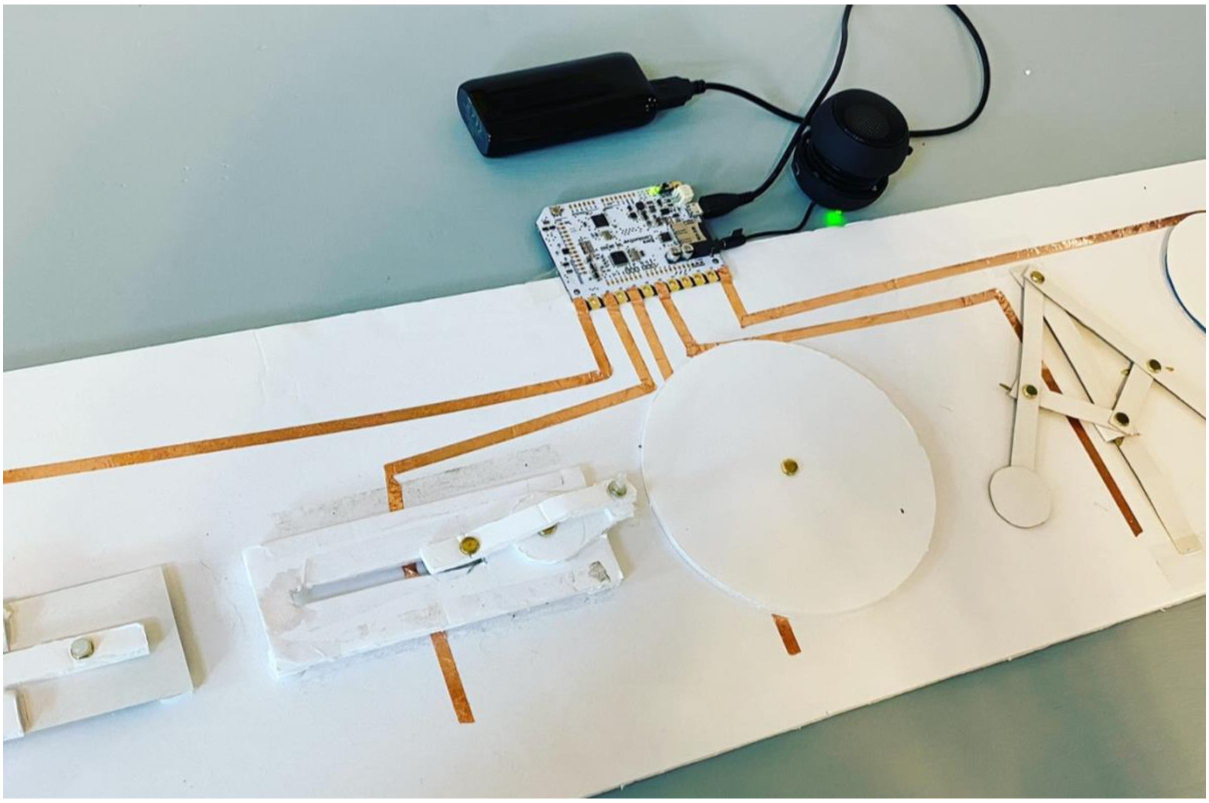


Figure 4-14: Prototype play panel wired up with Bare Conductive Touch Board to trigger audio.

In relation specifically to this prototype, the researcher made steps towards the aesthetical substance of the interactive digital display using the Grasshopper steam engine as an example. This engine was chosen out of the five because it had the most reference material available which was used as inspiration for illustration and animation. The researcher and SIM Content Team were keen for the digital content to be as inclusive as possible, in line with the science capital approach, and we were aware that the STEM narratives will need to be presented in a way that appeals to the widest possible audience, in particular families and young children.

At the time of research, the SIM Content Team were looking to utilise accessible illustrative techniques in the labelling and AV within the Power Hall as a whole. This decision was led by research already undertaken by the National Science and Media Museum for their Wonderlab exhibition, which in turn, will inform the new reinterpretation at SIM. In a report by their audience research and advocacy panel it was explained that the Wonderlab interpretation team took strategic decisions about their illustrative labels in an effort to engage a broader audience diversity and age range and to provide a real-life connection to the Museum's collection. An example of the illustration style used in the Wonderlab exhibition can be seen below in Figure 4-15.

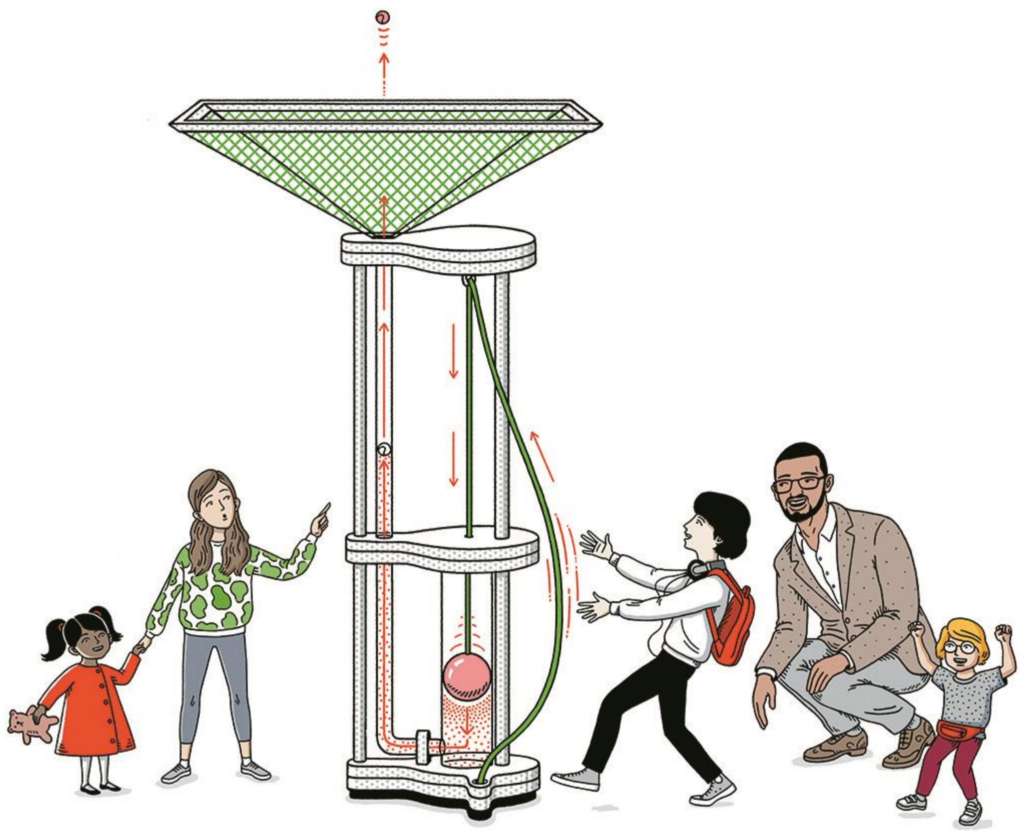


Figure 4-15: Example of the wonderlab illustration style developed by illustrator Andrew Rae retrieved from: https://andrewrae.info/The-Science-Museum *on 12.09.21. Copyright Andrew Rae (2020)*

Their use of a variety of people within the illustrations was met with positive review and some visitors commented on how the people on the labels reflected the audience of museum and the people of the city (Wood, 2017). The SIM Content Team and the researcher agreed that by depicting figures alongside the engine images was a good way to emphasise the human-engine relationship and to help to 'people' the gallery.

Following these discussions, two initial styles of animation were developed by the researcher and presented to the team (as seen in Figure 4-16 and Figure 4-17). These were then compared and discussed in detail.

Figure 4-16: Digital prototype: Vector style animated grasshopper engine created in Adobe Animate. https://youtu.be/GBAqvtHX7ts (animation created by Christina Buckingham)

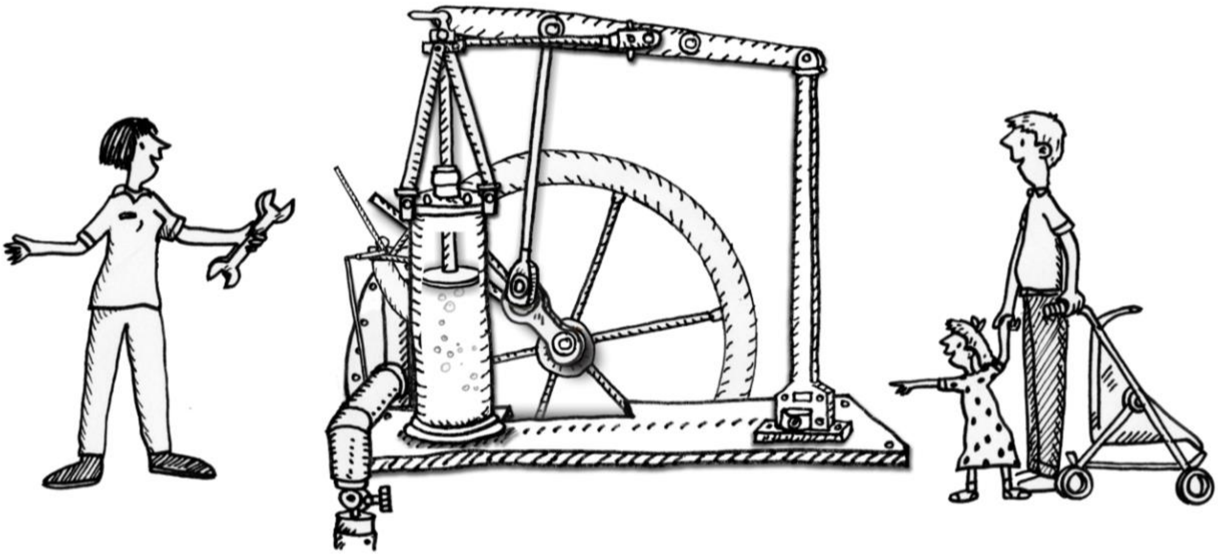


Figure 4-17: Digital prototype: Illustrative style animated grasshopper engine hand-drawn and animated in Adobe Animate. https://youtu.be/g9J_p2yodX0 (illustrative design created by Christina Buckingham)

The process led to a variety of experiments with presenting diversity and people in illustration form, as seen in Figure 4-18. The research and SIM Content Team discussed how this illustrative style could appeal to a wider audience and could be an area of formal research and investigation later in the project, building on the work conducted by the National Science and Media Museum for the Wonderlab exhibition.

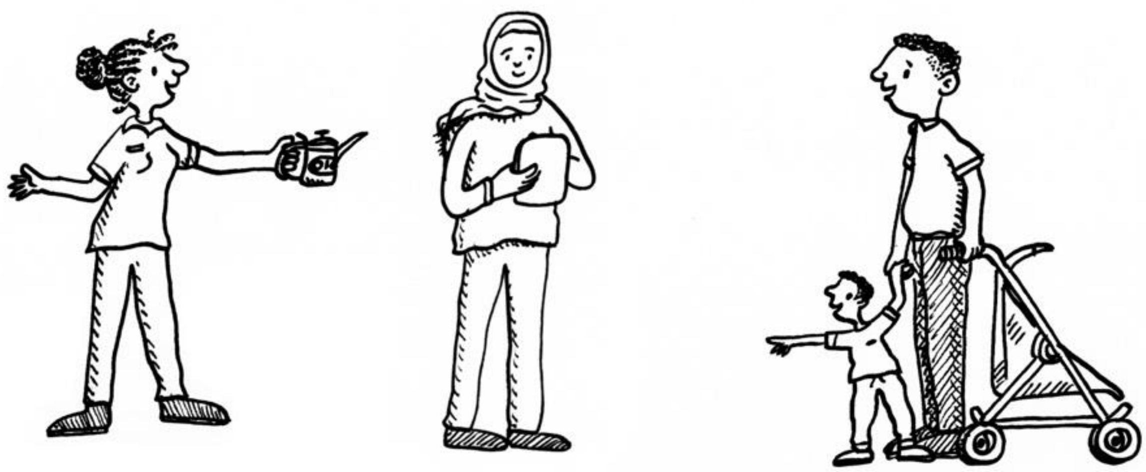


Figure 4-18: Experiments in diversity and the human-engine relationship in illustration form: Used as a conversational starter for discussions with SIM (illustrative design created by the researcher)

In addition to animation and illustration styles the researcher also made some preliminary experiments by projecting these animations onto different material surfaces such as metal, perspex and plywood. An example can be seen in this uploaded video link: https://youtube.com/shorts/GKK8RPx3NpM?feature=share. The researcher was interested to explore how she might utilise the benefits of working with digital technology such as animation but make the viewing experience more native to the environment of the Power Hall through the choice of physical materials.

As time progressed and COVID disruption continued, it became clear that it was going to be very difficult to test out this prototype with visitors. The biggest concern being that inviting visitors to touch the interactive would mean that it would need to be durable and easily cleaned. Without machinery and manufacturing expertise it was very difficult to pursue this avenue. A high-fidelity version of the prototype was not something that could be completed single-handedly from home during lockdown. Some time was spent trying to recreate the component parts with Lego, not only because this could be done from home, but it was also viewed as providing a good draw for younger visitors. Due to the nature of the material, a prototype made from Lego could be easily cleaned once the museum was open again for user testing. A sample of the Lego experiments can be seen in Figure 4-19, however, although the functionality worked well, it was difficult to make them stand up to repeated physical use. Gluing was not a good option due to the moving parts. The researcher and SIM Content Team were also becoming increasingly worried that when the museum opened again, visitors' engagement habits and preferences could have changed completely, and they may not want to touch anything at all.

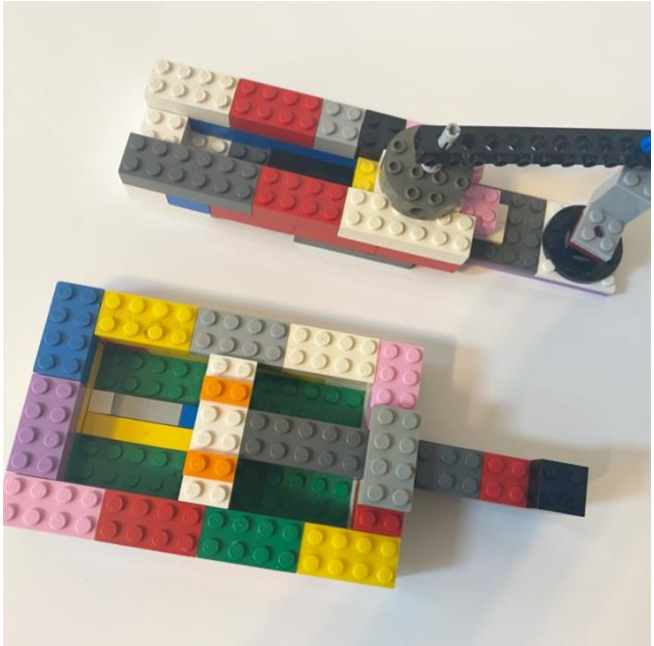


Figure 4-19: Experiments with Lego and replicating the engine parts.

Although this tactile, hands-on approach was put aside for the time being, a great deal of the ‘design thinking’, particularly around the interface and engine components, fed into the forthcoming prototypes.

4.2.1.2 Prototype Two: The Power Hall Online – A Digital Solution

Uncertainty around what museum interaction would become, considering the COVID-19 pandemic, led naturally to thoughts and online discussions about the possibility of creating an entirely digital and contact-free solution to audience engagement for the Power Hall. Although this was far from our original light touch (as defined by Donohue, 2017) plan for the exhibition interpretation, it seemed our only option at that point. A screen-based solution would offer visitors the opportunity to connect with the collection from an external environment, it could also have the future potential to function as an on-gallery touch screen which could be easily cleaned, or visitors could access it from their mobile device. The team also realised that an exclusively digital solution could offer excellent scope for COVID safe user evaluation, either through embedded cookies written into the code of the interface (for automated data collection) or remote evaluation via online observation and interviews.

The idea for this concept was to provide a collection of interactive pages where the user could explore the five engine parts by interacting with onscreen graphics in a playful way. The prototype was developed by the researcher in isolation with only online stakeholder collaboration from the SIM team.

After a period of functionality research and investigation, it was decided that the GreenSock Animation Platform (GSAP) could potentially offer an opportunity for recreating the playful tangibility that had been considered for so long, but in a fully digital format. Using the powerful functionality of the GSAP JavaScript library the researcher was able to explore how she could provide visitors with a sense of agency over the animations and content. The potential was recognised of utilising this tool to create a whimsical experience which would bring movement and playfulness to the fore.

The design was intentionally made to be in keeping with the existing SIM website as demonstrated in Figure 4-20 below, as well careful consideration of the SMG 'Web Design System' (Science Museum Group, 2022b) and the SMG Brand Toolkit (sample pages seen in Appendix H).

Figure 4-20: Frontpage Screen Grab from the Science and Industry Museum Website (Science and Industry Museum, 2023).

Focused on the five engine parts and using the original brief, the researcher explored how GSAP's playful animation features such as scroll triggers, physics functionality, masking and text morphing could be used to demonstrate how the engine parts move on a very simple entry level.

Cylinder

Users drag the piston back and forth to see how the mechanism is constrained within the space of the cylinder. Some users may also notice how the valve moves in the opposite direction. Sound effects are used to enhance the experience.

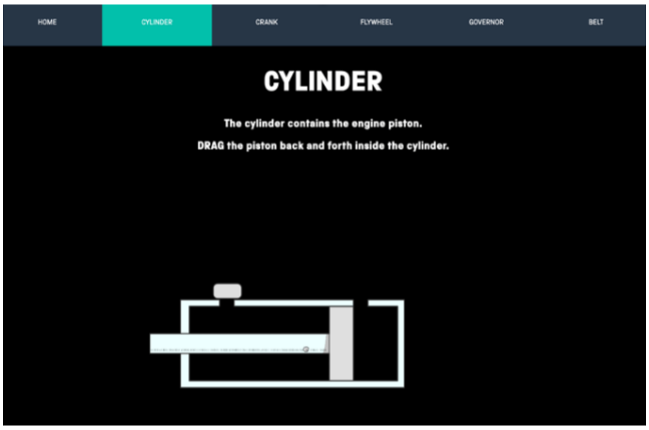


Figure 4-21: Cylinder interactive animation
(created by Christina Buckingham using GSAP technology)

Crank

Users can experiment by tinkering with the crank mechanism via the play, pause and reverse buttons. There is also the potential of dragging the oil can onto the mechanism to make the crank run faster, eliciting problem-solving opportunities within the engagement experience.

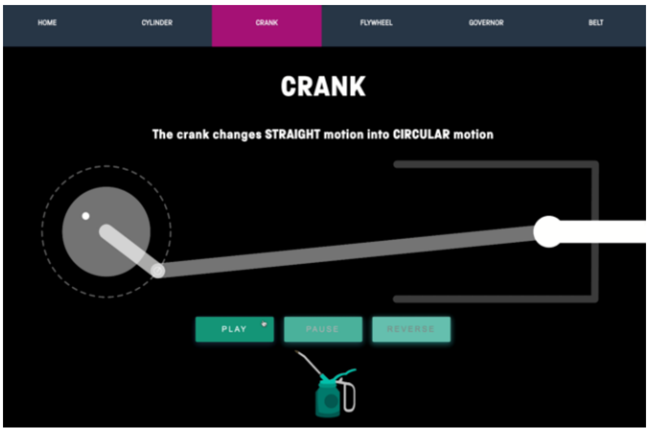


Figure 26: Crank interactive animation
(created by Christina Buckingham using GSAP technology)

Flywheel

Users spin the flywheel with either their mouse cursor or finger to get a sense of the inertia of the mechanism. This interactive animation can demonstrate how the wheel keeps spinning even after it has been released. Users can tinker with the effects in both directions.

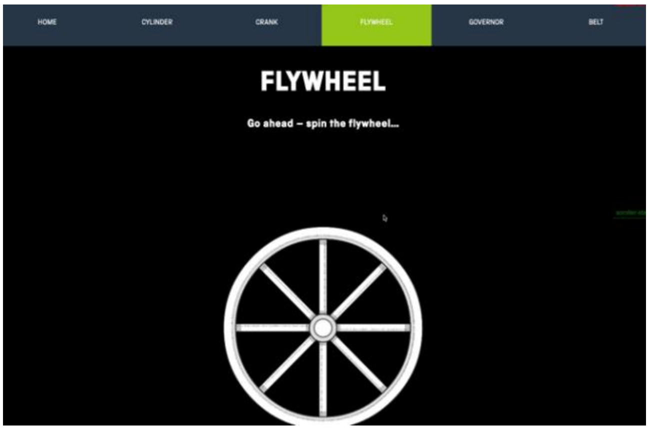


Figure 4-22: Flywheel interactive animation
(created by Christina Buckingham using GSAP technology)

Governor

The GSAP scroll trigger function is utilised to allow the user to manually scrub up and down through the animation of the spinning governor showing how the arms fly up as it turns. The experience promotes repetition and sense of playfulness.

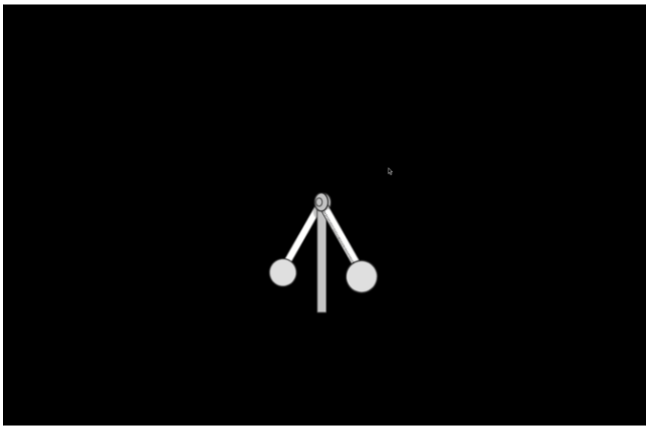


Figure 4-23: Governor interactive animation
(created by Christina Buckingham using GSAP technology)

Belt Connection

The scroll trigger function is utilised to turn the driver/flywheel and driven wheel. Scrolling up and down shows the wheels moving back and forth. Some users will notice the smaller driven wheel turns faster than the flywheel.

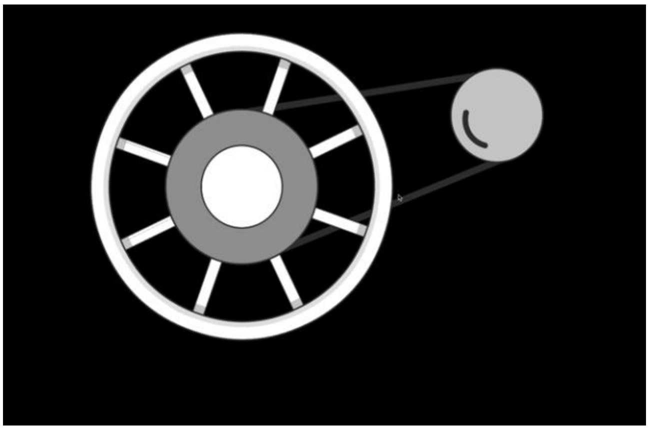


Figure 4-24: Belt connection interactive animation
(created by Christina Buckingham using GSAP technology)

The descriptions and images above (Figure 4-21 to Figure 4-24) show how a variety of interactive animation approaches were used to experiment with how engine parts could be tinkered with and investigated in an entirely online environment. Each one has an element of joy and playfulness to encourage repetition and user agency. The researcher paid heed to the Lego Foundation's characterisations of learning through play (Marsh et al., 2020) and conscious decisions were made to give no defined outcome and no requirement for the user to have to read instructions or achieve particular tasks. The method of playfulness provides an opportunity for users to focus on the action rather than the final result, allowing for more explorative or interactive behaviours (Navidi, 2016).

To set the scene for the interactions a light-hearted homepage was created featuring a scroll triggered animation and bold introductory text. A demonstration of the interface can be seen via this web link: http://www.thepowerhall.com/GSAP. Screenshots from this website, created by the researcher, can be seen below in Figure 4-25 to Figure 4-27. The experience was designed to be playful and atmospheric with the ambition to replicate the environment and ambiance of the Power Hall. SMG colours and typefaces were utilised by the researcher in order to demonstrate how this form of interpretation could fit with the existing aesthetics of the museums' digital presence.

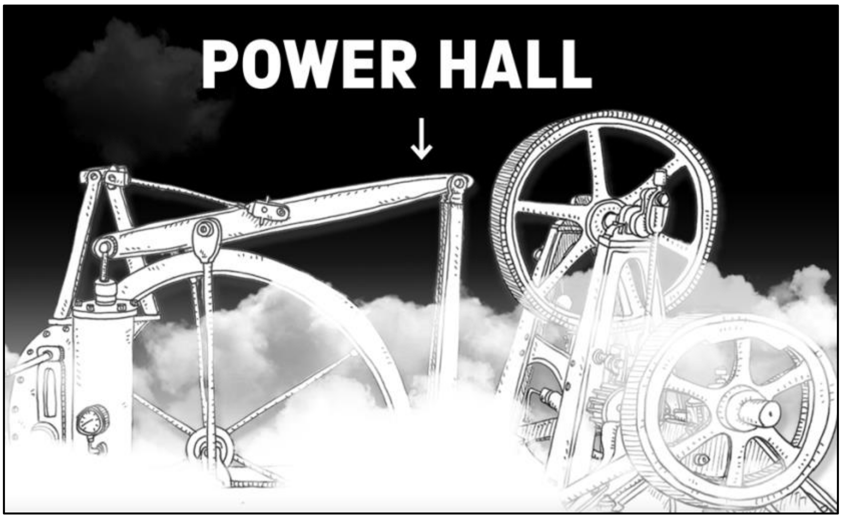


Figure 4-25: Landing screen for www.powerhall.com encouraging user to scroll/swipe downwards

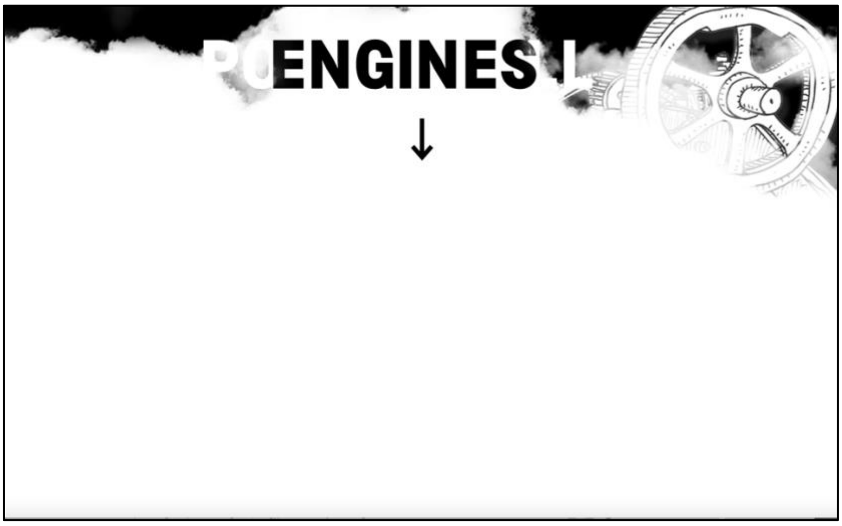


Figure 4-26: Scrolling/swiping downwards causes dynamic movement of the engines and steam.

Figure 4-27: Scrolling/swiping down further triggers playful text animations.

Due to the researcher being a new user of GSAP, and with only a small amount of previous experience with JavaScript programming, the development was very time-consuming and on occasions, frustrating. It was very clear that a developer with a better grasp of the technology would be able to produce more advanced features in a quicker timeframe. It was also palpable that this was not an ideal, inhouse rapid prototyping solution unless museum staff were very familiar with JavaScript coding. This work did however demonstrate great potential for a form of pandemic-proof digital interpretation that could give users a strong sense of agency and playfulness over the content and with minimum use of text. There was also the opportunity to explore how sound effects could be used to enhance the interaction experience, especially visceral sounds like squeaks, grinds and rattles. The functionality exploration and development experience demonstrated the opportunities that this technology could afford to playful engagement. The main downside of this method is the full reliability of screens, which the team were keen to avoid. It also became apparent that if the researcher was to follow the route of remote evaluation and data collection, she would need to resubmit an ethics approval application resulting in an even greater delay for the user testing stage. This, and the more promising outlook of the COVID-19 pandemic, led the focus to move towards the prototyping of a new hybrid interactive technology approach.

4.2.1.3 Prototype Three: Animated, Interactive Engine Projection Panel

Prototype three builds on the thinking done for the initial hands-on concepts but with two new goals in mind. Firstly, the researcher wanted to create a fun and playful approach to engine science with *minimum* user contact. Secondly, the researcher was interested in creating an interpretative tool that would not only show how each key part moved individually but also how it worked within the engine system as a whole.

In brief, this prototype demonstrates a graphical design of a simple engine upon which animations would be projected, triggered by user engagement. The design was created by the researcher initially in isolation with only SIM stakeholder feedback. As time progressed and pandemic lockdowns were eased, visitor consultation was then able to take place, informing the later phase of the design and development.

A major cognitive challenge is that all the engines in the compound are different in form, function and arrangement. Research was undertaken into how engine science is commonly explained and visualised to learners in other formats, and the researcher attempted to create a design with an accessible and logical approach. She took inspiration from the linear set-up used by online educational resource creators McManus (2016) and Walt (2016), and attempted to simplify the approach even more to enhance accessibility to a family audience. A novel animation was developed by the research using Adobe Animate, a screenshot of which can be seen in Figure 4-28 below.

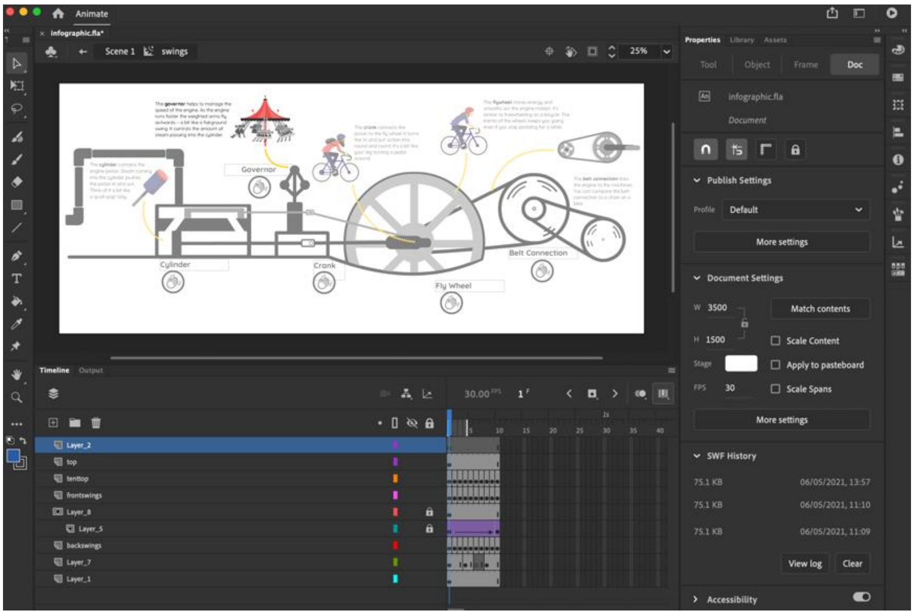
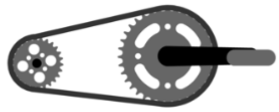


Figure 4-28: Screen grab from Adobe Animate showing animation construction.

As well as showing the engine working as a complete system, the researcher wanted to also single out each individual part in question. This was planned to be done by visually highlighting the engine part upon interaction, applying additional animations and supporting audio effects. With science capital theories in mind (Archer, 2018; Science Museum Group, 2020) and working in consultation with the Power Hall Content Team online, we thought about how each part could relate to an everyday object or process that most visitors would be familiar with. These everyday associations are outlined in Table 4.2 below.

Table 4.2: Initial everyday relevance ideas in connection with each engine part.

Part	**Animation Description**	**Image**
Cylinder:	Visual: Calpol/medicine syringe or push pop ice cream. Audio: Squirt noise or slide whistle.	 
Crank:	Lower leg on bike pedal (knee is the piston). Audio: Exertion or effort sound effect.	
Flywheel:	Freewheeling on a bicycle (later changed to a spinning top). Audio: "Weee!" or whirling sound.	
Governor:	Fairground swings or a person turning on the spot. Audio: Fairground music.	

Belt Connection:	Chain on a bike. Audio: Rattle or industrial winding noise.	

These animations and sounds were deemed to be crucial to the interactive interface. They were designed to be a tool for parents or carers to use as a catalyst for conversations with their visiting children (Silverman, 1995, p. 166). The researcher used accessible visuals to increase visitor confidence to engage with the content even if they had little existing knowledge or experience directly with steam engines. The audio was designed not only to spark emotions, memories and associations but also to increase the playfulness and enjoyment of the interactive. It was also hoped the sounds would be a draw for other families to engage or simply observe. A conscious decision was made not to make the audio too complex or compulsory due to the prediction that the Power Hall environment may be quite loud.

In addition to these connective associations to promote meaning-making, the researcher decided that some extra, hidden, playful animations should also be included to encourage more exploration and moments of joy. This was motivated and informed by play theory research where a sense of 'fun and playfulness' can create a greater sense of curiosity and a longing for more information as well as a method of making experiences more memorable (London, 2020; Richards, 2003). Four playful graphics were added to the interface and an animation and sound effect was planned for. These hidden 'easter eggs' are outlined below:

Oil can: Animation: squirt of oil.
Sound effect: squeak from the can.

Gauge: Animation: spinning hands and wobble of fluid.
Sound effect: comic spinning sound.

Whistle: Animation: comic sound marks.
Sound effect: whistle.

Spanner: Animation: spanner drops onto the floor.
Sound effect: clang of spanner hitting the floor.

The researcher aimed to draw upon the pedagogy of play framework with an intent to create a sense of delight, wonder and choice (Mardell et al., 2016). Using learnings from the review of literature regarding guided play (e.g. Skene K et al., 2022), the design was produced to encourage a sense of empowerment, spontaneity and intrinsic motivation giving users the freedom to interact with the variety of elements, repeat functions and access the content at their own pace.

Before moving to the next stage of development the research and SIM Team agreed that it would be good time to get some user feedback on the visuals and everyday relevance examples. The museum had just reopened after the first lockdown and this formed the initial period of informal user testing and pilot evaluation with real museum visitors.
The evaluation station was set up in the Conversation Space next to the Textiles Gallery at the Science and Industry Museum. This area had plenty of space for visitors to keep socially distant and it was a relatively quiet environment in terms of atmospheric noise; this made it suitable for talking to visitors face-to-face without the need to shout. To reiterate, these points were all important during the pandemic for hygiene control. The researcher, visitors and staff were all wearing facemasks and cleanliness was a significant priority. A one-way system was in place at the museum and visitors flowed down a ramp into the Conversation Space area, this gave a convenient opportunity to identify groups or dyads suitable for consultation (adults with a child aged between four and eleven years).

As outlined in the methodology section 3.3.2.4, for the first proof-of-concept prototype, the visuals which were printed onto acetate sheets and laminated, making them easy to clean (Figure 4-29). Informal, qualitative consultation sessions were conducted with visitors to see if they thought the design made sense and if they were familiar with the everyday objects we had chosen. By overlaying the acetate sheets to represent the projected visuals, informal discussions with families took place about how the animation would work and what their response was to the content being presented.

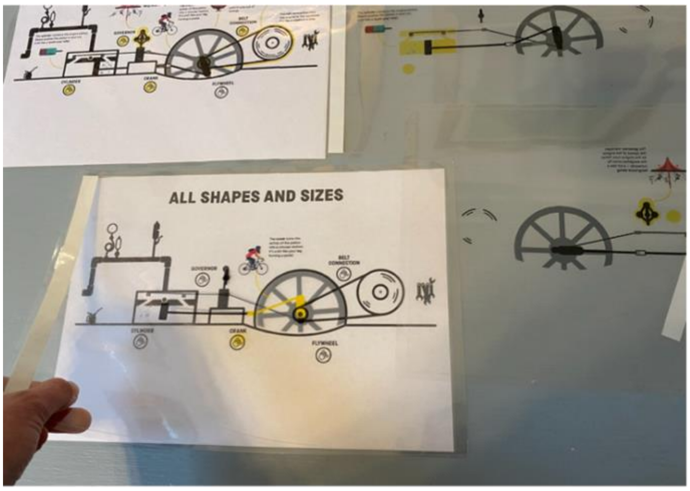


Figure 4-29: Discussing the user interface with visitors using overlayed acetate sheets.

During this first, early discussion session, the researcher was interested in getting feedback about the 'everyday relevance' examples used in the interpretation (as outlined previously in Table 4.2) and whether they were generally familiar to the target age group. Some notable phrases from this this session included.

- "He *just* wants something to play with!" Parent/carer referring to approx. six-year-old child.
- "I want to see it moving – how will it move?" Eight-year-old child.
- "You know what a spinning top is… you had that stripy one when you were a baby. We've still got it up in the loft." Parent/carer talking to child.
- "I've got a red bike, my old one didn't have pedals." Five-year-old child.

No formal questionnaire was conducted at this stage however key takeaways identified in the fieldnotes from this first informal session can be seen below:

- Feedback upon interaction needs to be clear, this should include a noise and a graphic signal.
- Overwhelmingly visitors were keen to hear noises and sounds.
- Pop-up text could be shortened in places.
- The push-pop lolly was preferred over the syringe.
- The two bikes were causing some confusion (although this might have been to do with the graphics being static).

- There was good feedback about the fairground swing and the chain on a bike.

For the next phase of prototyping and following informal user feedback, the development of operative 'buttons' was finalised by the researcher (developed using Adobe Animate and JavaScript coding). The interface was exported using HTML5 canvas functionality to enable the digital simulation of the projections to run in an online environment. Graphics, animations and sounds were added to the working interface design with the intention to mimic the projected experience. Using digital interactivity and playful sounds the researcher looked to explore how she could prompt unexpected moments of connection between the users and the engines. Some adjustments were made to the 'everyday relevance' associations in response to the first informal feedback session. The amended 'everyday relevance' visuals can be seen in Figure 4-30 below.

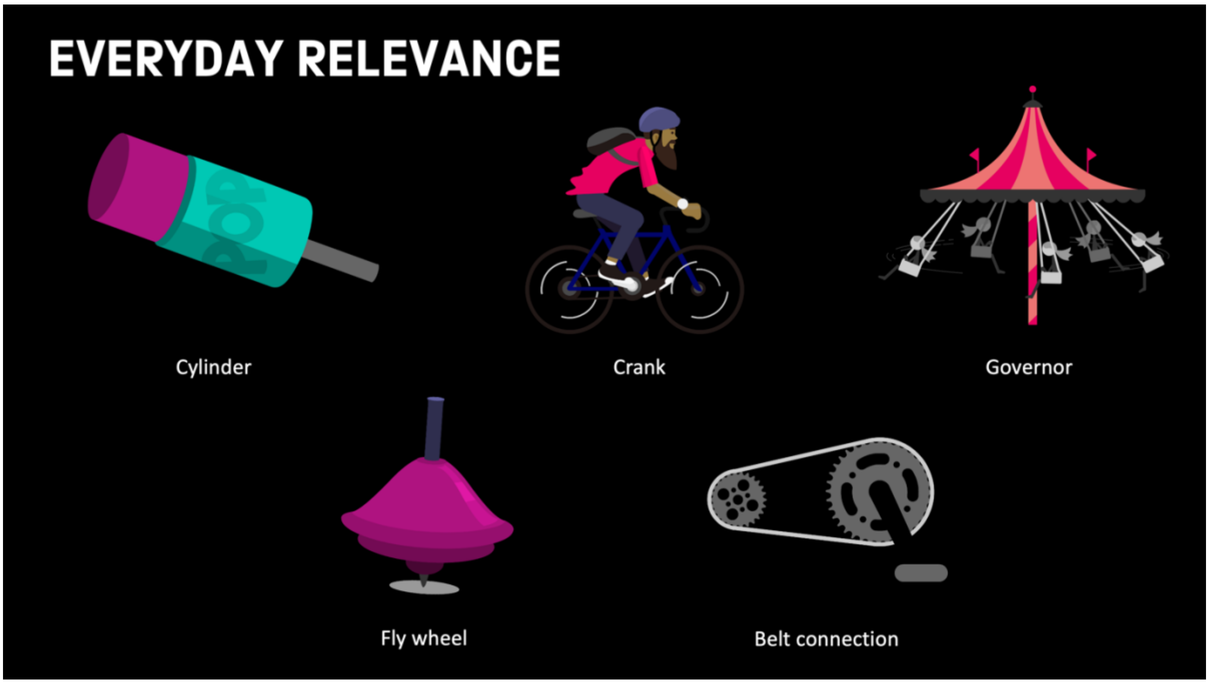


Figure 4-30: Examples of chosen everyday relevance connected to each engine part

The animated interface can be seen demonstrated via this weblink: https://thepowerhall.com/engine-interface/. This allowed for a second session of informal user testing concerning functionality and animated everyday relevance using a tablet touch screen that could be easily cleaned (see Figure 4-31).

Figure 4-31: Testing the user interface and visuals in the museum.

Ten families participated in this session by trying the interactive interface and answering the short pilot questionnaire as a family at the end of the session. The results of this pilot session can be seen in Appendix N. The responses were analysed with regard to prototype progression and the success of the evaluation method was also considered (Further reflection regarding these informal, pilot sessions can be seen in section 4.2.2).

Once various edits had been made as a result of the visitor feedback, progress to creating the interactive panel and projections could then commence. Having previously seen the capabilities of the Bare Conductive Touch Board during a commercial exhibition project, it was anticipated that this could provide a hands-free solution via proximity sensors which could be used to trigger the digital projections and audio.

Animations were exported from Adobe Animate and final edits were made in Adobe Premiere. MadMapper (projection mapping software) and Arduino coding (an open-source electronic platform) were used by the researcher to program the layered projections and test out the functionality of the Touch Board. Figure 4-32 shows the animations being calibrated to the Touch Board functionality.

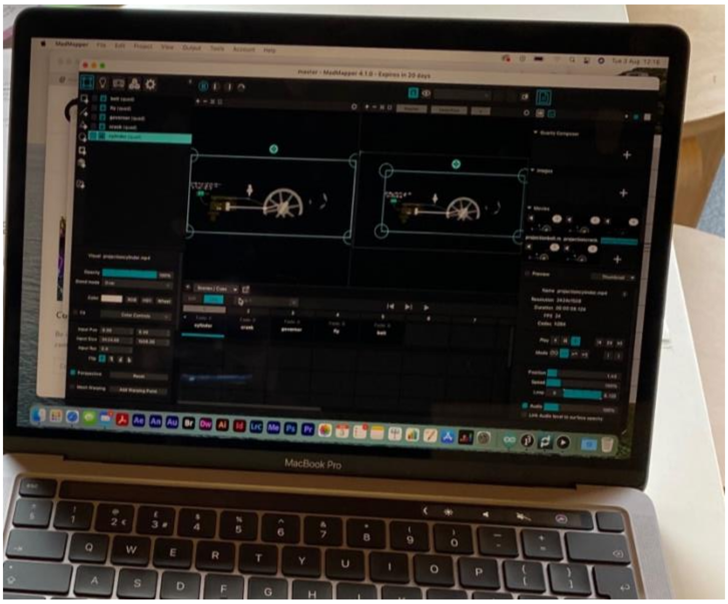


Figure 4-32: MadMapper interface where animations are calibrated to the Touch Board.

Firstly, the projections were tested on a pieced together print out of the display using a basic projector as see in Figure 4-33. Once the functionality was working, the prototype progressed to professionally printed A1 mountboard panel which was ordered online. This provided a more substantial based to work with.

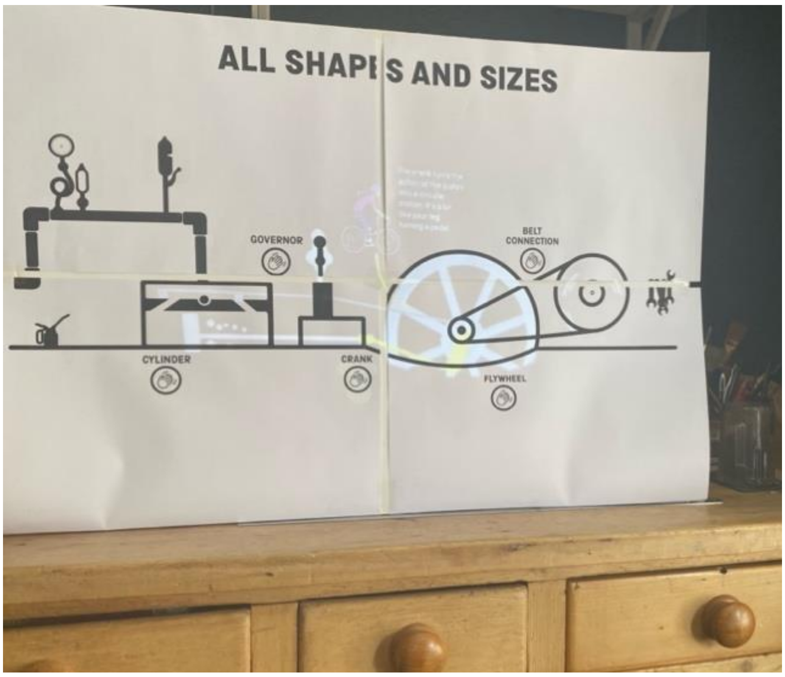


Figure 4-33: Testing projection animations on mocked-up display.

The researcher attempted to perfect proximity sensors so that the projections could be triggered without the need for the visitor to physically touch or make contact with the panel. She was able to test the reliability of the sensors using Grapher[2] to visualise the electric signals. Creating home-made sensors with copper tape (Figure 4-34) proved to be erratic, therefore ready-printed sensors were purchased (Figure 4-35).

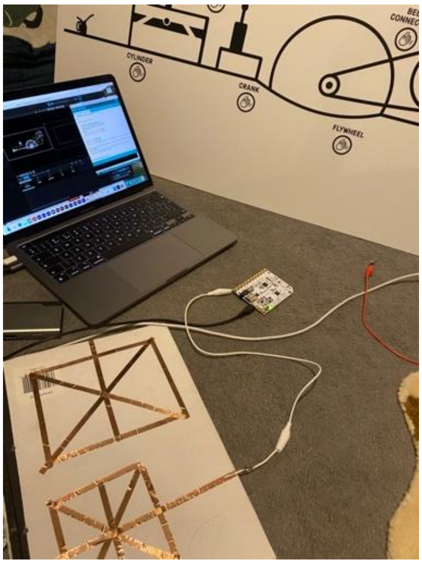


Figure 4-34: Creating distance sensors with copper tape and the Touch Board.

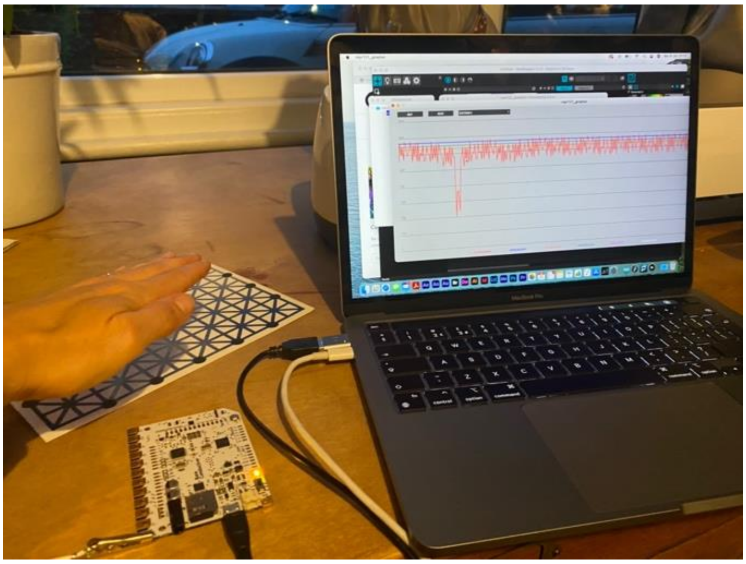


Figure 4-35: Testing sensor reception and functionality with Grapher and the Touch Board.

Although these proved to be more stable the success was intermittent and it was decided that this functionality should be put on hold. Although the researcher could see the hygiene potential and possibilities, there was a worry that the 'flakiness' of the system would detract from the content and the purpose of the brief during user testing and data collection. In addition, the impact of the COVID-19 pandemic was seemingly beginning to settle, and the previous pilot user feedback session had not indicated that the visitors had a particular aversion to touching interpretation interactives. For these reasons the researcher decided to pursue a more reliable hard-wired approach. Small hand shapes were created on a digital cutting system (Cricut) and painted with conductive ink (Figure 4-36). The hands were attached to the panel and connected to the Bare Conductive Touch Board with copper tape

[2] Grapher is a capacitance visualisation program owned by Bare Conductive and run with the open source 'Processing' application. It is a useful tool for observing the behaviours of the sensors and checking for any noise issues which may be causing problems.

which was laid in tracks hidden behind the panel (Figure 4-37). A video of the prototype in development and being tested by the researcher at home can be seen at: https://youtu.be/YLBTaRkW9C0.

Figure 4-36: Hand shapes cut out and painted with conductive ink

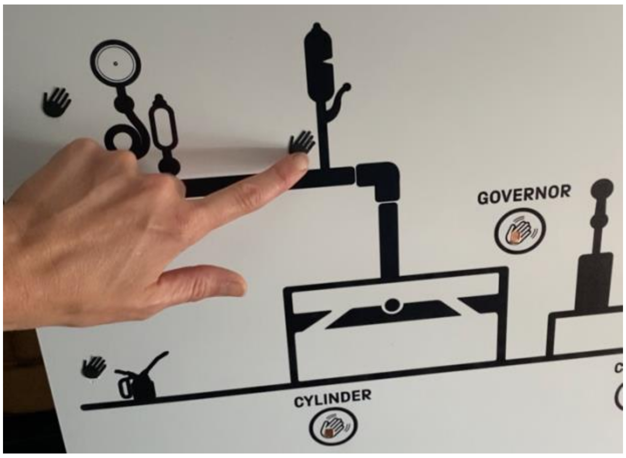


Figure 4-37: Hardwiring the interface made the functionality more reliable

This new ‘hard-wired’ set-up made the prototype more substantial and reliable.The final prototype, calibrated with a high quality short-throw projector was ready for the formal evaluation phase described in 4.3.3.

4.2.1.4 Prototype Four: Augmented Reality Enhanced Multimodal Trail

The final prototype in discussion for this chapter of practice research is an augmented reality enhanced multimodal trail. Driven mainly in response to the COVID-19 pandemic, the researcher was looking to create a form of digitally enhanced interpretation that visitors could pick up in the gallery, engage with, and keep hold of (to avoid any issues with hygiene). This took the form of a paper-based interpretation concept providing printed content, digital enhancement (via augmented reality) and a craft activity. The researcher was interested in exploring how visitors could continue their experience by taking the interpretation away with them and extend the learning opportunities beyond the museum walls. The multimodal trail features a variety of engagement approaches including an aspect of augmented reality providing a visual overlay of visual, digital information onto real-world imagery (Ishii & Ullmer, 1997, p. 236). Augmented reality is seeing increased use in science museums as a way of uniting the visitor with the primary experience of the museum space and the mode of interpretation (Snyder & Elinich, 2010, p. 87). The researcher saw augmented reality as tool to connect the visitor to steam engine science in a playful and interesting way that would also be somewhat ‘pandemic-proof’ due to the use of their own device. Furthermore, she was particularly interested to see how digital augmentations could serve as valuable scaffolds for conceptual learning (Yoon, 2012, p. 211). Photographs of the double-sided printed prototype can be seen in Figure 4-38 to Figure 4-40 below.

Figure 4-38: Multimodal trail leaflet prototype (inside pages)

Figure 4-39: Multimodal trail leaflet prototype (folded)

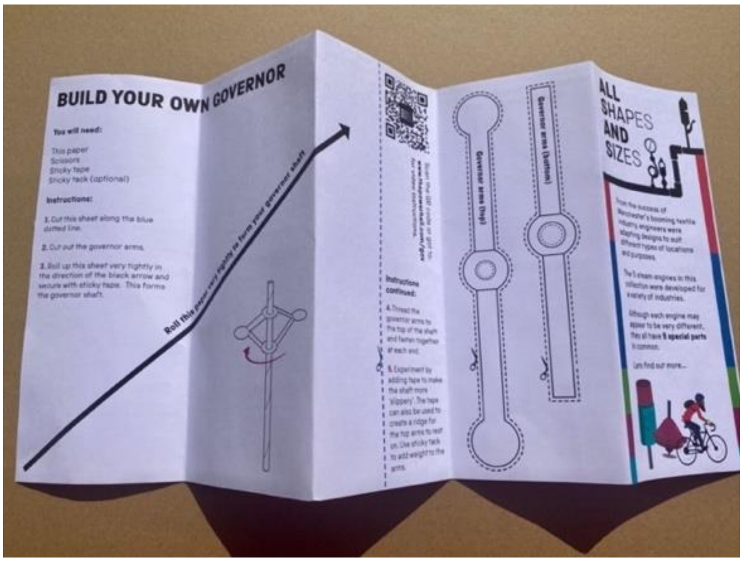


Figure 4-40: Multimodal trail leaflet prototype (outside pages)

The multimodal trail leaflet has been designed to feature engaging and accessible graphics and illustrations to provide the 'visitor hook'. The artwork was inspired by the previously described research for the SMG Wonderlab and intends to afford a refreshing and modern perspective on steam engine science. The SMG brand toolkit (Science Museum Group., 2018) (sample pages seen in Appendix H) and previous SIM and SMG printed outputs were researched and referred to for design guidance as well as taking inspiration from other paper-based interpretation from other museums and science centres. Figure 4-41 shows a selection of these existing resources which were used as guide for the house style. The non-standard, five-page accordion format, was designed to be playful, tactile and easy to handle for a variety of ages.

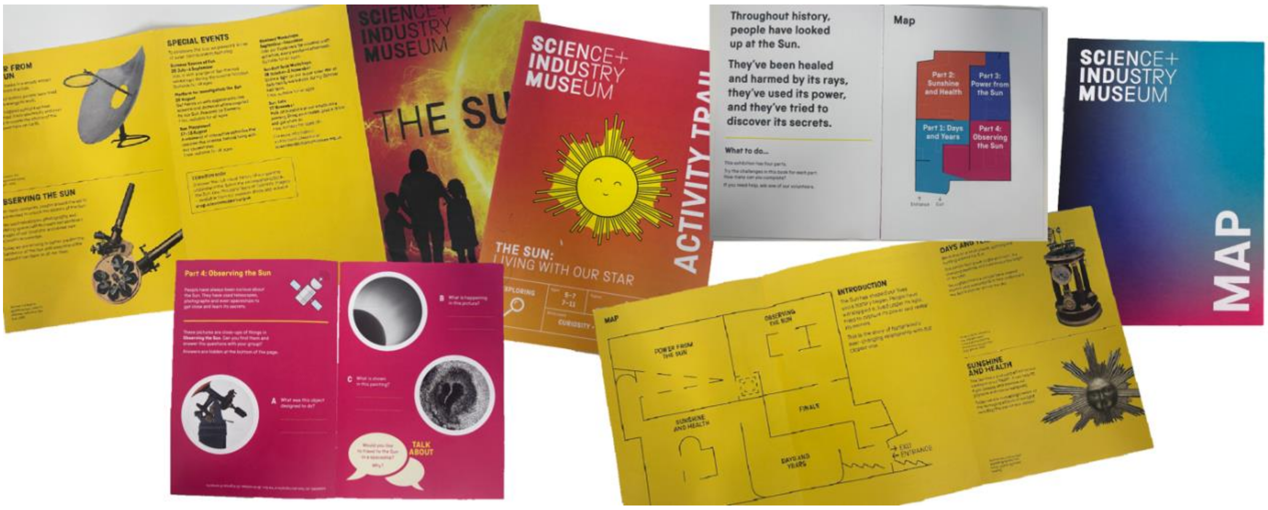


Figure 4-41: A Selection of SMG and SIM Print-based Media.

Informed by the existing printed media, the prototype features bold colours and a simple design with the aim of appealing to the widest audience segment. The leaflet is folded into five colour coded sections (as seen Figure 4-38 to Figure 4-39) with the inner pages each containing visuals and information relating to the five engines in the compound.

Illustrations of the engines have been designed to be family friendly and fun whilst still retaining a degree of complexity to promote intrigue and appeal to adults as well as children (as seen in Figure 4-42). As supported by the literature regarding intergenerational engagement (e.g. Henson, 2016; Whitebread, 2012) the researcher did not want the design intervention to appear overly childish in order to encourage a broader age group of participation. Text and language on the paper trail has been written with the aim of being inclusive and personable. As with the other prototypes, the researcher used published SMG guidance for further direction regarding communication principles, for example:

"Always communication: Never decoration. We focus on the essential aspects and eliminate superfluous noise."

"We ask questions, we reveal interesting facts and we encourage our audiences to get involved. Clear and succinct, we avoid jargon, but we don't dumb down. We focus on what our audiences can do, not what they can't."

(Science Museum Group, 2022b)

For interpretative text, work conducted by Serrell (2015) was significantly drawn upon alongside a comprehensive guidance report from Smithsonian (2021). Informed by this existing knowledge key considerations regarding the interpretive text included:

- Text should be written for the non-specialist.
- Language should be simple, concise and non-technical.
- Sentences should contain 15 to 20 words or fewer.
- Sentences should contain just one idea.
- Text should be written for reading aloud.

Using a myriad of carefully considered techniques of presenting what is usually considered quite complex content, the researcher intended to reach and connect with an audience that may normally feel disengaged or disinterested in steam engine science.

The main objective of this interpretation concept was to explore a more unusual, playful and unexpected approach to engine science. The researcher and the Power Hall Content Team wanted to investigate how interpretation could be used to get visitors to move their bodies like the parts of an engine. It was intended that by learning and playing kinaesthetically in this embodied way, we could attempt to create a more joyful and memorable experience. The researcher and SIM team agreed that this would help to connect with younger visitors and give parents and carers a tool to encourage interaction and engagement with the content. It was this aspect of the interactive interpretation concept that became the starting point of the design intervention.

The physical element encouraged through this interpretation prototype draws upon the work of researchers involved with embodied cognition (e.g. Bakker, 2011; Limerick et al., 2014; Skulmowski & Rey, 2018). There are robust suggestions that where science activities are delivered via an 'embodied lens', sensorimotor experiences can help to support meaning-making and discourse. Furthermore, participants become exposed to multiple forms of communication which in turn can support alternative modes of knowing (Skulmowski & Rey, 2018; Thomas Jha & Price, 2022, p. 1660). The researcher considered this to connect with science capital theories where emphasis is placed upon lived and felt experiences whether that be tangible or abstract (Archer, 2018).

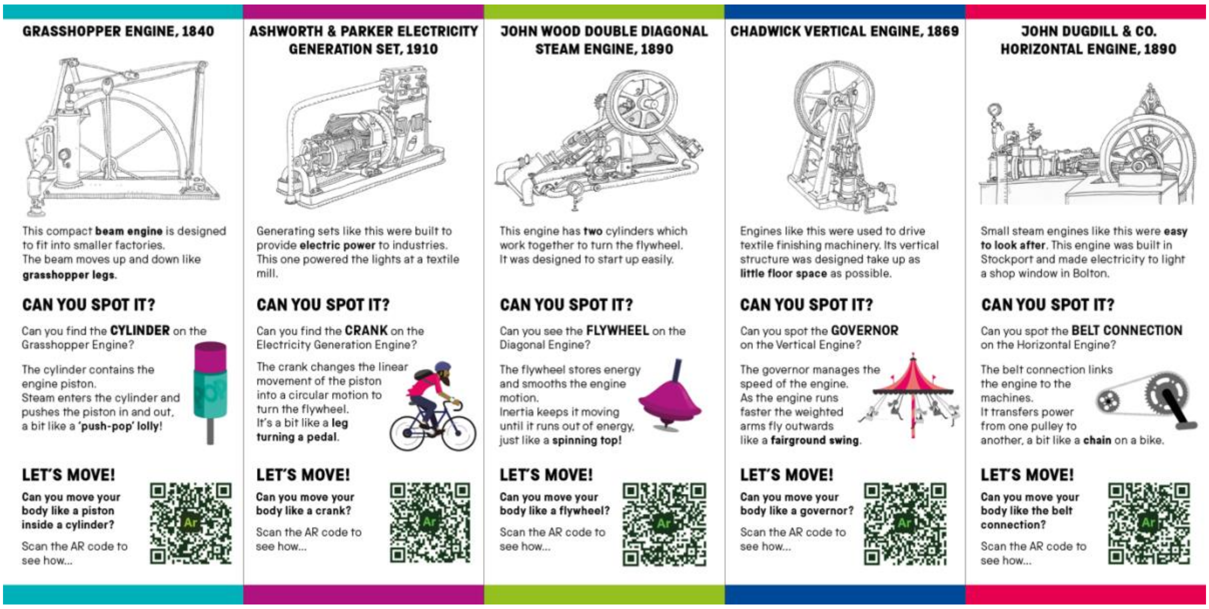


Figure 4-42: Spread view of the paper trail (inner pages)

How it works: Visitors scan one of the five QR codes from the leaflet with their personal device and the augmented reality interface instructs them to find a particular image (as seen in Figure 4-43), which, in theory, would be located next the relevant engine within the All Shapes and Sizes compound where the real engine part can be clearly seen. These images were designed by the researcher to provide a clear and recognisable icon for each engine part, they also offer a simple indication of directional force.

Figure 4-43: Trigger images that the user is instructed to find during the trail

Once the trigger image has been located by the user, this opens an augmented reality experience demonstrating the playful action and encouraging the visitor to join in (Figure 4-44 shows an early test of the augmented reality in development). For each QR code/engine part there is a video of a child demonstrating a fun and associated action to make, moving their body like the relevant engine mechanism.

The researcher and SIM Team looked to use this as a way of bringing the human element into the experience; peopling the exhibition in a light-hearted way to get families moving and engaged.

Figure 4-44: Phone screen grab from first stage of AR prototyping for the piston video

For rapid prototyping purposes, the augmented reality functionality for this prototype was created using the free development app Adobe Aero. It proved to be a good way to develop and test out ideas without the expense and commitment of involving external developers. As a team, we were excited by the opportunities this could open for further development and felt positive about the ‘unexpected’ element of the interpretation. We began to think about ways that we could make this experience more diverse and inclusive using more human representation, different genders, ethnicities and physical abilities. This would give visitors a better chance of seeing and connecting with ‘someone like me’. The concept also showed that augmented reality has the capability of being prototyped inhouse with minimal augmented reality development experience. The video sequences were created relatively easily at home by the researcher during lockdown (with the assistance from a young family member), using a makeshift greenscreen along with a tripod and camera (as seen in Figure 4-45).

Figure 4-45: Makeshift greenscreen set-up for AR video clip production

The basic ‘pop-up’ video sequence of the augmented reality experience was built upon by adding animated labels, audio and clickable content to add more layered content. This allows for scaffolded engagement and is ideal for older children who may not want to physically join in with the actions. Tapping elements on the screen triggers voice descriptions and further explanations (as seen in Figure 4-46). This was designed to support family friendly, experiences based on the theoretical framework of science capital development and Vygotsky’s social constructivism rational by placing emphasis on social interactions between children and adults as they move through the stages of the interactive interpretation experience, learning through play and guided discovery (Krieg et al., 2023, p. 7).

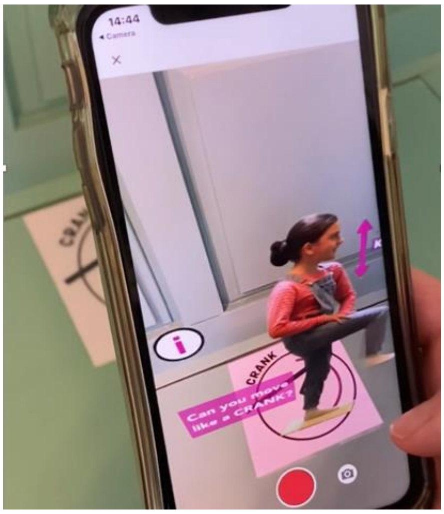


Figure 4-46: AR interface with more layered content

With stakeholder consultation, the physical movements for each engine part were decided to be:

Cylinder:	Standing on one spot, crouching down, then stretching tall.
Crank:	Standing on one leg, pedalling the other leg round and round.
Flywheel:	Spinning around on one foot.
Governor:	Turning quickly on one spot with arms relaxed at the side
Belt Connection:	Two people holding hands to form a chain, passing kinetic energy from one to the other.

On the reverse side of the trail leaflet the researcher designed a ‘Build your own governor’ paper craft activity (Figure 4-47 and Figure 4-48). The governor was chosen due to it being a strange and intriguing part of the engine and could be the element which requires the most explanation to novice visitors. It also offered valuable opportunities for STEM orientated learning. In short, the governor is a speed regulator for the steam engine. It is attached, usually by gears or a belt, to the flywheel making the central shaft or spindle rotate. If the spindle rotates too quickly, centrifugal force makes the arms of the governor move out and up against gravity. The action of the arms rising closes a valve, limiting the steam supply to the cylinder which in turn slows down the speed of the engine. As the arms lower again (due to gravity) the valve is reopened.

The QR code on the leaflet links to a supporting 'how to video' which demonstrates more about how the governor works (with footage of a working governor) as well as step-by-step instructions about how to build the paper governor. This hands-on activity could potentially be done at home, helping to embed and build on the initial learning and extend the engagement experience. Like the augmented reality exercise, this activity utilises embodied cognition theories and opens new avenues for communication, discourse and learning as social and shared experience.

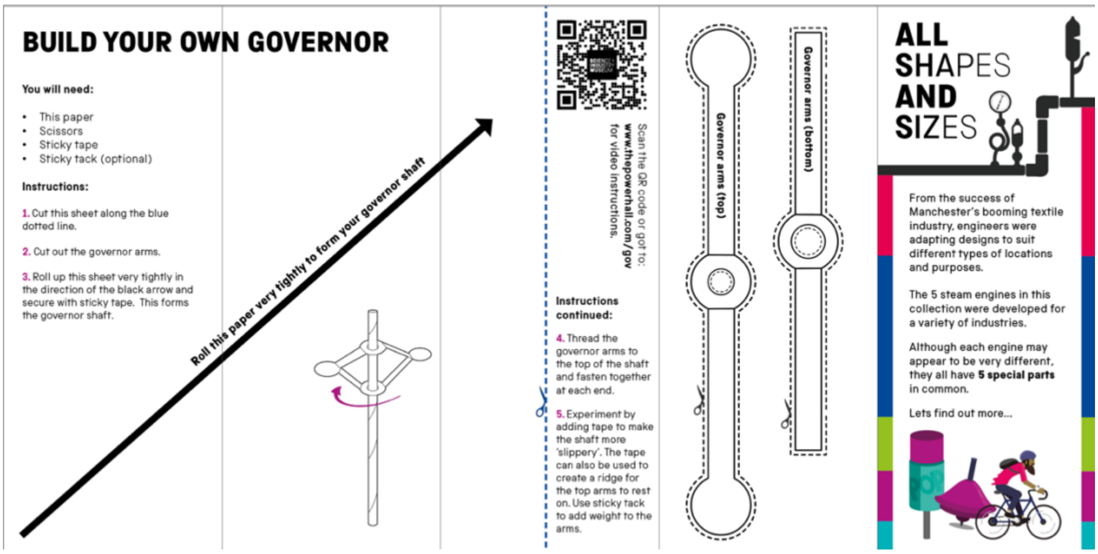


Figure 4-47: Spread view of the multimodal trail 'hands-on' activity (reverse pages)

Figure 4-48: Paper governor being cut out for the trail

The activity was carefully developed to be suitable and appealing to a wide range of visitors and offers lots of opportunity for tinkering with the design to enhance the experience even further (see SIM terminology in 3.3.1.1). A conscious effort was made by the researcher to make the activity both adult and child friendly, making this a rewarding family project that could be built together as a social experience of learning through play promoting a reciprocal and dynamic exchange of information and ideas (Krieg et al., 2023, p. 3). On a rudimentary level, the paper governor was designed to be joyful to play with, the paper arms fly up and out as they spin and the coloured stripes on the governor shaft have a mesmerising visual appeal, rather like the fairground ride referred to in the everyday relevance. More able/advanced users are encouraged to experiment with the design by exploring the effects of tape and sticky tack to reduce friction and add weight to the fly-balls. It is unique and simple tool for demonstrating scientific engineering concepts including centrifugal force, friction and gravity. A video of the paper governor in action can be seen via this link: https://youtube.com/shorts/FvIAxQUXZuE and in Figure 4-49 below.

Figure 4-49: Paper governor hands-on activity

With the prototype perceived to be at a good standard for sharing with visitors, a third session of informal user testing took. This session was used to test the visitors' initial response to the augmented reality features of the interactive interpretation prototype and was to conduct a preliminary observation of the paper model activity. At the end of the engagement the group was asked to complete the pilot questionnaire (3.3.2.4) and the results of this session can be found in Appendix O.

4.2.2 Discussion of the Informal User Testing and Pilot Questionnaire

Fortunately, between the disruptions of the COVID-19 museum closures the researcher was able to successfully conduct a reasonable degree of visitor consultation and informal, qualitative user testing at three different points during the development of the two principal creative outputs described above. As a recap, only prototype three (the animated, interactive engine projection panel) and prototype four (the augmented reality enhanced multimodal trail) were carried forward to further development and informal user testing because they were deemed to be most suitable by both the researcher and the SIM Content Team due to:

- their low contact and hygiene capabilities.
- their potential for encouraging family-friendly playful engagement.
- their capacity to be developed to an advanced, high-fidelity standard from the researchers own home.

Prototype one (the hands-on play panel) was abandoned because the tactile nature was not suited for 'pandemic-proof play' and a high-fidelity could not be developed without the need for advanced resources and workmanship. Prototype two (the Power Hall online, digital solution) was abandoned due to the potential easing of the COVID-19 lockdowns; a fully screen-based design intervention was not seen as an ideal solution for achieving intergenerational play opportunities in an exhibition setting.

Following the three informal sessions, iterative adjustments were made to the prototype designs particularly in relation to the everyday relevance, word counts, edits to language and scaffolding features of the augmented reality. It was also observed that users were missing the playful ‘easter egg’ features of prototype three (the animated, interactive engine projection panel) such as the spanner and oil can. Future iterations made these elements more obvious.

On the whole feedback was positive and exciting, however it was noted that visitors were happy to chat more about the everyday relevance examples than there were about the engine science. It was also evident during these initial sessions just how interesting visitor dialogue and discourse could be to evaluation. Even though testing out these preliminary and fledgling prototypes there were numerous moments of joy that were occurring despite these being proof-of-concept engagement experiences. Some notable statements gathered from fieldnotes included:

- “Haha, I’ve got them all moving at once!” Nine-year-old playing with the iPad interface for prototype three (the animated interactive engine).
- “We should have bought Grandma here; she loves things like this.” Eight-year-old playing with the iPad interface for prototype three (the animated interactive engine).
- “I want to take this into school to show my teacher.” Eight-year-old playing with paper governor for prototype four (the multimodal trail).
- “Oh wow, that’s cool! How did that work?” Ten-year-old viewing AR trail for prototype four (the multimodal trail).
- “Aaah, that’s too loud!” Five-year-old playing with the iPad interface for prototype three (the animated interactive engine).

It was clear that these elements in a user testing session were extremely valuable, but their worth could easily go undocumented in an evaluation session with a sole focus on standardised exit questionnaires. Even in a detailed observation session, the researcher considered that evidence of science-talk and meaning-making can be easily dismissed for general or seemingly unrelated conversations. For example, it was noticed that much of the discourse observed in these iterative stages related to memories of belongings or experiences that had happened in the past, as opposed to a sudden moment of insight directly and more obviously related to steam engine science.

It was noted that the questionnaire responses often lacked a degree of energy, integrity and enthusiasm from the visitors in comparison to the few moments before when they were engaged in the exercise. This may have been partly due to the circumstantial difficulties imposed by COVID-19 restrictions. Rather than handing the participant a clipboard and pen, the researcher asked the questions out loud and wrote down the participants' responses to mitigate hygiene issues. This may have led the visitor to feel more self-conscious and uncomfortable, it may also have led to modified or refined answers. The process in general was greatly impacted by the fact that all adults and some children were wearing face masks making it difficult to hear one-another, especially in a relatively noisy environment. All these elements added to the sense of fatigue surrounding the experience.

Also, because the interview questions were qualitative and purposely open-ended (to encourage visitors to provide more constructive feedback) it was realised that, although iterative improvements to the designs could be made, the researcher was not getting the solid and important data with which she could clearly compare the science capital and intergenerational engagement success of one prototype to another. Furthermore, the information that was collected proved difficult to analyse and convey efficiently to stakeholders and the wider team without extensive explanation. It was at this point in the research that there was convincing evidence for an alternative approach to evaluation and data collection.

4.2.3 Summary of the Development Phase

In summary, this section of the 'Presentation of Research' chapter has described the development phase of the generated design interventions. This practice research was conducted in answer to the brief provided by the collaborative partner. The creative outputs were deemed necessary to address the main research question and to provide a basis from which to answer the emergent subsidiary questions. The section has also included descriptions of informal user consultation at three stages of the practice research, the results of these sessions led to further development and amendments as well as a reflection of the evaluation and consultation process itself. This section has also detailed the researchers' reflexive responses to the COVID-19 pandemic.

In the following section the researcher explains how the prototypes were formally evaluated using a modified data collection system focussed on visitor discourse. This system was designed to compare advanced versions of the previously described prototypes three and four.

4.3 Formal Evaluation Phase (Data Collection)

The closure of museums during the COVID-19 lockdowns of 2020/21 gave the ideal opportunity to not only work on the prototype developments but also to reflect and prepare a clear plan for more formal user testing and data collection. This chapter provides details about the formal evaluation phase incorporating prototype user testing and data gathering with an emphasis on a discourse evaluation system.

Through a mixed method process, as described in section 3.3.3.1 of the methodology, the researcher devised a framework for addressing the subsidiary research questions and trialling an ambition to efficiently compare the STEM engagement success of one prototype to another; a process which the researcher labels as proto-scoping.

Building on the literature review findings outlined in section 2.7 and discussions with the SMG and SIM audience research team described in 4.1.8, the researcher was interested in adopting learnings about prototyping timelines from the work of De la Rosa (2017, p. 4473) and applying this to the field of exhibition interactive interpretation. Inspired by De la Rosa, the researcher was looking to develop an efficient way for exhibition content teams to embrace a participatory and exploratory stance toward the development of interactive interpretation solutions by exploring a variety of options rather than funnelling down to one idea too soon. Put simply the researcher presents proto-scoping as a framework for scoping out multiple approaches to the same interactive interpretation design problem (or brief) using the method of participatory prototyping and discourse analysis. The researcher was keen to make the proposed framework of proto-scoping interesting, informative and efficient for both the participants and those involved in the data collection. STEM-focussed discourse analysis provided the central lens through which the intergenerational engagement success of the prototypes could be compared.

The approach to evaluation consisted of four elements:

1. A discourse analysis scoring system focused on science capital-themed utterances.
2. A visitor graded 'experience score' with a supporting visual reference.

3. A measure (in seconds) of how long the participants spend engaging with the prototype (dwell time).
4. A short survey featuring just two qualitative questions to facilitate further iteration.

4.3.1 Formal Baseline Test and Pilot Study

As outlined in the methodology (3.3.3.2), the baseline test and pilot study were first conducted using the previous Power Hall interpretation signage (seen in Figure 3-8). The objective was to achieve some reference data which the researcher could compare with the evaluation results of the new interpretation prototypes. It was additionally used to trial the variety of methods used in the evaluation system before the formal evaluation of the new high-fidelity prototypes.

Copies of four old interpretation signs for the ‘All Shapes and Sizes’ compound were printed out and laminated and parent/caregivers were invited to look at the signage with their child. The researcher used a stopwatch to record the dwell time of the activity (how long the visitors were engaged with the interpretation), and an evaluation sheet (Appendix I) was completed for each dyad engagement. Any science capital-themed discourse was tallied and collated to provide a quantitative **discourse score**. The purpose of the score was to facilitate the efficient comparison and analysis of one experience to another from the perspective of intergenerational STEM engagement.

Seven dyads consisting of one adult and one child (between four to eleven years) were identified and invited over to take part in the baseline testing experience. Table 4.3 below presents the data collected from these sessions which includes the discourse score, experience score and dwell time.

4.3.2 Results of Formal Baseline Test and Pilot Study

Using tallied results from the seven engagement experiences it was possible to collate the data into a single table, as shown below.

				Connection & Linking						
	Enjoyment or surprise expression	Reading text aloud	Strategic talk	Activity or event	People or place	Object, action or skill	Positive cognitive/ perceptual talk	Discource Total	Experience score (out of 5)	Dwell time (seconds)
Dyad 1		1			2			3	2	88
Dyad 2		1						1	3	48
Dyad 3		2						2	2	72
Dyad 4		3		2				5	4	54
Dyad 5		1						1	2	52
Dyad 6					2			2	3	63
Dyad 7		1						1	2	77
Total	0	9	0	2	4	0	0	15	18	454

Table 4.3: Data collected from baseline tests of old Power Hall interpretation.

From the compiled data shown in the table above the researcher determined the following:

Average discourse score: 2.1

Average experience score (out of five): 2.6

Average dwell time: 1 minute 5 seconds

Responses provided to the two qualitative questions:

1. **What was your favourite thing about it?**
    a. I like the orange and blue colours.
    b. The text is quite big, which is good.
    c. The old pictures are quite nice.
    d. There’s not too much text.
    e. It’s nice how it’s laid out, quite logical.
    f. The colours.
    g. The boxes of information are good instead of one big piece of text.

2. **What do you think could be better?**
    a. The photos, they just look a bit old, and one’s missing.
    b. I don’t like that there is not a photo here.

c. I’m still not really sure what they are meant to do, are they for machines?
d. I’m not sure, I just feel a bit indifferent about it.
e. I wish there wasn’t any missing information, it would be better if all the information was there.
f. I’d like something to do, or press, or play with.
g. It would be better if the photos were all there.

As expected, this process was found to be a challenging part of the data collection process. Problems were experienced in getting younger children to give any close attention to the documents and there were palpable signs of frustration from families, most probably not helped by the COVID-19 pandemic restrictions such as the one-way systems and lack of interactive interpretation availability; many hands-on and playful installations had been closed off for hygiene reasons throughout the museum. Furthermore, there were no real engines for the children to see or relate to. Parents tended to be the main communicators, mostly reading out elements of the text to their children and trying to get them to look more closely at the photographs.

Although this collated data was not particularly beneficial for the development of the new prototypes and the comments were gathered too late to be of any particular impact on this work, it was a useful process to test out how the discourse analysis scoring system would work before moving forward to the formal comparative prototype evaluation, discussed in the next section of this work. Following this pilot study, no significant changes were made to the structure of the mixed methods system however the researcher built her confidence in the delivery and explanation of the study and gained experience of the logistics of conducting the evaluation experience in this new space. It was perceived that the evaluation of the new high-fidelity would be more enjoyable for the participants when engaged with more playful and interactive modes of interpretation.

4.3.3 Formal Prototype Evaluation

Once the baseline test had been completed and prototype three (animated, interactive engine projection panel) and prototype four (augmented reality-enhanced multimodal trail) were developed to a satisfactory level of maturity, the researcher was able to move forward to formal comparative prototype evaluation. The process as described in the methodology (described in 3.3.3) would form a substantial trial of the proposed discourse analysis proto-scoping technique and provide a methodology to address the subsidiary research questions.

The researcher was aware that for this approach to work she would need the prototypes to be functioning to a realistic standard in order for visitors to use them unaided with minimum intervention. Figure 4-50 and Figure 4-51 show the two interpretation prototypes set up in the MyDen testing area.

Figure 4-50: Photograph of the interactive projection panel prototype set-up in the SIM 'MyDen' area

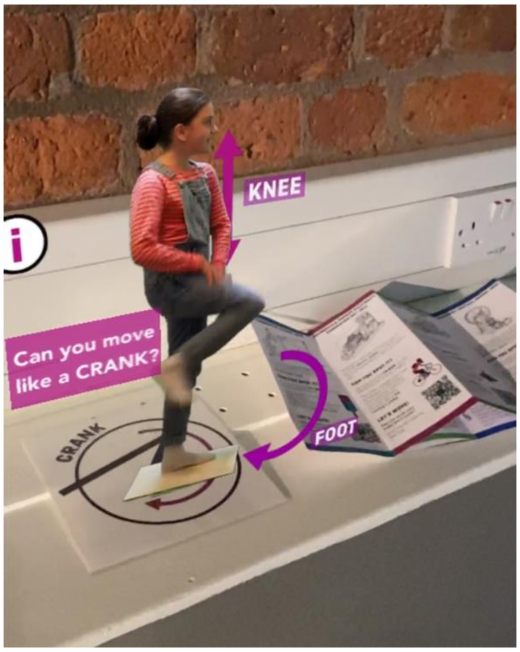


Figure 4-51: Photograph of the multimodal trail prototype set-up in the SIM 'MyDen' area

A video of the interactive projection panel prototype in situ in the 'MyDen' testing area at the Science and Industry Museum can be seen via this web link:
https://youtu.be/s9J82f0_Mrk

A video of one of the AR features from multimodal trail prototype in situ in the 'MyDen' testing area at the Science and Industry Museum can be seen via this web link:
https://youtube.com/shorts/Zcmb8qVoDAY

A total of 26 unique data collection instances using the science capital discourse analysis methodology took place. Each family dyad was asked to look at the **two** interpretation prototypes in turn: the interactive projection panel and the augmented reality experience for the multimodal trail, which resulted in 52 sets of data (26 for each prototype). The order in which the prototypes were presented to the visitors was alternated to avoid any bias due participant fatigue. The relevant discourse from each sample was tallied in the discourse chart as seen in Appendix I and the dwell time was recorded. Following each prototype engagement, participants were asked to give the prototype an experience score out of five (supported by the star chart) and asked to answer the two evaluation questions.

4.3.4 Results of Formal Prototype Evaluation

26 dyads participated in testing both the interactive engine projection panel and the multimodal trail, resulting in 52 engagement data sets. Using tallied results from each of the data sets, it was possible to compile the figures into a single system as seen below in Table 4.4. Using this table, the researcher was able to calculate total quantities for the thematic STEM discourse generated by the two prototypes. In addition, average numerical figures for 'discourse score', 'experience score' and 'dwell time' could be determined (as seen in Table 4.5). These figures made it possible to compare one interactive interpretation concept to another, a process that would have been very difficult using only qualitative data as a result of a sole questionnaire/ survey strategy. A discussion of the outcomes and assumptions achieved through this data are discussed in the following chapter.

Table 4.4: Table of results for 26 data collections sessions comparing the two prototypes

					Connection & linking									
		Enjoyment or surprise expression	Reading text aloud	Strategic talk	Activity or event	People or place	Object, action or skill	Positive cognitive/ perceptual talk	Discourse total score	Experience score (out of 5)	Dwell time (secs)	Experience/ discourse positive correlation	Experience/ discourse negative correlation	N/A
Dyad 1	**Interactive Panel**	1	3		2		2	2	**10**	**4**	110	1		
	Multimodal Trail	1	1	2					**4**	**3**	81			
Dyad 2	**Interactive Panel**		2		4			2	**8**	**5**	190	1		
	Multimodal Trail	2							**2**	**4**	110			
Dyad 3	**Interactive Panel**	1	2				2		**5**	**4**	122			
	Multimodal Trail	1	2	1	2	2	4		**12**	**5**	240	1		
Dyad 4	**Interactive Panel**	2	2	2			2	2	**10**	**5**	195	1		
	Multimodal Trail							2	**2**	**4**	90			
Dyad 5	**Interactive Panel**		1		2			2	**5**	**4**	60		1	
	Multimodal Trail	1	2			2	4		**9**	**3**	88			
Dyad 6	**Interactive Panel**	1	4			2	4	2	**13**	**5**	148	1		
	Multimodal Trail	1	2		2		2		**7**	**4**	236			
Dyad 7	**Interactive Panel**	3	1		2	2			**8**	**5**	77			1
	Multimodal Trail	2		1	2	4		4	**13**	**5**	160			
Dyad 8	**Interactive Panel**		**1**	**2**			**2**		**5**	**3**	**140**			
	Multimodal Trail		**2**		**2**			**2**	**6**	**4**	**180**	**1**		
Dyad 9	**Interactive Panel**		3	1		4		2	**10**	**4**	135			1
	Multimodal Trail		1				4		**5**	**4**	160			
Dyad 10	**Interactive Panel**		2	2					**4**	**4**	62			
	Multimodal Trail	1	3			2	2	2	**10**	**5**	90	1		
Dyad 11	**Interactive Panel**	2	4		2		2	2	**12**	**5**	158	1		
	Multimodal Trail	1	2			2			**5**	**4**	120			
Dyad 12	**Interactive Panel**	1	1			2		2	**6**	**5**	130	1		
	Multimodal Trail		1		2		2		**5**	**4**	180			
Dyad 13	**Interactive Panel**		1		2		2		**5**	**4**	80			
	Multimodal Trail	3		2		2	4		**11**	**5**	258	1		
Dyad 14	**Interactive Panel**		1		2		4		**7**	**5**	95	1		
	Multimodal Trail	1						2	**3**	**4**	63			
Dyad 15	**Interactive Panel**	2	1			2	2		**7**	**3**	78			
	Multimodal Trail		1	1	2	2	2		**8**	**4**	140	1		
Dyad 16	**Interactive Panel**	2	3	1			2	2	**10**	**5**	136	1		
	Multimodal Trail	2	3	2				2	**9**	**4**	180			
Dyad 17	**Interactive Panel**				2				**2**	**4**	58		1	
	Multimodal Trail	1				2	4		**7**	**3**	147			
Dyad 18	**Interactive Panel**	1			2	2		2	**7**	**5**	150	1		
	Multimodal Trail		1		2		2		**5**	**4**	105			
Dyad 19	**Interactive Panel**	3		1	4	2			**10**	**5**	95	1		
	Multimodal Trail	1	1		2		2		**6**	**4**	130			
Dyad 20	**Interactive Panel**	4					2		**6**	**5**	90	1		
	Multimodal Trail		1	2	2				**5**	**4**	120			
Dyad 21	**Interactive Panel**	1				4		2	**7**	**5**	65	1		
	Multimodal Trail		1	1	2		2		**6**	**3**	90			
Dyad 22	**Interactive Panel**	1					2		**3**	**4**	80			1
	Multimodal Trail			2		2		2	**6**	**4**	114			
Dyad 23	**Interactive Panel**		4		2		2	2	**10**	**5**	205	1		
	Multimodal Trail	1	1						**2**	**4**	165			
Dyad 24	**Interactive Panel**	1	3		2	4	2		**12**	**5**	133	1		
	Multimodal Trail				2				**2**	**4**	88			
Dyad 25	**Interactive Panel**		2		2	2			**6**	**4**	70	1		
	Multimodal Trail	1							**1**	**3**	57			
Dyad 26	**Interactive Panel**	1	1		2	2			**6**	**5**	78	**1**		
	Multimodal Trail				2		2		**4**	**4**	65			

	Enjoyment or surprise expression	Reading text aloud	Strategic talk	Activity or event	People or place	Object, action or skill	Positive cognitive/ perceptual talk						
Total Interactive Panel	27	42	9	32	28	32	24	194	117	2940			
Total Multimodal Trail	20	25	14	24	20	36	16	155	103	3457	**21**	**2**	**3**

Table 4.5: Average figures for discourse total score, experience score and dwell time.

	Interactive projection panel	**Multimodal trail**
Average discourse analysis score:	7.5	6
Average experience score out of five:	4.5	4
Average dwell time:	113	132

The results of the two evaluation questions asked after each engagement sample are summarised below in Table 4.6. Where different participants said similar things, these have been organised together in brackets []. Some participants did not provide an answer while others provided multiple points.

Table 4.6 Summarised answers to the two evaluation questions for each prototype

Interactive Projection Panel		Multimodal Trail	
What was your favourite thing about it?	**What do you think could be better?**	**What was your favourite thing about it?**	**What do you think could be better?**
Animations [9]	More tactile/3D [3]	Different and unusual [7]	Needs a fixed gallery digital device [5]
The noises and sound effects [5]	More colourful [2]	Fun to use [4]	Provide alternative to mobile phone [2]
Big/shared experience [3]	Make bigger [2]	Use of own device [4]	Hard to use/a bit fiddly [2]
Fun to use [3]	Video of a real engine for reference	The extra activity for home [4]	Link to social media to share videos [2]
Easy to use [3]	Bigger text	Something to do together [3]	Bigger screen for easier viewing/ hard to see [2]
Logical/makes sense	More information about real steam engines	Pictures/illustrations [2]	Use different characters for AR

Helps learning	More sounds and music	Tactile/hands-on [2]	Provide a mirror
Different / surprising	A computer screen could take you to find more information	Colourful and bright [2]	See the steam engine in AR
Understandable		Quick and easy to use	Improved noise levels
Real world connections		A souvenir of the visit	Use older children
Pictures/images			Use AR to turn visitor into an engine
Not too much text			Link to a webpage to find out more
			Do a steam engine dance to music
			Make the AR bigger so people can get into the shot
			Be able to move around in the AR world

4.4 Summary of the Presentation of Research

This chapter has presented a description of how the researcher has utilised a process of design research and ethnographical fieldwork, practice research through prototyping and a methodology of mixed methods in order to address the design brief provided by the collaborative partner. Research strategies of participatory design and action research have been demonstrated by consulting with SIM stakeholders and museum visitors, and responding reflexively to the dynamic demands of this real-world project.

To recap, the discovery phase involved a process of becoming attuned to the requirements of the 'client' by obtaining knowledge of the wider organisation (SMG), the museum site (SIM) and exhibition project (Power Hall) objectives. It was important to become embedded within the collaborative team in order to achieve a good understanding of the museum nuances and to facilitate a valid and rigorous response to the design problem. This early work provided the important foundation of design research and project scoping ready for the more focussed development of creative solutions.

The development phase drew together the findings of the literature review, the theoretical framework and the learnings of the discovery phase to form a collection of interactive interpretation concept ideas in response to the design brief. Action research was applied to the process by way of planning, acting/creating, observing/discussing and reflecting/reflexing at each stage of the project progression until two high-fidelity prototypes were satisfactorily developed and a strategy for evaluation had been achieved. The strategy focussed on an approach for the comparison of one prototype to another through the lens of STEM-focused intergenerational conversations. This formed the fundamental component of the researcher's devised STEM interactive development framework labelled as 'proto-scoping' described in more detail in the discussion chapter.

Participatory design is applied to the practice research by communication and ideation with the SIM stakeholders along with prototype consultation with the visitor audience. Participatory design is also present in the devised proto-scoping framework by enabling visitor discourse to be the driving factor in interactive interpretation design direction. This process brings the playful family engagement experience to the fore, valuing moments of joy and wonder and acknowledging discourse of seemingly disparate connections triggered by the STEM content.

The formal evaluation phase has been used to collect data about the STEM engagement success of the two high-fidelity prototypes created during the development stage using the new evaluation strategy focussed on STEM discourse. This stage of the study not only provides data to evaluate the interactive interpretation concept's abilities to illicit meaning-making and the development of science capital, but also facilitates a trial of the evaluation procedure itself, offering the researcher the opportunity to assess if the process delivers meaningful and beneficial results. The following discussion chapter draws closer attention to the analysis of the collated figures (achieved through the mixed methods research approach) allowing the researcher to make assumptions and recognise data patterns.

Chapter 5: Discussion

Following the presentation of the practice research and the formal evaluation phase, this chapter aims to analyse and discuss the results of the data collected during this work alongside a discussion of the applied methods and strategies. The discussion chapter aims to draw together the main outcomes of the study and critically review them against the existing field and in reference to the literature review.

During this inquiry, four different interactive interpretation prototypes were developed to answer a specific design brief and to investigate the main research question:

> *How can digital interpretation techniques be developed and explored to encourage playful engagement with steam engine science?*

Prototype one (a hands-on play panel) and prototype two: (The Power Hall Online) were eventually rejected due to their unsuitability as a viable option for the Power Hall exhibition. However, prototype three (an animated, interactive engine projection panel) and prototype four (an augmented reality enhanced multimodal trail) were progressed to the formal data collection phase which utilised a mixed methods strategy with a particular focus on discourse analysis connected to science capital themes. 26 participant dyads were engaged in the data collection experience. Analysed data sets were then used to identify patterns and to facilitate the capacity to formally answer the two subsidiary research questions:

1. *To what extent can engagement with playful interpretation prototypes be measured and compared through the lens of science capital-themed learning talk?*
2. *Does the prevalence of science capital-themed learning talk correlate with the visitors' perceived enjoyment of playful interpretation?*

5.1 Discussion of Formal Prototype Evaluation Results

5.1.1 Discourse Analysis Total Scores

In review of the collated discourse analysis shown in Table 4.4 and the averages calculated in Table 4.5 it is possible to make several deductions regarding the data. Overall, the results suggest that the interactive engine projection panel elicited the most science capital-themed discourse. This was calculated by adding up the discourse tally from each engagement experience to give a discourse analysis score; these were then added together to form a total score for each prototype. The discourse analysis total scores were 194 for the interactive engine projection panel and 155 for the augmented reality-enhanced multimodal trail.

5.1.2 Average Experience Score

Similarly, the interactive engine projection panel was also perceived to be most enjoyable by the sampled family visitors due to it achieving the highest average experience score. As shown in Table 4.5, the average scores were 4.5 for the interactive projection panel and 4 for the multimodal trail. As a reminder, the experience score was achieved by prompting the younger member of the dyad to give the interactive interpretation concept a score out of five. This was supported by a visual reference making question more child-friendly (Figure 3-7).

5.1.3 Correlation Between Discourse Analysis Score and Experience Score

The results shown in Table 4.4 allowed the researcher to recognise that 21 out of 26 samples also showed a positive correlation between the discourse analysis score and the experience score. This can be seen by comparing the highest discourse analysis score against the highest experience score for each dyad as they tested the two interactive interpretation prototypes to see if they correlated with the same prototype. In other words, in 81% of cases, the prototype that elicited more science capital-focused discourse was also rated to be the most enjoyable experience by the participants.

In only two cases did the opposite occur, where the prototype indicated to be most enjoyable by the dyad scored lowest in the discourse score. The remaining three samples were inconclusive due to an equal rating of either the discourse score or the experience score.

5.1.4 Dwell Time

An unexpected result from the gathered data was that although the interactive engine projection panel was suggested to be the most enjoyable concept by the participants (according to an average experience score of 4.5 compared to 4 for the multimodal trail) and the one that produced the most science capital-themed discourse (indicated by a total discourse analysis score of 194 for the interactive engine projection panel compared to 155 for the multimodal trail), it had the lowest average dwell time out of the two tested prototypes. As seen in Table 4.5, the interactive engine projection panel had an average dwell time of 1 minute 53 seconds and the multimodal trail had an average dwell time of 2 minutes 12 seconds. This aspect of the findings generates an element of inconsistency related to what has been suggested in the review of literature where some researchers and museum professionals describe dwell time as an indicator of visitor engagement (e.g. Jambor et al., 2020, p. 6; Warpas, 2013, p. 158). The results may simply be an anomaly in the data for this particular study, or it may suggest that the STEM discourse analysis score and the experience score are not ideal indicators of visitor engagement. On the other hand, perhaps controversially, it may suggest that dwell time should be viewed as a more nuanced measure of engagement and not a 'cut and dry' way to compare the engagement success of one interactive interpretation concept to another.

5.1.5 Thematic Categorisations of STEM Discourse

Analysis of the thematic categorisations of the STEM discourse also reveals interesting information worthy of discussion. Visualised in Figure 5-1 below, the catalogued instances of science-talk which occurred over the course of the data collection enabled the researcher to see that interactive projection panel scored highest in five out of seven categories. This coincides with the interactive projection panel being rated overall as the most enjoyable interactive when compared with interactive engine projection panel the augmented reality features of the multimodal trail.

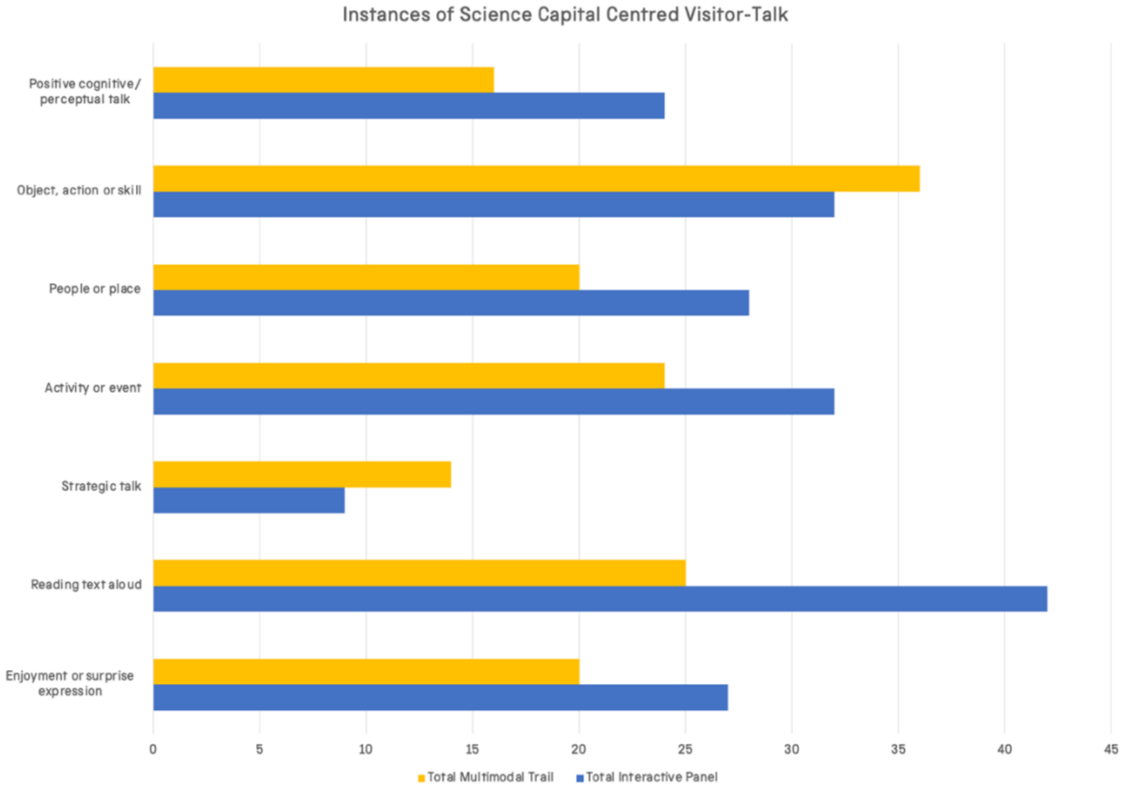


Figure 5-1: Graph to show the recorded instances of science capital related talk during 26 data collection sessions

Using the evaluation system in this way allowed the researcher to identify which prototype performed better at drawing out particular types of science-talk. For example, the interactive engine projection panel appeared to work well at eliciting talk where participants refer to an activity or event. This may suggest that this interpretation approach is helping visitors to extend the reach of the experience by inspiring connections and links with the visitors' own lives. On the other hand, the multimodal trail appears to encourage more strategic-talk than the interactive engine projection panel. This may suggest that the participant, when engaged with the multimodal trail, is taking control of the interpretation experience with a stronger sense of agency and independence. One of the most obvious results was that the interactive projection panel worked better at encouraging dyads to read text information out loud. This *could* suggest that the content is more consumable and fit for purpose in a family-friendly exhibition setting when compared to the multimodal trail. This may be because the text on the interactive projection panel only appears at specific engagement times and upon interaction, whereas the text content on the multimodal trail is more static and only scaffolded with extra text during the augmented reality experience.

5.1.6 Qualitative Questions

In reference to the two questions asked at the end of each engagement experience and collated in Table 4.6, the researcher was able to achieve a simple qualitative data set with which to efficiently review the success and opportunities of the interactive interpretation prototypes. Although the question "What was your favourite thing about it?" helped the researcher to identify which parts the participants particularly enjoyed, the question "What do you think could be better?" was more illuminating in terms of prototype progression and supported the concept of looking toward the periphery of the problem. It was interesting to see that seven participant dyads inferred that there was some negativity around having to use their phone for the augmented reality experience on the multimodal trail. This can be surmised because five dyads stated that the experience could be improved by having a fixed gallery device and a further two more felt that an alternative to using a mobile device was required. Conversely, four dyads stated that the fact that they could use their own device was their favourite thing about the prototype.

Other key take-aways from these qualitative questions were:

- Nine dyads all raised similar points that suggested that the animations were their favourite thing about the interactive projection panel. Audio elements and sound effects were also seen as positive attributes noted by five dyads.
- Seven dyads all stated that their favourite thing about the multimodal trail was that it was different and surprising. The idea that interpretation should be something 'out of the ordinary' is clearly of importance to visitors and in line with the literature review findings which stated that unusual museum experiences can help to generate a sense of wonder and promote memorability (London, 2020)
- Dyads had the most creative and constructive comments about the multimodal trail. This prototype appeared to spark the imagination of the participants with many feeling inspired to suggest adaptions and development ideas.

5.2 Baseline Test Comparison

As described in section 4.3.1, the evaluation methods were initially used with the original Power Hall interpretation in the form of a pilot study and baseline test. Although this was conducted primarily to trial the discourse analysis scoring system and evaluation strategy, it also provided some useful comparative data. The results revealed that the old Power Hall signage had an average discourse analysis score of 2.1 compared with 6 for the multimodal trail and 7.5 for the interactive panel. Likewise, the old Power Hall signage had an average experience score of 2.6 compared with 4 for the multimodal trail and 4.5 for the interactive projection panel. On a superficial level, it could be suggested that the two newly developed interpretation concepts work considerably better at eliciting more science capital-themed discourse from participant dyads and are considered to be more enjoyable to engage with. The new concepts also encouraged the participants to engage for longer, this is determined by comparing the average dwell times, which were 1 minute 53 seconds for the interactive projection panel, 2 minutes 12 seconds for the multimodal trail and 1 minute 5 seconds for the original Power Hall interpretation.

5.3 Discussion of Development Framework and Proto-scoping

During the practice research and in working to provide solutions to the SIM design brief, new ways of thinking about systematic processes for the development interactive interpretation for science museum exhibits have been tried and tested. The process (which has been followed during the course of this research) is outlined in the development framework visualised in Figure 5-2. Embedded within the framework is the *proto-scoping phase* which the researcher puts forward as a contribution to the field of science museum interactive interpretation development.

With the benefit of hindsight and direct experience, this framework has been finetuned and amended allowing the researcher to define a system that could be used as a basis for future STEM interactive interpretation design projects at SIM and other science museum settings. The proposed framework puts emphasis on audience consultation and values visitor input from an early stage in the interactive interpretation development lifecycle.

Underpinned by the theoretical framework outlined in section 3.2.2, the proto-scoping strategy uses a social constructivist ideology and a science capital approach using intergenerational engagement and science-focussed discourse to evaluate the potential of interactive interpretation concepts developed in answer to same design brief.

Proto-scoping promotes an exploratory methodology for looking at interactive interpretation development from a variety of different angles and is reinforced by a strategy for evaluation that could help to gauge intergenerational science engagement success when comparing one interactive interpretation prototype to another.

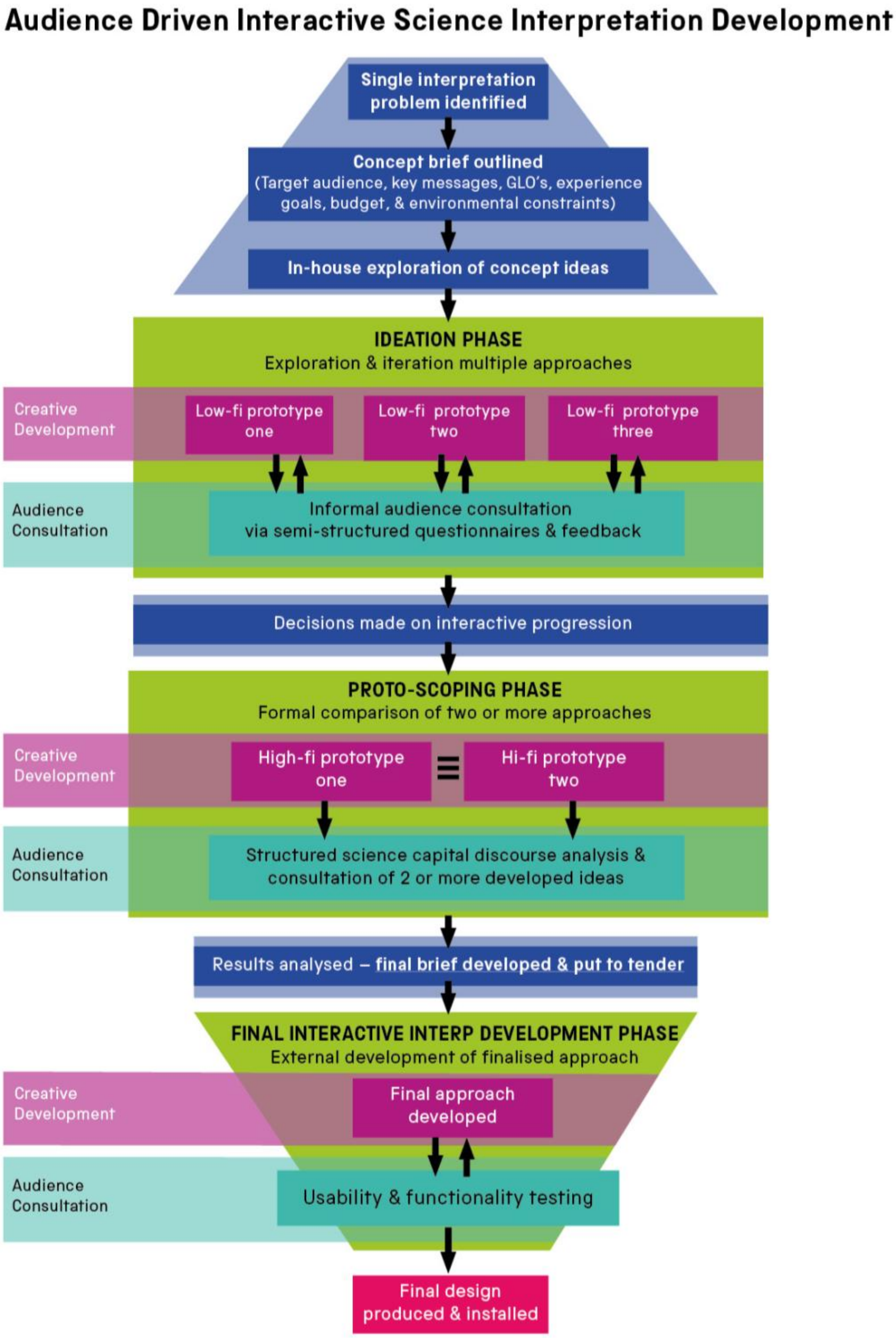


Figure 5-2: Flow diagram to show the newly proposed proto-scoping framework for audience-driven science interpretation development.

Within the proposed science-based interactive interpretation design framework, the researcher suggests that the proto-scoping phase should take place after an interpretation problem has been identified and a *preliminary concept brief* has been created to outline: the target audience, key messages, GLOs, experience goals, estimated budget, and environmental constraints. Proto-scoping should also be preceded by an initial playful and exploratory ideation phase of primary concept ideas translated via low-fidelity prototypes. The results and successes of the ideation phase should feed into the comparative process of proto-scoping using high-fidelity prototypes and a science capital-focused discourse analysis evaluation system demonstrated in the formal data collection element of this research. Following this proto-scoping period of audience consultation and prototype comparison, the museum would then be in a stronger position to create a specific design brief for interactive interpretation approach that promotes science capital development and supports intergenerational meaning-making.

For clarification, proto-scoping differs from the current methodology of prototyping used at SIM and the wider science museum field due to its nature of being more exploratory, comparative and positioned earlier in the interpretation timeline. As discovered during the ethnographic fieldwork of this study, prototyping at SIM and SMG usually focusses on testing one approach in isolation and if successful, carrying it forward to stages of refinement and iteration (see section 4.1.7). The proposed proto-scoping technique instead playfully explores a range of different prototypes in an effort to answer the same interpretation challenge. This fosters a method of thinking creatively about different approaches, testing out ideas and encouraging audience leverage at an especially early stage.

Together, the ideation phase and proto-scoping phase can help to widen the horizon of the interpretation development lifecycle. The framework has been designed as a methodology to think more openly about museum interpretation approaches and to promote new ways of valuing audience input. Offering multiple prototype ideas facilitates an inspiring opportunity for both museum content teams *and* participants, to think more creatively about the interpretation problem. This is opposed to testing out just one desired solution which may risk inhibiting wider thinking or different technological approaches.

In addition, the proto-scoping phase could offer a more insightful way to measure the science capital engagement success of one idea against another, quickly and efficiently, as opposed to detailed observation sessions and questionnaires. The framework's merits lie in its ability to be disruptive. It lends itself well to following different trajectories of interactive interpretation and supports the idea that participants may benefit from this relaxed, creative environment, promoting a sense of freedom to foster new ideas, make pertinent suggestions and take ownership of exhibition decisions. The practice research highlighted that this consultation period led to visitors often feeling liberated to suggest other ideas and approaches that could be considered, even without directly asking for them, some of which were quite different from what was being presented, or used a new technological approach entirely. It was felt that this freedom and creativity would not have been experienced in a later or more restricted phase of prototyping, where just one idea is presented and tested for elements like usability, functionality and visual appeal.

Interestingly, within the proposed proto-scoping format, the creative process *itself* can be used to support science capital development; the participants get 'behind the scenes' exposure to museum interpretation processes and an 'out of the ordinary' opportunity to see how different technologies are being utilised. It facilitates a genuine occasion for their opinions and feedback to be highly valued and participants can take ownership and agency through the consultation process. In this exercise alone, 26 children and their caregivers experienced their voices being acknowledged and their feedback respected. By presenting these interpretation prototypes in an exploratory manner, explaining to the participants that we are investigating different options and comparing multiple approaches, children and families felt free and empowered to suggest new ideas, adaptions and improvements.

An integral part of the proto-scoping phase is the mixed methods evaluation strategy which has also been trialled within the bounds of this study. The discourse analysis method was the focus of the strategy and involved the researcher keeping a real-time tally of categories of science capital-themed utterances during each prototype engagement experience. The tally system and scoring scheme is demonstrated in Figure 3-6 and described in section 3.3.3.1.

By creating a quantitative value for each prototype engagement experience, based on intergenerational science capital-themed conversations, the researcher was able to compare and scope multiple approaches with a view to making confident and authentic exhibition interpretation decisions. Although the literature review suggested that it is not possible to measure how an experience has made an impact on an individual's science capital development (Archer et al., 2015; Science Museum Group, 2020) the categories chosen in the scoring scheme were used to ascertain if the interactive interpretation concepts were eliciting a sense of connection with the science content, invoking moments of joy, reminding visitors of everyday objects and experiences, and promoting social engagement and shared attention.

In comparison with the experience of Allen (2002) and Silverman (1990) (discussed in the literature review section 2.8), who each made recordings of visitors conversations and decoded the audio after the event, the 'on-the-fly' method of the Power Hall/All Shapes and Sizes discourse analysis demonstrated in this study appeared to be more efficient and easy to use. This mode of evaluation found success by being conducted in a more focused situation where participants were engaging with individual interactive interpretation concepts in a controlled space. Furthermore, the coding scheme was focused on a more nuanced, and smaller set of categories compared to existing methods used in museum evaluation. Although discourse analysis studies conducted by Allen (2002) and Silverman (1990) were believed to be very fruitful forms of evaluation and perhaps more naturalistic, they involved much larger exhibition spaces, investigated a broader range of interpretation techniques and involved a more complex coding scheme. Allen and Silverman were then required to listen back through lengthy audio recordings to decipher and analyse the data which was expensive and time-consuming.

The results of this study appear to suggest that intergenerational conversations have the potential to be a valid method of evaluating high-fidelity prototypes especially when supported by other forms of evaluation such as a short qualitative questionnaire. Considering this perspective, the discourse analysis coding scheme makes a contribution in its own right to the field of interpretation development and evaluation in a science museum setting. The method proved to be quick and insightful and has the potential to be particularly suitable for evaluation sessions involving young family audiences. The researcher perceived little participant fatigue as the discourse analysis took place whilst they were engaged with a playful form of interactive interpretation and the brief method of qualitative questioning was kept to a minimum.

5.4 Recommendations

5.4.1 Design Process Recommendations

First-hand experience at the Science and Industry Museum has led to the observations of the systemic processes involved in developing ideas for playful interactive interpretation productions. The approach taken in this research specifically, has been quite different to the observed existing methods. By taking the key objectives and learning outcomes, and exploring a variety of technological approaches, a playful, audience-centred scoping phase could take place through the framework presented in this study (as described in section 5.3). This newly developed, creative process has the potential to generate more clarity on what works for both the visitor and the exhibition. The process allows content teams to test ideas and technological approaches as opposed to teams deciding on one interpretation approach and carrying this straight through to user testing and development.

The researcher found that some SMG ideation processes had the potential to lack a degree of audience direction and although prototyping of the interpretation does indeed take place, this process often comes too late to make significant changes in approach. Neither was there noted a standardised process for audience participation in science interpretation development within SMG. Content teams may benefit from well-defined guidance for audience consultation and visitor agency when developing new exhibition interactives. It is therefore suggested that a scoping and exploratory phase, as demonstrated in this report, may help to identify successful methods of delivery and engagement via audience participation at a much earlier point. This would be a particularly beneficial approach for high value interactive interpretation projects.

The framework would lend itself well to ‘speed proto-scoping’ where a greater number of prototypes could be tested within the same session and compared on the basis of science capital-themed dialogue. If prototyping capabilities or capacity cannot be sourced within the museum, this might take shape as a paid ‘hackathon-style’ process where creative interpretation companies are invited to spend a limited number of days developing their ideas or approach. Alternatively, tendering processes could be delivered with a broader brief requesting a proof of concept which could then be compared against others through a science capital and conversational lens in order to evaluate engagement success. The results of such playful, collaborative and creative processes could lead to interactive interpretations that are more equitable, socially engaging and possess greater powers to build science capital.

5.4.2 Design Solution Recommendations

This work has investigated playful digital interpretation techniques to make visitors feel more connected to steam engine science, provide a sense of joy in the museum environment and support intergenerational engagement. However, the prototypes have a great deal of scope for further inquiry and development where visitor equity and accessibility are concerned.

Firstly, the augmented reality technology utilised on the multimodal trail is only available to audience members with a modern mobile device, this may exclude some visitors from being able to use this feature entirely. The role of the 'Bring your own device' (BYOD) within this investigation was initiated for two reasons. Firstly, by the hygiene considerations triggered by the COVID-19 pandemic, meaning that visitors could use their own device as a tool to access certain elements of interpretation rather than being concerned about cleanliness. Secondly, augmented reality was investigated because this was a technology that could be developed and scrutinised by the researcher from home without the need for external resources. A more equitable solution might be to have exhibition digital devices on hand or installed at the compound of engines. These could be tethered to the compound and set up with the augmented reality elements ready to play. Or another perhaps more user-friendly and inclusive alternative would be to have similar visuals displayed on a large interactive mirror, similar to that seen in Figure 5-3.

Figure 5-3: Example interactive mirror by Abyss Glass (Abyss Glass, 2022)

An interactive such as this would be easy to clean, be highly social (due to its size and capacity for multiple visitors to see) and have an element of fun and surprise for family visitors. It may also bring a further layer to the concept of embodied learning as the visitors would be able to see themselves performing the engine movements in the reflection.

In further reference to accessibility, augmented reality by its nature leans heavily on the visual experience and the prototype is not currently accessible to visitors with visual impairments. Likewise, the interactive projection panel is also visually focused and would benefit from having more enhanced audio features to improve accessibility to a wider audience. Some of the qualitative feedback also revealed ideas to make the interface more three-dimensional, this could be achieved by a raised, tactile outline provided around the engine shape. At the start of this research, it was the intention to make the explored interactive approaches as physical and tangible as possible, not only to increase visitor accessibility and equity but also to explore the more 'hands-on, minds-on' approach. The researcher and SIM team were interested to explore avenues that would enable the visitor to feel the physicality of the engine science being described, for example, the warmth of the cylinder and the inertia of the flywheel. However, again due to the interruptions and the unknown factors of COVID-19 the researcher was forced to look at a less tactile approach to interactive interpretation. It is recommended that if these prototypes were to be carried forward to the gallery environment, special attention should be made to improve equity and accessibility, one such example would be to feature a variety of people in the augmented reality visuals; there is a lot of potential for the easy integration of different genders, ethnicities, and physical abilities.

5.4.3 Investigation Recommendations

With regard to the identified correlation which has been documented between the science capital discourse analysis score and the visitors' experience score, it must be recognised that this was identified on a small sample size and only two different prototypes were tested in this way. It is therefore recommended that a further study might involve a larger sample size and could include an increased number of prototypes to analyse if this correlation can still be seen. Also of note is that although this study only investigates discourse related to science capital themes and categories, it may be that discourse of any kind could be an indication of a visitors' perceived enjoyment of an experience. This may be an additional opportunity for further investigation in the future.

Finally, it should be stated that the scoring scheme is not exhaustive in terms of reliability, particularly related to the codification and the organisation of science capital-themed utterances. A balance was sought between the efficiency of the tool and the identification of science-talk; usability and family-friendly evaluation was made paramount however some may perceive the scoring system to be too generalised or rudimentary. It is recommended that more research time should be applied to this scoring system by testing the requirement for more detailed categories or adding further complexity to the scoring system in order to make sure valuable information is not being missed.

In the analysis and discussion of results, the researcher has drawn out the main outcomes of the study and critically reviewed them in reference to the literature review and the existing field of visitor meaning-making and interactive interpretation development in a science museum setting. The chapter has summarised the main learnings achieved from the evaluation data and discussed the success of the trialled development framework with particular attention to the proto-scoping strategy.

Chapter 6: Conclusion

Via the process of practice research, a new audience-focused and exploratory framework for the development of playful science museum interpretation has been trialled and examined. This involved the creation of four new prototypes focused on engaging families with steam engine science, two of which were formally evaluated using a novel proto-scoping strategy. The researcher utilised a variety of technologies, including animated projections and augmented reality, with the aim to provide family audiences with the tools to playfully investigate and discuss engineering concepts and to facilitate informal learning about five key steam engine parts.

Following a discussion of the data and findings from the high-fidelity prototype evaluation, this concluding chapter provides a summary of the main areas covered in this research and presents defined responses to the research questions (6.1). It discusses the original contributions to knowledge (6.2), outlines industry interest (6.3), research limitations (6.4), summarises project challenges (6.5) and finally, suggests possibilities for future research and development (6.6).

6.1 Research Summary

The practice research conducted in this study has not only been used to address the research questions and investigate the design brief provided by the Science and Industry Museum but it also embodies the proof-of-concept for a unique, audience-driven approach to the development of family-focussed, playful, interactive interpretation for science museum settings (see the previous development framework and proto-scoping strategy discussion in section 5.3). In this case, the theme of steam engine science has been the exploration focus, however, a similar process to the presented framework could also be applied to a wide variety of science interpretation topics. Proto-scoping offers an opportunity to playfully explore an interpretation design problem before the commissioning of a specific concept. It involves the development of a variety of comparative prototypes in response to the same initial brief and assists the ability to evaluate the science engagement success of the concept through a social, intergenerational lens using discourse analysis. Underpinned by the theoretical framework of science capital and social constructivism, the discourse analysis scoring scheme provides each prototype engagement experience a numerical weighting according to the logged instances of science capital-themed talk from the participant dyad. These were scored in real-time according to statement categorisations and quantities via a recording chart and tally system (Appendix I). This approach was designed to give priority and focus to the science capital-themed visitor dialogue that an interactive interpretation prototype may or may not elicit. This situated data collection is presented as being a quick and efficient way to measure science engagement and meaning-making during a family-focused interactive interpretation experience and suitable for fast-paced, comparative prototyping scenarios. It also values and acknowledges Vygotsky's Zone of Proximity by providing evidence of family and intergenerational engagement including utterance to utterance relationships.

By drawing together a variety of informal learning design methodologies and techniques, the researcher has explored a range of technologies and concepts to support steam engine science engagement via the practice of creative ideation and prototyping. The developed products have included online interactive animations via the Green Sock Animation Platform, interactive projections via the Bare Conductive Touch Board/MadMapper as well as an augmented reality enhanced multimodal trail via Adobe Aero and ZappAR.
Although these technologies are certainly not new, they have been utilised in novel ways to explore possible playful avenues to support the development of tacit skills, science capital and in general more joyful, memorable and inspiring experiences with engineering themes. Without being immersed in the practice itself, including the design thinking, ideation and prototype development, it would not have been possible to have a full appreciation of the nuances of an interactive science interpretation project, nor would it have been possible to test the proposed framework for prototype development. The practice has enabled the direct experience of an interactive ideation lifecycle and has illuminated how playfulness can be successfully interwoven within the journey of exploring and analysing interpretation solutions as well as within the product itself.

6.1.1 Main Research Question Conclusion

On reflection of this experience, the researcher has been able to address the main research question: *How can digital interpretation techniques be developed and explored to encourage playful engagement with steam engine science?*

In the literature review, current thinking around the topics of informal STEM learning, playful engagement, user experience design and prototyping situated in the field of science museum exhibition interpretation have been examined. Key themes were synthesised across these topics in order to develop the practice research context. Elements of user agency (Limerick et al., 2014), social engagement and language (Wertsch, 1985) connections and everyday relevance (Limerick et al., 2014; Silverman, 1995) active learning (Antle, 2007) and the disparity of motivations between adult and child engagement with heritage interpretation (e.g. Schaller et al., 2002) all fed into the considerations for a range of design interventions and prototype concepts.

The literature review and fieldwork identified the need for an efficient strategy of development, prototyping and analysis regarding playful, family-friendly engagement concerning complex STEM concepts within an informal science museum setting.

The researcher considered that current methods were not significantly weighted toward the visitor audience and did not offer enough creativity and flexibility to explore interpretation design problems widely. Furthermore, research suggested that evaluation methods used at SIM and the broader field of science museums were not appropriate for comparative prototyping with families.

The results of this study have enabled the main research question to be answered as follows: Digital interpretation techniques can be developed and explored to encourage playful engagement with steam engine science by fostering a mindset for whole family appeal. Interactive interpretation interventions within a science museum setting should have the ability to support intergenerational experiences by promoting engagement with exhibition content and importantly, each other. This study has demonstrated two interactive interpretation concepts that have proved successful at engaging family audiences and eliciting intergenerational discourse when compared to the previous steam engine interpretation for the Power Hall. Broad methods which can help to promote family engagement as well as museum equity include the following:

- Designing STEM interactive interpretation interventions that do not look overly childish nor too adult.
- Use of carefully considered text as a conversational tool, supporting parents and caregivers to feel confident and empowered to distribute and expand upon content.
- Representation and visualisation of every relevance examples to build connections and association. This may promote verbal recall of previous experiences to build further knowledge.
- Physical engagement such as gestures and movement can be used to support embodied learning and promote meaning-making.
- The integration of interactive, playful elements to make experiences more memorable, friendly and accessible, including the 'Pedagogy of Play' characteristics of delight, wonder and choice (Mardell et al., 2016).
- Digital technology offers the ability to enhance experiences and offer appeal to hard-to-reach audiences but fully screen-based solutions should be avoided if possible to promote social and physical engagement within family groups.
- Digital enhancement can be used to facilitate content scaffolding. This helps to support engagement and interest for a wider variety of age groups and abilities.
- Audio features and animation can help to support shared attention and promote a sense of wonder and joy.

When developing family-focussed experiences, a playful, participatory and comparative prototyping approach should be taken to explore the design problem more widely and allow museum visitors a sense of agency and ownership of the design process. The development framework proto-scoping strategy presented in this research is an example of how this process could work in a museum setting. By providing participants with a selection of prototypes as a starting point for collaboration and feedback they can become quickly attuned to the key learning objectives of the project and are provided with a springboard to provoke new ideas, additions or amendments. Offering participants a range of different conceptual approaches can stimulate a more creative and empowering approach to consultation as participants are aware that opportunities are open for enquiry not just finetuning.

6.1.2 Subsidiary Question One Conclusion

The proposed proto-scoping strategy has been used to address subsidiary question one: *To what extent can engagement with playful interpretation prototypes be measured and compared through the lens of science capital-themed learning talk?* This study has presented one example of how discourse analysis can be used to quickly and efficiently compare the success of one interpretation prototype to another. The discourse analysis coding scheme described in section 3.3.3, had its foundations in the work of Allen (2002) and has been adapted in line with a social constructivist ideology and science capital themes (defined by Archer et al. (2015) and Science Museum Group (2021b)). The process supports real-time data gathering to form an easy to compare qualitative outcome and promote visitor co-creation. When supported by a small and child-friendly selection of qualitative questions regarding concept ideation, the discourse analysis coding scheme has shown to be an effective and illuminating way to measure engagement with playful interpretation prototypes.

6.1.3 Subsidiary Question Two Conclusion

The scoring system used within the proto-scoping discourse analysis enabled the researcher to answer subsidiary question two: *Does the prevalence of science capital-themed learning talk correlate with the visitors' perceived enjoyment of playful interpretation?* Signs of a positive correlation between science-themed discourse and experience enjoyment were identified when participants gave their experience a score from one to five (or a visual scale of one to five stars). This figure was then compared to their discourse analysis score for the given prototype. 21 out of 26 samples showed a positive correlation between the discourse analysis score and the experience score. In other words, the more the dyad conversed or vocalised about science capital themes, the higher they appeared to rate the overall enjoyment of the interpretation experience. This may indicate that interpretation enjoyment could have a connection to the level of discourse elicited, and in this case, science capital-themed discourse. This is a significant result because it demonstrates further evidence that by using tools and techniques to promote social and conversational opportunities via museum interpretation, museum content teams may be able to make enhanced contributions towards fostering a more enjoyable museum experience.

6.2 Research Contributions

Besides the creation of two novel, high-fidelity concepts to support playful engagement with steam engine science, this study makes a unique contribution to the field of interpretation design and development within the context of science museum exhibitions. Existing research presents a propensity for a separation of exhibition content for children and adults which usually features different approaches of design, development and evaluation for these two distinct groups. This study, in contrast, offers a departure from this perspective by drawing together methodologies that support meaning-making for a wider range of family or group members and in turn, facilitating social engagement *with* and *beyond* science museum content.

Demonstrated through a new interactive interpretation development framework (discussed in section 5.3), the researcher presents a practical strategy to support visitor consultation through a process of comparative *proto-scoping* (visualised in Figure 5-2). The proto-scoping stage of the devised development framework involves a formal yet exploratory appraisal of two or more high-fidelity prototypes using the evaluation lens of science capital-themed discourse. Existing strategies of participatory prototyping currently used in the field of science museum interactive interpretation development have been found to commonly take place in the later stages of the design lifecycle, after a concept and technological approach have been chosen by the exhibition content team. Such existing prototyping methods are traditionally more iterative and focus on finetuning the visuals and functionality of one approach, in isolation, to achieve a desired solution. Notably, proto-scoping is presented as an additional and earlier phase in the development process with the aim to investigate and scope a range of different approaches in answer to the same interpretation challenge and to open opportunities for evaluation and analysis before a final design brief is written and commissioned. In short, the process aims to broaden the investigation field of prototyping rather than narrowing it too early. In this format, the interpretation concepts become objects of research, supporting adaptations, and facilitating the emergence of new knowledge and direction driven by the target audience.

The discourse analysis scoring scheme which has been trialled during this work contributes to the field of science museum interpretation design and evaluation as it offers an expedient format for prototype analysis which is suitable for STEM-focused family participation and real-time data collection. Previous evaluation strategies are weighted more towards adult participants for constructive feedback and have involved time-consuming surveys and more laborious codification systems (Allen, 2002; Silverman, 1995). The discourse analysis demonstrated in this study forms an integral part of the proto-scoping phase and offers an expedient and efficient way to evaluate the success of a prototype by its potential for eliciting social engagement related to science capital themes. Importantly, the quantitative score for each engagement experience facilitates the ability to easily compare one prototype to another and provides tangible data to share and discuss with the exhibition content team and stakeholders.

Furthermore, using only a very limited number of qualitative questions for each dyad made the evaluation experience practical and straightforward. This was especially appreciated when working with families with younger children who were not keen to stand still for long. It was felt that these participants would not have relished a long questionnaire to complete after using each prototype.

This research contributes further evidence that discourse analysis is a valuable tool for gauging social meaning-making and family engagement. The positive correlation identified between the discourse analysis score and the experience score (as discussed in section 5.1.3) showed further support for the value of utterances and conversations during interactive interpretation engagement. The results suggest that a high level of STEM discourse could be a good indicator of experience enjoyment as well as science capital development. A sense of enjoyment may help a visitor to feel more welcome and connected to the museum environment and may support a reaction that the STEM exhibition content is 'for them'. These are notable steps in building on a visitors' level of science capital (Science Museum Group, 2020). From a broader museum perspective, this awareness of family enjoyment may also lead to making repeat visits in the future, shared news about the experience, and possible enhancements to museum equity.

6.3 Industry Interest

Interest and enthusiasm surrounding this practice research have been expressed from SMG team members and further afield. The researcher has presented the interpretation prototypes and the evaluation strategies at the 2022 Visitor Studies Conference under the theme ‘Evaluation Challenges’ and at the 2021 Museums+Tech Conference under the theme

‘Data Tales’ where she received positive engagement with the work. The craft-based governor activity featured in the multimodal trail was also the focus of a Being Human Festival event hosted at the Science and Industry Museum in November 2022, where 87 adults and 146 children were involved in this humanities research showcasing opportunity. In addition, the practice research is now being used as a case study for Future Museum, the Museum Booster research project, which focuses on supporting museums to apply contemporary and forward-thinking concepts in their strategic planning and developments.

6.4 Limitations

Although efforts were made to make this study as accurate and insightful as possible, there are several limitations that should be acknowledged to appreciate the results in full context. Firstly, the researcher looks toward the limitations of the scoring system being used as the primary evaluation tool to measure and compare science engagement. The technique investigated through this study focuses largely on a science capital discourse analysis framework with an objective to generate quantitative data that can be assessed easily and used as an efficient method for comparing different playful interpretation approaches. The tool has also been used to help to identify any correlations between the quantity of science capital-themed intergenerational utterances and the perceived level of enjoyment of the playful interpretation experience. However, the researcher recognises that this method is not an exhaustive way to evaluate an interpretation prototype and is not a good solution for revealing elements such user interface issues, content concerns and useability problems. Other techniques such as detailed observations and questionnaires may well provide a clearer visitor response and lead to more valuable iterations and refinement in the latter stages of interpretation design. Science capital-themed discourse analysis has the potential to instead enhance and support other evaluation techniques with authentic insights. It is particularly helpful in the illumination it provides from younger children who may not have the attention span or patience for detailed questionnaires.

With further thinking on the topic of discourse analysis, categorising science-talk, moment-by-moment, can also have its limitations. Although the scoring system was intentionally designed to be simple and easy to use, it is possible to miss certain statements, especially in a particularly vocal or excited situation. Similarly, one statement could sometimes be applied to two different categories therefore the researcher must quickly decide which category to score the instance. Although recording visitor conversations carries more ethical considerations and requests for permission, it may be that this route would make the results more accurate because the researcher could return to each session and listen more closely or repeatedly. On the other hand, this would also increase the evaluation time required which has purposely been kept to a minimum in order to reduce fatigue and speed up the prototyping evaluation process. One of the key objectives for this newly developed evaluation process was to ensure maximum efficiency when consulting with visitor audiences.

Another limitation to the study is the hawthorn or observer effect which may have had a degree of influence upon the amount of discourse that occurred during the engagement experiences. Although it was not made explicit to the participants that a discourse analysis was taking place, simply through their awareness of being observed by the researcher (holding a clipboard and pen), participants may have changed their behaviour or vocalisations. This awareness may have encouraged the family dyads to talk more frequently and with more detail in an effort to appear to be more engaged or more enthusiastic about the interactive interpretation prototype. From an opposite perspective, the observer effect may have caused some participants to have talked less, due to a feeling of self-consciousness, uneasiness or being worried about saying the wrong thing. In hindsight, this limitation of the study could have been avoided by commencing more subtle or even undisclosed observation sessions to achieve more authentic or genuine visitor responses.

On a similar note, not unexpectedly, the results found that where the discourse score was recorded to be high for a particular dyad experience, dwell time was also recorded to be particularly long. Although this is a great result for museum interpretation it may be explained that by the very nature of spending more time engaging with an interactive interpretation product, participants simply had more time for more discourse. This could have been due to many reasons, and not just, as one would like to think, because they were feeling especially engaged with the experience. For example, some participants may have been feeling less time pressured that day or generally more relaxed, others in comparison may have felt more rushed and had anxiety about disruptions to their planned day, wanting to get back to their museum visit. Although participation was voluntary and visitors had the option to refuse to join the study, these nuances in visitor mood or circumstance have not been taken into account in this investigation.

In relation to the suitability of this study to be utilised or adopted by the Science and Industry Museum, the Science Museum Group or further afield, the extraordinary circumstances of this thesis must be drawn to the fore. Most pertinent is the fact this study was carried out over an unusually extended period of time due to the Power Hall project being put on pause and delays caused by the COVID-19 pandemic. This resulted in the prototyping phase having the fortuitous advantage of an abnormally generous design period. This time allowed the researcher the freedom to explore unfamiliar technologies and the fundamentals of their development. It is apparent that in normal circumstances, exhibition timescales would commonly be more expedient and time-pressured which may result in less matured prototypes or a limited scope of exploration.

It was considered that the discourse analysis worked particularly well in the user testing and data collection phase of this study because these high-fidelity prototypes were developed to a stage where they could be used independently by the visitor, without the need for too much intervention by the researcher. The prototypes felt reasonably close to gallery installations in comparison to paper prototypes for example, which require more facilitation from the researcher. These advanced productions led to a more natural engagement experience where the visitor could feel more immersed in the interactive, as opposed to a more underdeveloped prototype, produced in more limited time frames, which would require more support from the research team and more imagination and cooperation from the user.

In connection to this point, the introduced concept of proto-scoping took up a variety of resources and a lot of time. Although this may result in a more suitable and fit-for-purpose product, potentially resulting in a more valuable and engaging interactive interpretation solution, some museum teams may view this framework as being too excessive, costly and time-consuming. This view may be taken since the concept involves creating numerous interactive prototypes in answer to a single interpretation problem. If done in-house, the museum employee(s) would need to have awareness of a range of digital skills as well as the time to explore them in detail. A more practical solution could be to commission outside creative organisations to develop the prototypes in a paid bid to tender for the final production, however this process may add significantly to the project costs and impact the final interactive budget.

Finally, from a slightly different *limitations* perspective, it should be noted that none of the user testing and data collection sessions took place in the vicinity of a 'real-life' steam engine. The Power Hall has been closed to both visitors and staff for the duration of this research, and for this reason, the interactive interpretation had to be tested out of context. This was the case for both the researcher and the museum visitor participants. Although this is not considered unusual for the development and prototyping of an interpretation interactive, it may have been more realistic and insightful if the prototype testing had taken place within the Power Hall with the visitor immersed within a steam engine environment, or at least near to a steam engine. It may have fostered more evidence of meaning-making and science capital-themed discourse and a broader sense of connection to engine science. The researcher may also have noticed visitors making more connections and indeed more utterances, in relation to the engine parts featured on the interpretation and those on the 'real-life' engines.

6.5 Project Challenges

When talking about the challenges of this study, the impact of the COVID-19 pandemic cannot be avoided. The situation forced SIM, SMG and the wider heritage and culture industry to think more carefully about engagement and interaction formats in public exhibition settings. For a certain amount of time during the study, the researcher and the Power Hall content team worried that this transformation in physical engagement and contact free play would be a permanent change. For this reason, the researcher had no choice but to move away from the tactile play opportunities that were initially in consideration and look toward opportunities that would allow for far less physical contact. Furthermore, due to museum and university closures as well as public lockdowns, creative and practical development was forced to take place in the researcher's home environment. This meant that the researcher could consider only interpretation prototype ideas that she could create single-handedly without the need for outside support.

Numerous members of key museum staff were furloughed, and the researchers access to resources was reduced. For a large proportion of the second year of this study museums were closed to the public, and physical presence within the SIM environment as well as other museum sites was not at the originally anticipated level. This not only impacted on the amount of in-person gallery research but also the number of data collection sessions, which ideally would have been greater in number. In addition, during the testing events that did manage to take place after the museum opening, a clear sense of anxiety was noticed from many parents particularly those with young children. There was a lot of frustration about gallery interactive features and areas of the museum being closed and children were desperate to engage and play. The researcher was also frequently made aware that the one-way system in place throughout the museum had negative effects on their visit, limiting options for exploration and freedom. As well as the general aura of the visitor experience, the researcher found that they had to work particularly hard to engage with visitors whilst wearing a mask, predominantly with younger children who may have felt more at ease to see a smiling face. During user testing, the researcher had to ensure that all the prototypes that were being used by the participants could be easily cleaned as well as enabling visitors to keep a safe distance apart. Detailed COVID risk assessments had to be made before each session and safety measures were always at the forefront of the consultation sessions.

However, despite the pandemic disruptions, the researcher was able to conceive the constraints as positive and energetic design challenges. The researcher was forced to think more widely and creatively about how to overcome these restrictions which resulted in ideas and techniques that may not have been considered in normal circumstances. Furthermore, staff changes and the ease of online meetings with team members from museums within SMG meant that a more varied group of people were able to collaborate and feedback on the work, helping to refine concepts and identify opportunities. The pandemic challenges required creativity and innovation in the face of a period of uncertainty and both the scholarly research and practice-based ideas and solutions helped to bring a sense of stability and advancement.

Aside from the difficulties bought on by COVID-19, a further noteworthy challenge was simply the sheer breadth of the task in hand. In the early phase of the project, significant time was spent grappling with the project scope and trying to find a relevant and useful position within the ecosystem of the Power Hall reinterpretation. During the first year of work, the researcher was interested to observe how the Power Hall exhibition team wrestled with steer and direction from the wider SMG group, and how the leading SMG methodologies could sit within SIM's thinking and decision-making process, particularly regarding the key goals for the gallery interpretation. Take for example the term 'tinkering' which was a common thread throughout the many discussions. It was clear that there were some complications around the definition of this term and what learning opportunities could be specifically met, when by its very nature, the action of tinkering was characterised to have no set outcome. It was raised that a pure tinkering activity may not be able to offer the 'So what?' value, nor would a tinkering experience easily allow visitors to recognise that they were using specific STEM skills – all features that the team were seeking to fulfil. The team acknowledged that without levels of intervention or instruction, specific learning outcomes were difficult to achieve and hard to measure in a purely tinkering activity.

Similarly, the SIM and SMG approach to climate science was continually put into question during the first year of work. Again, steering from higher up in the organisation led to mixed messages about how, when and where the museum should be addressing this topic. Questions were raised about whether the environmental impact of steam power should instead be the focus of this interpretation task. During this period of exploration, it was an effort to remain focused on the topics of playful informal learning and UX design without travelling too deeply on a variety of related research paths such as psychology, sociology and museology. The focus of the study had to be balanced between meeting the needs of the Science and Industry Museum, managing direction from key supervisors and keeping sight on professional and academic development goals. These experiences made for a particularly valuable learning process by integrating multidimensional stakeholder perspectives into coherent goals and directions through a scholarly framework and iterative prototyping processes.

6.6 Recommendations for Future Research

Although the creative elements of this work have been undertaken specifically for the Science and Industry Museum and the Power Hall project, the interactive interpretation development framework, proto-scoping phase and supporting evaluation strategy are transferrable to other science museum sites. For this reason, there are multiple ways in which this research could be further progressed and tested.

As explained in the limitations section (6.4), this study was conducted over an extended period due to pandemic lockdowns and an exhibition pause. To test the development framework, proto-scoping phase and evaluation strategy presented in this research, a study in a shorter timeframe could be conducted. This would help to examine the feasibility of the process in more realistic conditions and provide a stronger judgment on the practical transferability of the interactive interpretation development framework.

Secondly, an additional aspect of further research could be to test a greater quantity of STEM-focused interactive interpretation prototypes using the proposed discourse analysis scoring scheme. This study only involved the formal evaluation of two high-fidelity prototypes: an interactive engine projection panel and an augmented reality-enhanced multimodal trail. It would be beneficial to investigate if the scoring scheme was successful with a wider variety of different concepts such as a physical, hands-on concept or an entirely digital approach.

Thirdly, the researcher recommends that the evaluation strategy that has been followed during this study should be tested with a larger sample size. This particular study consisted of gathering data from 26 participant dyads for the formal evaluation stage, however, to be more confident in the finding that the prevalence of science capital-themed learning talk correlates with the visitors' perceived enjoyment of playful interpretation (as investigated via subsidiary research question two) a larger sample size should be achieved.

Finally, this thesis has explored and evaluated two interactive interpretation techniques to playfully engage family audiences with steam engine science, however, there is of course a wealth of other avenues and technological approaches that could be explored within this genre. Using the collection of methodologies drawn together from the literature review and empirical research (summarised in 6.1.1), strategies of family engagement could be further utilised and developed. The work acknowledges and underlines the societal value of science museum settings, emphasising that these rich spaces are a powerful asset for developing intergenerational relationships, meaningful engagement and memorable learning opportunities. The researcher recognises that there is much more space for investigation regarding interactive interpretation design and the reciprocal benefits this can bring regarding social interaction between adults and children. The concept approaches developed the within this Power Hall study were heavily influenced by the need for them to be developed single-handed from a home environment due to a large majority of the practice research development taking place during the COVID-19 pandemic. However, with enhanced teamwork, professional skills and additional resources, more technically advanced and creative methods could be developed and evaluated.

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Appendix A. **Draft Creative Brief**

Power Hall Reinterpretation Project

All Shapes and Sizes subsection Enhanced Interpretation

Draft V1 5 May 2020

Creative Brief for Collaborative Award PhD Student Christina Buckingham.

Through a comprehensive knowledge of the Power Hall Project and its aims and objectives, combined with sector research, produce two outline concepts for playful digital interpretation to support STEM literacy in the All Shapes and Sizes subsection of the Making More section of the Reinterpreted Power Hall, one of which should be worked up to prototype testing stage in consultation with the museum team and academic partners.

1. Context

Christina Buckingham has been embedded in the Power Hall Project team since the start of her collaborative award PhD studentship in October 2019. The academic partner for the PhD, *Developing Methodologies of Play in a Science Museum Setting - How can playful digital curation be developed to encourage and support informal learning, intergenerational conversations and the development of science capital*, is the University of Salford, School of Arts and Media.

2. The Power Hall Reinterpretation Project Vision

We will create a beautiful and engaging display that responds to the rich content and inspiring collections that complement the powerful architecture of the gallery. The design and reinterpretation will work seamlessly together to create a visitor journey which draws upon our senses, both when the engines are running and when they are not. The displays will better connect our visitors to the core story of the gallery, exploring the dynamic relationship between humans and engines. We will create a must-see Manchester experience.

Project Objectives

- Create a clear and compelling visitor journey which easily conveys our central narrative.

- ‘People’ the Power Hall, through expression of a new narrative and strong graphic approach.
- Enhance the aesthetic appearance of the gallery by stripping back current clutter to open vistas across the impressive space and producing beautiful and engaging displays.
- Significantly enhance the learning experience for our target audiences by increasing opportunities for participatory experiences and visitor contributions and embedding the principles of ‘Science Capital’ in the interpretation.
- Reveal the inner workings of the gallery, and the maintenance that goes into keeping the engines working, notably in the Technical Hub.
- Careful integration of planned learning programme and engine demonstrations within the gallery design.

3. Narrative

The reinterpreted Power Hall will explore the development of our complex relationship with engines. Ingenious technicians and engineers applied power to industry, transforming the way we live and work. The impact of that transformation was first and forcefully felt in the textile mills of Manchester and Lancashire as the scale of production dramatically increased. The impact rapidly transcended geographical boundaries as the skills and products of the industrial revolution spread across the globe.

Our remarkable assembly of working engines roots us in late industrial revolution Manchester when engines and mass production went hand-in-hand, affecting the very rhythm and quality of our daily lives. The engineers who underpinned the emergence of the first industrial city transferred industrialisation and its products across the globe; having remade Manchester, they helped remake the world in Manchester’s image.

The dynamic relationship between humans and engines is at the heart of our story. Every working engine is a rich convergence of complex moving parts and the intuitive, tacit skills of the operator. Diverse and surprising technicians’ stories will spark wonder at the human vision and skill that make it possible for us to use engines as an extension of our body and will. Visitors will also reflect on human dependency on engines and the immediate and long-term consequences for people, the place they live, and the world we share.

Our interpretive approach will take its lead from the physical, sensory experience of making, maintaining and running engines. Visitors will feel awe at the huge scale and power of the engines, and they will marvel at the beautifully crafted fine details. From the smell of oil and the shriek of steam, to the rhythmic vibrations from a running engine - like the working engines it features, the gallery experience will engage all the senses.

The reinterpretation will raise the profile of technical skill. A hive of human activity is required to make the engines work. Exciting engine care and maintenance activity will be visible, revealing the people and skills needed to keep the Power Hall running like a well-oiled machine. A carefully curated suite of bespoke open-ended tinkering opportunities, engaging interactives and a toolkit of tactile opportunities will allow visitors to engage intuitively and read the engines for themselves. Through participating in the activities visitors will recognise in themselves the key attributes of technicians – problem-solving, precision, logic and team working. These hands-on elements will also be used to reveal some of the key physics principles behind the engines.

The following **Key Messages** will underpin all content:

- There is a dynamic relationship between humans and engines
    - As the world's first industrial city, Manchester is the perfect place to explore the development of our relationship with engines
    - The revolutionary rise and spread of engines between 1850 and 1950 transformed the way we live, work and consume

4. All Shapes and Sizes

Key message and section description tbc

All Shapes and Sizes features 5 working engines in one compound;

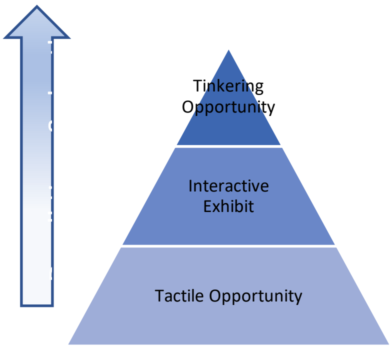
- Grasshopper beam engine, Y1973.13
- Single-cylinder vertical engine, made by John Chadwick, Y2002.19.750
- Double diagonal engine, made by John Wood, Ramsbottom, 1890, Y1970.33
- Horizontal engine and dynamo made by John Dugdill and Sons Ltd, c.1890, Y1970.11

- Steam-driven high-speed electricity generating set, comprising a steam engine made by Ashworth & Parker, Bury, and generator made by Mather & Platt, Manchester, 1910, Y1979.8

See the content hierarchy for detailed content description of All Shapes and Sizes.

5. Hands-On Activities in the Power Hall

There will be three levels of hands-on activity as illustrated below.



It is anticipated that the enhanced engagement for the All Shapes and Sizes subsection would sit at the Interactive Exhibits level of hands-on elements. For detail on the ambitions for the different levels of hands-on activities please see table below.

	What do they contribute to the learning experience?	How might they manifest on gallery?	Hands-on opportunities will:
TACTILE OPPORTUNITIES	A 'taste' of the dynamic relationship Connect to materiality of the collection	Height accessible to 0-4 True to the collection (replica or original object) Appeal to touch Text-lite	- Meet the needs of the target audience ○ Be Fun & Appealing ○ Be Intuitive & Inviting

<table>
<tr><td></td><td>Assist visitors in ‘reading’ engines
Add to multisensory experience
Enhance base-level access and inclusion</td><td>Sensory/Dynamic
Short dwell time</td><td rowspan="3">○ Be Robust & Safe
- Be permanently on gallery
- Work as standalone but enhanced with facilitation
- Provide variety for diverse learning preferences
- Reduce distance between visitors and collection
- Have an illustrated Label
- Be height accessible to wheelchair users</td></tr>
<tr><td>INTERACTIVE EXHIBITS</td><td>‘Illuminate principles/concepts’ of dynamic relationship
Make connections to the collection & story
Deliver key knowledge and understanding
Create a spectacle
Provide ‘light-bulb’ moment
Lighter touch</td><td>True to collection (link to specific object / concept)
Industrial aesthetic
Fixed input
Obvious call to action
Playful
Output is a shared experience
Single-user?
Short dwell time</td></tr>
<tr><td>TINKERING OPPORTUNTIES</td><td>‘Reveal process’ of dynamic relationship
Use & celebrate relevant skills on gallery
Deepen engagement through first-person experience
Doing what ‘they’ did
Empowering visitors – ‘I can do it’</td><td>Authentic – link to real world
True to collection (inhabit skills/roles of people)
Open-ended
Multiple outcomes
Social
Space and time to explore
More than one family unit</td></tr>
</table>

	Increase self-recognition on gallery – 'like me' Drive empathy in visitors	Loose parts?	

6. Supporting STEM Literacy in the Power Hall

The reinterpretation of the Power Hall will support STEM literacy through effective STEM engagement, informed by a science capital approach. Our unique technical collection, the concepts manifested within them and the stories they hold are a fantastic learning resource that have the potential to inspire wonder and ignite curiosity around the impacts of STEM on our everyday lives now, and in the future.

STEM literacy & Science Capital

STEM literacy: "the ability to identify, apply, and integrate concepts from science, technology, engineering, and mathematics to understand complex problems and to innovate to solve them"

Broadening and deepening STEM literacy has both individual and societal benefits. The concept of science capital helps us to understand why some people actively seek out and engage with STEM experiences and others do not. It also highlights how these patterns of engagement map against existing societal inequalities.

Effective STEM engagement should:

- Start from and value peoples existing STEM knowledge and build on it
- Broaden their perceptions of what science is and where they might use and encounter it
- Consider the visual and verbal language used to communicate STEM to ensure that people feel included and empowered

Target Audience and their attitudes to STEM

The target audience for the Power Hall, and therefore for this enhanced interpretation is our Engaged Community Drivers segment. Engaged Community Drivers;

- Made up 52% of visitors to the museum in 2018/19 (most recent complete data)
- Vast majority are on a general visit rather than here for something specific
- Stay for a couple of hours
- Just over two thirds visit as a family with 1 in 3 having a child under 4 with them
- Experiment! is their favourite thing
- 15% BAME, 72% NS-SEC 1-4
- Just under half are from Gtr. Manchester
- Around a third are repeat visitors
- Nine out of ten would definitely recommend a visit

Engaged Community Drivers arrive at the museum with a learning motivation and expectation. They are warm to STEM content and want to understand how it affects people's lives, in the past, present and future.

To connect to technical collections and stories they want to develop their understanding of how things work, in a way that is social and shared. They want to understand how technology has changed over time and need technical content to be creatively interpreted. They believe science is a valuable tool to increase our understanding of the world but do have concerns around negative impacts on communities and the environment.

We recognise that there will be varying degrees of prior knowledge within (and outside) our target audience but are aiming to make the STEM content as intellectually accessible as possible, drawing upon everyday knowledge and familiar language encountered in the wider world.

How will supporting STEM Literacy help deliver our key message?

Our approach to STEM literacy needs to chime with our other key areas of STEM engagement around Transferable skills, People like me and Everyday examples. These will bring the concepts and phenomena alive for our target audience in a personalised and memorable way.

“There is a dynamic relationship between humans and engines”

Supporting STEM literacy in the Power Hall will:

Provide an accessible introduction to the key concepts that underpin how engines work – using familiar visual and verbal language

Invite people into this dynamic, ongoing story by building upon their lived experience

Broaden perceptions of STEM as something that they can use, shape and influence

Add to visitors’ sense of enjoyment and satisfaction

STEM Content in the Power Hall

We know from audience research that a key question visitors want their learning experience to answer is ‘How does (it) work?’, It is this question that we feel the enhanced interpretation in All Shapes and Sizes could support our visitors to explore.

A satisfactory answer to this question can range from ‘What was it’s purpose?’ through to ‘What is the phenomena I am observing?’. However, central to a satisfactory learning experience is developing an understanding of how what they are engaging with relates to them and their life.

This relevance can be built through a conceptual or social lens, or indeed combine both.

Building on lived experience and prior knowledge

Given the historical and technical nature of our collection it is likely that the majority of visitors will have limited prior knowledge and understanding. Where they do (i.e. gas boiler at home) we anticipate they will need to be actively supported to make the connection and apply this knowledge in our gallery.

Our STEM approach will need to reduce the (perceived) intellectual distance between them and the objects.

A Power Hall Curriculum

We have been influenced by the content narrative developed for NRM's Wonderlab gallery to identify simple principles which are supported by an accessible knowledge statement to frame them as interlinked concepts.

As well as these specific content links to the National Curriculum, there is significant opportunity to link our Skills approach to the embedded curriculum strand of 'Working and thinking scientifically'.

	"There is a dynamic relationship between people and engines"		
Concept	HEAT & EXPANSION	MOVEMENT	ENERGY TRANSFER/POWER
Narrative explanation	Engines need a heat source to start a chemical reaction that releases energy.	An engine's design captures energy to exert a force and create movement	Once running, the moving parts of an engine can be used to transfer energy and generate power to do work
Simple scientific explanation	When you **heat** a substance up, **energy** is transferred to the tiny particles it is made from. They move more, taking up more room and cause the substance to **expand.**	A **force** is needed to **move** something or change its position. The amount of **energy** required to exert a force is called **work**.	To do **work**, you need to **transfer energy.** The rate at which it is transferred is measured as **power**.

Curriculum links	Changes of state and materials Chemical reactions and particle models. Fuels & combustion Pressure	Shapes and direction Forces & friction Speed, momentum & direction	Energy/power transfer Mechanisms/mechanical systems for energy transfer Electricity circuits Voltage and current Efficiency of energy transfer
Collection links (Best examples and star objects)	Lancashire Boiler (MM) Crossley Atmospheric	(ET) Haydock Colliery Beam* (MM) Firgrove* (C) Pender*	(MM) National Workshop* (MM) Firgrove Mill* (OD) National Diesel Buxton* (C) Pender*
Key vocabulary	Solids, liquids, gases, changes of state, pressure, chemical reactions, particle model, energy, combustion, exothermic, endothermic.	Movement, linear, rotary, forces, friction, resistance, speed, pushes, pulls, momentum, newtons, direction.	Electricity, circuits, conductors, insulators, levers, pulleys, gears, voltage, mechanisms, changes of state, current, volts, ohms, properties of materials, efficiency, renewable, non-renewable.

7. How might this work for the All Shapes and Sizes subsection?

When the gallery is unfacilitated we appreciate that conveying the full story of how an engine works through standalone interpretation alone is challenging.

- The mechanics of an engine are connected chain where each step is vital to their function

- There is no single object that has archetype examples of all the key parts
- Not all key parts or phenomena are visible even when an engine is running

Static text and even diagrams are limited in overcoming these challenges but there is an opportunity for animated labels/interpretation.

Within the content hierarchy a subsection within Making More, All Shapes and Sizes, is designed to examine how an engine's form and function are intrinsically linked.

The objects in All Shapes and Sizes comprise a clearly defined compound of small working steam engines. They are in close proximity to each other, visually distinct and had a variety of interesting applications.

We believe this section and arrangement of objects provides us with a rich opportunity to introduce the idea that all engines have common features which can be arranged in different ways to solve different problems.

We want to explore how enhanced interpretation for this group of objects could provide a useful overview of the mechanics of an engine in relation to the distinct features visible on each engine. We imagine this would combine both object level (tactile opportunity?) and group level (AV or digital) interpretation.

We hope that this display would provide a starting point for less-confident visitors and empower them to explore other areas of the gallery. Almost an interactive suite within an object-rich gallery that becomes a destination for supporting STEM Literacy.

Engine	Key part

Grasshopper	Cylinder
Double Diagonal	Fly wheel
Chadwick A-Frame	Governor
Dugdil	Belt connection
Ashworth & Parker	Crank

8. Summary of How Engines Work

Please note this is for context and understanding. It is not suggested that all the detail below is including in the enhanced interpretation.

There are two broad types of engine in our gallery;

- Steam (External combustion)
- Internal Combustion

And some moving engines

- Locomotives

Steam

https://www.youtube.com/watch?v=fsXpaPSVasQ

1. A BOILER full of water is heated by burning fuel (coal or gas)
2. When water is heated to boiling point it evaporates, turning into steam.
3. As the water turns into steam, it expands and tries to take up 1700 times more room than the water but because it's trapped inside a boiler it can't. This creates really high pressure and when we let it out of the boiler it rushes along the pipes to the engine's STEAM CHEST
4. From the steam chest, the steam rushes into one end of the engine's CYLINDER and pushes the PISTON across (linear motion)
5. At the end of the piston is a CONNECTING ROD attached to a CRANK

6. The crank is mounted off-centre on the FLYWHEEL to turn it (rotary motion)
7. Each rotation of the wheel moves a VALVE in the steam chest to switch which side of the cylinder the steam can enter, when the steam goes in at the other end of the cylinder, it pushes the piston back again and pushes out the used steam through the EXHAUST.
8. This moves the connecting rod back and forth (either vertical or horizontal motion)
9. Once the wheel is turning this can be used to drive BELTS and transfer the power to a MACHINE
10. The belts carry rotary motion from the flywheel but you can change the type of motion with GEARS

N.B. Some engines have two cylinders, so they use the steam twice before it leaves through the exhaust pipe; once in the high pressure [small] cylinder and then once in the low pressure [big] cylinder. Really big engines use the steam three times before exhausting it; the third time they cool the steam down really fast to make a vacuum and this helps suck the piston towards one end of the cylinder as well as pushing it with the steam.

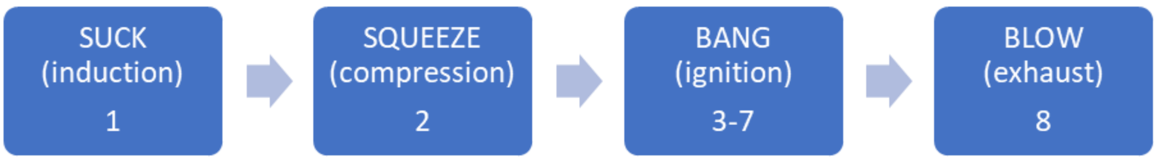
Steam engines require large amounts of fuel to create steam and are inefficient in terms of turning that heat energy into power.

Internal combustion (four-stroke)

https://www.youtube.com/watch?v=Pu7g3uIG6Zo

1. The PISTON is drawn out (manually on old engines by a slight turn of the wheel) like a syringe to suck in air (oxygen) through the AIR INTAKE and fuel in through a VALVE. Air and fuel mix together in the CYLINDER (gas/diesel)
2. As the piston moves back it compresses the fuel and oxygen, this gets it really hot and ready to ignite.
3. The IGNITION provides a spark to trigger an explosion.
4. The force of the explosion throws the piston really fast to the other end of the CYLINDER.
5. At the end of the piston is a CONNECTING ROD attached to a CRANK
6. The crank is mounted off-centre on the FLYWHEEL to turn it (rotary motion)

7. The power generated by the explosion provides enough momentum for the wheel to keep turning and keep the cycle going.
8. The piston is pushed back by the momentum from the flywheel and pushes out the used gas and air though its EXHAUST VALVE, (linear motion, vertical or horizontal).
9. Once the wheel is turning this can be used to drive BELTS and transfer the power to a MACHINE
10. The belts carry rotary motion from the flywheel but you can change the type of motion with GEARS



With an internal combustion engine because the ignition happens within the engine a small amount of fuel can produce a big power stroke.

Locomotive

1. There is no further transfer of power required
2. The ENGINE turns the WHEELS
3. The locomotive moves along the TRACK

Regulating engines

GOVERNORS – Engines can gather too much momentum as they run and spin the wheel out of control. As the flywheel turns it also drives a spinning set of hanging circular weights. The faster they spin, the more lift they generate through centrifugal force. As they lift they pull a valve across to restrict the amount of steam or fuel able to enter the cylinder and slow the engine down. They are called the governors because they are the 'boss' of the engine.

FLOW RATE OF FUEL – On most of our engines you can manually adjust the flow rate of steam or fuel coming into an engine's cylinder to regulate its power.

WATER JACKET – the cylinders on combustion engines get so hot from housing repeated explosions that they could melt themselves! Instead a coolant is used to stop this from happening. On our engines this is often a tank that wraps around the cylinder, with a constant cold water supply being flushed through it.

OILING – all moving parts on an engine need oiling to reduce friction. Unwanted friction not only makes your engine less efficient but leads to wear and tear on the parts. The type of oil you use depends on the function it is lubricating. Parts that come into contact with steam need thick, treacly oil so it doesn't get blown away by the lively steam. The other parts of the engine need a thinner oil that can soak into all the nooks and crannies.

9. Visitor Experience

   The enhanced interpretation should be creative and fun, appealing to both adults and children. It should be attractive with an obvious call to action when not in use by visitors drawing visitors to it.

   It should encourage intergenerational conversations – parents and carers sharing knowledge with children, but also thanks to use of curriculum linked language enable children to support parents.

   We want visitors to feel active while engaging with this interpretation.

   The object level interpretation should be accessible by 2/3 visitors at once (with the main limiting factory probably being space around each object). The Group level interpretation would be accessible by a larger group of around 6-8.

   We would like to encourage a dwell time of 1-2 minutes in this area of the gallery.

10. Learning outcomes

11. Design requirements

- **Design Style** - the development for the design style for the prototype will most likely precede Concept Design sign-off for the Power Hall Reinterpretation project, therefore the style at present should follow the SMG Brand Guidelines. It may then need to be adapted going forward as the gallery design progresses.

- **Robustness** – any concept should be able to be reproduced on gallery to give a robust, low maintenance exhibit. It is anticipated that
- **Lifespan** – the gallery will have a 15-year life span. Consideration should be made as to how often the interactive might need to be updated in this time and what that might involve.
- **Facilitation** – the Power Hall will be staffed daily but in most instances visitors will be using this exhibit independently. This will be an important consideration during design development especially in relation to intuitiveness and robustness.

12. Access

The Science Museum Group adopts the social model of disability, which focuses on the barriers within society that disable people, rather than on individual differences or needs. We recognise that visitors face a range of barriers when visiting museums including:

- **Sensory barriers**: including; only providing information visually or the creation of noisy environments
- **Physical barriers:** including; narrow walkways, insufficient seating or lack of knee-space for exhibits
- **Intellectual barriers:** including; the use of complex scientific information, lengthy written information or unclear instructions
- **Attitudinal barriers:** including; negative representation of people who have disabilities (i.e. as victims) or the lack of representation of disabled people within society

The aim to increase access for visitors with disabilities will therefore focus on reducing barriers.

The design of the Power Hall must be fully accessible, both physically and intellectually. It is the Science Museum Group's aim not just to meet the minimum requirements of the Equality Act, but to exceed them through inclusive design solutions, which benefit all our visitors. As far as possible working within an existing object layout the design should comply with the SMG ACCESS TOOLKITS.

13. Formative evaluation

There should be at least a two stage prototype testing for this stage of the ideas development

1. **Proof of concept** – a simple prototype should be created to illustrate to the museum team how the concept will work
2. **Prototype testing** – a prototype of the exhibit should be tested by museum visitors (minimum numbers to gain reliable data of 20-30 visitors). This stage should include observing visitors' use of the exhibit/s at close quarter, then interview the visitors about what they did, why they did that and what they feel about the exhibit. Concentrate on evaluating whether visitors can operate the exhibit (and if not where and why do they get stuck); whether they find the activity challenging and appealing; and whether there is any evidence that the learning objectives are being met. A concise written summary of findings should be provided to the museum team.
3. **Updated prototype testing** - If required a new prototype should be developed incorporating improvements identified during the testing with visitors at Stage 2. The same procedure should be followed as for Stage 2 prototype testing.

14. Budget

15. Programme

W/c 4 May 2020	Creative Brief issued to CB
May 2020	Development
Mid-late May	Schedule in session with PH team to discuss any issues
Early/mid June?? 2020	Initial concepts pitch (CB to PH team)
July 2020	Pitch to SMT?
End July	Concept approval & discussion on how to take forward
July-September	Design development
October Half term?	Prototype testing

Appendix B. **Participant Information Sheet**

OBSERVATION SESSION

Title of study: Developing Methodologies of Play in a Science Museum Setting - *How can playful digital curation be developed to encourage and support informal learning, interaction and intergenerational conversations?*

Name of Researcher: Christina Buckingham

You are invited to take part in a study of the use of digital interactives at the Science and Industry Museum. The observations from these sessions will help to inform the future development of digital interpretation within the galleries.

We will be looking at how you engage with the newly developed prototype installation and whether you come across any problems. The data we use will not include any personal information such as names or contact details and we will not be taking photos or videos.

The observation will not last longer than 15 minutes and will simply involve the researcher observing and taking notes of your actions.

If you have a concern about any aspect of this study, you should ask to speak to the researcher by email (Redacted) who will do their best to answer your questions. Following this, if you have any issues or complaints, you may contact the research supervisor Dr. Insook Choi by email (Redacted) or by telephone (Redacted).

University of Salford MANCHESTER

Appendix C. **Participant Consent Form**

OBSERVATIONAL STUDY

CHILDREN AND YOUNG PEOPLE

Date: 07.03.20 Version: 3

We are conducting research on the usage of digital interpretation at the Science and Industry Museum through observational studies. We will be looking at how you and your child/young person engage with a newly developed prototype installation.

The data we use will **not** include any personal information such as names or contact details and we will **not** be taking photos or videos of you, your child or your group.

We would like your permission before we take notes and observations.

CONSENT:

I confirm that I have read the Participation Information Sheet dated 07.03.20 (version 3) for the above study. I have had the opportunity to consider the information and ask questions. I am therefore happy to proceed with the activity and give permission for my child/young person to be observed.

Signed	
Date	

University of Salford MANCHESTER

Appendix D. **Ethical Approval**

Research, Enterprise and Engagement
Ethical Approval Panel

Doctoral & Research Support
Research and Knowledge Exchange,
Room 827, Maxwell Building,
University of Salford,
Manchester
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk

11 March 2020

Dear Christina,

RE: ETHICS APPLICATION–AMR1920-007 – Developing Methodologies of Play in a Science Museum Setting - How can playful digital curation be developed to encourage and support informal learning, interaction and intergenerational conversations.

Based on the information that you have provided, I am pleased to inform you that ethics application AMR1920-007 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting A&M-ResearchEthics@salford.ac.uk

Yours sincerely,

Dr Samantha Newbery
Chair of the Arts & Media Research Ethics Panel

Senior Lecturer in International Security / Politics and Contemporary History
School of Arts and Media
University of Salford
Salford M5 4WT
t: +44 (0) 161 295 3860
s.l.newbery@salford.ac.uk

Appendix E. **SMG Audience Engagement Framework**

SCIENCE MUSEUM GROUP

AUDIENCE ENGAGEMENT FRAMEWORK

HOOK, INFORM, ENABLE, EXTEND, REFLECT

A good science and audience engagement experience needs five simple ingredients – **Hook, Inform, Enable, Extend** and **Reflect (HIEER).**

HOOK

How you capture people's attention or spark their interest.

A good hook can be achieved through:

- Introducing the content in surprising ways, e.g. with games, humour, popular culture.
- Sparking curiosity ('did you know...?').
- Inviting, open questions and language.
- A captivating stand or event title.
- Using the awe and wonder of seeing the 'real thing' or something new, bright or intriguing.
- Linking content to people's everyday lives and interests.
- A genuine smile and a warm welcome.

INFORM

How you share information or content and how you link and build on people's existing knowledge.

Information can be shared by:

- Providing information (including skills, STEM content) through a variety of formats, e.g. 1:1, video, animation, images. text, labels
- Using objects or working models to highlight STEM principles and concepts.
- Using social, historical or personal stories which help put STEM into context.

ENABLE

How you give people the opportunity to actively do something and interact with the content for themselves.

Get people involved through:

- Thought-provoking questions that get people thinking and talking, by themselves, with you or each other.
- Doing hands-on activities.
- Challenges or competitions which 'gamify' the experience.
- Self-discovery activities to help people take ownership of the experience (e.g. plat, exploring with all senses, experimentation)
- Using and developing STEM skills

EXTEND

How you make your experience last longer and encourages people to continue exploring.

Ideas include:

- Challenges to complete on the way home
- Links to other things (e.g. in the museum, event, other curriculum topics)
- Suggesting questions for people to think and talk about or research further
- Activities to do at home, at school or out and about, e.g. digital games, hands-on activities.
- Signpost to further information

REFLECT

Continually reflect on your audience's experience and your practice **before**, **during** and **after** developing and delivering any STEM activity using the engagement reflection points and make appropriate changes.

sciencemuseumgroup.org.uk/ academy

Appendix F. **Discovery Phase Events**

Date	**Title of training course/module/conference**	**Key learning aim and/or relevance to study**
9.10.19	Salford Induction	Ascertain formalities and requirements for university studies.
28.10.19	NWCDTP Annual Conference	Meet cohort make NWCDTP links. See where links can be made, and possible knowledge and resources shared.
9.10.10	PGR Welcome and Induction	Explanation of the researcher roadmap - planning ahead for key milestones.
10.10.10	Researcher Development. How to pass the IA & IE assessment.	Exploration of what the assessment is and what is expected. Plan for how the IA and IE will help to inform the thesis and prepare for the viva.
10.10.10	Researcher Development. Strategies for developing your thesis.	Support and guidance for developing the research question/s. Spot gaps in the research. Provision of Salford library information.
10.10.10	Researcher Development. Integrity and Compliance.	Awareness of google scholar profile. A PhD is original and public. Make a data management plan, Office 365/fig share.
10.10.10	Research Ethics Workshop.	Information about ethics application – note this can take up to 3months. Awareness of

		due diligence process. Need to complete GDPR course.
11.10.10	Researcher Development. Literature Searching for your PhD.	Best practises for literature review – use proquest and google scholar. Set up alert on Zetoc British Library Resource. Make a keywords list.
11.10.10	Researcher Development. Introduction to Endnote and Reference Management.	Using EndNote X9 to build library of references. Instructions on how this links with Word. Advise on where to store files, create groups and manage references. APA 6th
24.10.10	Media Framework Training	Introduction and access to Media Framework, identifying opportunities for development and project integration.
26.10.10	Learning Design Research (LinkedIn course)	Quantitative and qualitative research techniques. Detailed information on ethnographic data gathering and graphic research.
28.10.10	Meeting of Minds Conference	NWCDTP introductions, funds available for fieldwork or partnerships. Access to training at other universities. Think about: What is my unique area of focus
04.11.19	Science Museum Group Conference: The Place of Industry	Get a wider context of the museum group. Listen to key presentations and identify networking opportunities. Talks about relevance to modern audience and advancing understanding and knowledge.

		Key relevant terms: active learning display and transformative experience.
07.11.19	LinkedIn Learning Course: Time Management	To support with techniques for managing time and work progress. Help with working more effectively and efficiently.
19.11.19	Future Museums Conference: Play and Design	Made industry links and awareness of current research in play. Collected information for literature review and learnt about current research techniques at the V&A.
25.11.19	NWCDTP Residential	Met cohort, made NWCDTP links. Learnt about placement and internship opportunities.
29.11.19	Completion of **GDPR** Online Training Course and Examination.	Data collection considerations – awareness of GDPR and privacy.
2.12.19	Researcher Induction & Research Ethics Online Module	Certificate received.
11.12.19	Siemans Apprentice Presentations	Analysis of approach to research. Evaluation of opportunities for collaboration and to build on established work.
12.01.20	LinkedIn Learning Course: Raspberry Pi Fundamentals	To get an initial understanding of 'Internet of Things'. Review of use with practical project.

21.01.20	Submitted Ethics Approval	To analyse ethical considerations and to gain permission to conduct / record observations.
22.01.20	Media Framework training session	Deeper understanding of MF and how such sessions are delivered and to identify opportunities for collaboration and use of existing skills and resources.
27.01.20	Power Hall Pin-Up Workshop	Greater understanding of the Power Hall content and the goals of the exhibition.
29.01.20	SIM away day	Project management awareness. I learnt about past, ongoing and future exhibitions.
11.2.20	LinkedIn Learning Course: Prototyping for play: tinkering with hardware in a connected world / with Jerry Belich. 6 hr online training session.	Learn more about the capabilities for electronics, alternative controllers. Gained inspiration for tactile user interfaces.
19.2.20	Visit to Think Tank (Birmingham) Steam Exhibition	To look at what is on offer at other science museums. Case study work and research.
27.2.20	Designing Museum Experiences in the Digital Age. Gallery X Study Day	To gain inspiration for developing a digital museum experience at SIM. Learnt about the significance of taking risks and pushing boundaries.
11.2.20	Sun Exhibition Evaluation Session. Summative	Emphasis on serving visitor expectations.

	Evaluation of a Temporary Exhibition	Methodologies used for data collection; tracking, observation and focus groups. Importance of audience profiling (Engaged Community Drivers).
11.03.20	Ethics Approval Granted	To commence in data collection.
16.03. 20	Observation of User Testing Session at MediaCityUK	To see the process of an 'in action' user interface testing session. Understand more about evaluation techniques.
1.4.20	Skills Engagement Workshop (SIM Content Team)	Skills are the bridge between the human engine relationship. Skills provide relevance for people today. – They bring the story of the power hall up to date (the contemporary story).
8.4.20 and 15.4.20	People Stories Workshops (SIM Content Team)	'People' need to be represented on every form of interpretation in the Power Hall. People and their stories are tangible. Visitors like to make connections between the past and the present.
16.04. 20	LinkedIn Learning Course: Designing Emotion – How to use design to move people	Thinking about bringing 'people's stories' into the Power Hall. Drawing on emotions and ethnographic design challenges. How and why people respond to design and interpretation. Visceral/behavioural/reflective response.

28.04.20	STEM Literacy Session (SIM Content Team)	Clarify STEM language based on 3 core principles: Heat and expansion, movement and Power Transfer.
29.04.20	Contemporary People Stories Development Session (SIM Content Team)	Observation of team meeting and understand how exhibition content can be bought up to modern day. Compare past with present.
01.05.20	University of Salford Writing Bootcamp	Writing session to help focus literature review and report. Help will concentration techniques.
06.05.20	Interpretation Ecosystem Workshop (SIM Content Team)	Gain a perspective on interpretation goals – empower adults to feel it's for them, intuitive call to action. Identify key skills e.g. observation, experimenting, testing, teamwork, creativity, problem finding, adapting, improving.
14.05.20	All Shapes and Sizes Creative Briefing Meeting (SIM Content Team)	Gain more clarity and direction for the chosen exhibition direction.
21.05.20	Power Hall content - Gallery & Section GLO's (SIM Content Team)	Get a better grasp on the key learning outcomes for the 'All Shapes and Sizes' compound.
22.05.20	LinkedIn Learning Course: 'Working in teams and leadership	Learning about psychological safety within the team and evaluating my own approach within the SIM team.

Appendix G. **User Personas**

Persona 2			
Age:	5	School Year:	Year 2
Gender:	Female		
Personality:	Bold and confident, eager to please and eager to learn. Loves museum trails and watching the museum shows.		
Motivations for visit:	A regular visitor to the museum, her dad in particular enjoys the exhibitions and facilitates the trip.		
Experience with technology:	Not overly familiar with tech, very limited use of screen and devices at home besides TV.		
Relationship to science:	Interested in dinosaurs and space science and wants to be an astronaut.		
Museum visit group:	With mum, dad (who works as an engineer) and older brother.		
Profile:	Penny is five years old and lives with her parents and older brother close to the city centre. She loves crafts and visiting interesting places. They usually visit museums and attractions in Manchester on a Saturday.		
Goals and Pain Points:	She enjoys reading to her ability but prefers to do hands-on activities. She does not like to spend too long in one space, and gets annoyed with her dad for spending a long time reading labels. Her dad is always on the lookout for interesting facts to share with Penny.		

Persona 3			
Age:	8	School Year:	Year 4
Gender:	Female		
Personality:	Energetic, fun loving, likes football and other sports.		
Motivations for visit:	His second visit to the museum, this time it's an outing with friends. The visit was organised by the 'mums'.		
Experience with technology:	Very familiar with gaming tech, uses his parents mobile phone a lot, and has his own tablet and Xbox.		
Relationship to science:	Not that interested in science, his only obvious connection is through school but he does enjoy experiments.		
Museum visit group:	With mum and two brothers visiting to meet up with another family.		
Profile:	Jamil is eight years old, loves football and plays for a team on Sunday mornings. He likes to play on the Xbox online with friends. Does not like reading or writing very much. Mum works as a teaching assistant, Dad is a PE teacher.		
Goals and Pain Points:	He likes to be physically active especially when out and about at the weekend. He likes museums that give him the chance to get actively involved. His mum likes to find activities that will get him away from a screen. Jamil gets annoyed when his mum and her friend are not taking any notice of the museum activities, she doesn't join in, just stands talking to her friend.		

Persona 4			
Age:	6	School Year:	Year 3
Gender:	Female		
Personality:	Shy, inquisitive, enjoys board games, animals and swimming.		
Motivations for visit:	On her first visit to the museum, she is with her grandparents for the day, they have travelled into the museum on a train then a tram.		
Experience with technology:	Quite confident with tablet technology, and uses her parents mobile phone regularly. Does not play many computer games. Enjoys going to coding club after school.		
Relationship to science:	Quite interested in science, her Dad is a computer consultant and her Mum is a midwife. Enjoys science at school.		
Museum visit group:	With both grandparents. They are on a tight schedule as they are going to the theatre after lunch.		
Profile:	Sara is an only child, she spends most Saturdays with her Grandparents which she enjoys. She		
Goals and Pain Points:	She enjoys finding out new things and likes to read broadly. She is looking for easy-to-learn facts to tell her parents and teachers about. She picks up any flyers available. She likes to take her time around the museum and does not like to rush. She avoids taking part in group activities and gets nervous in crowds.		

Appendix H. **Sample Pages from the SMG Brand Toolkit**

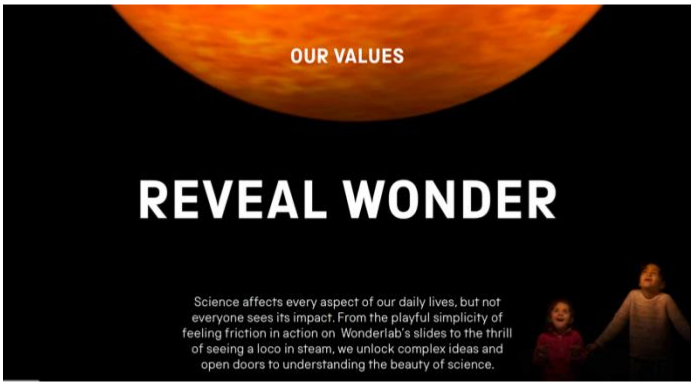


Figure 0-2: Brand Toolkit Page 8 (Science Museum Group., 2018)

Figure 0-3: Brand Toolkit Page 12 (Science Museum Group., 2018)

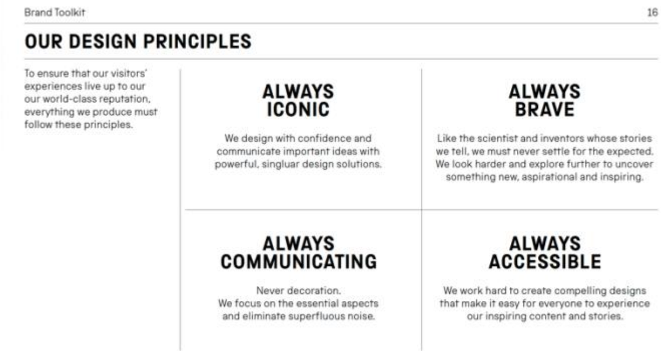


Figure 0-5: Brand Toolkit Page 16 (Science Museum Group., 2018)

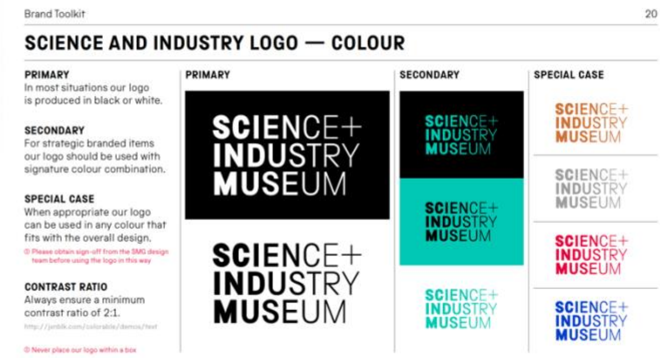


Figure 0-4: Brand Toolkit Page 20 (Science Museum Group., 2018)

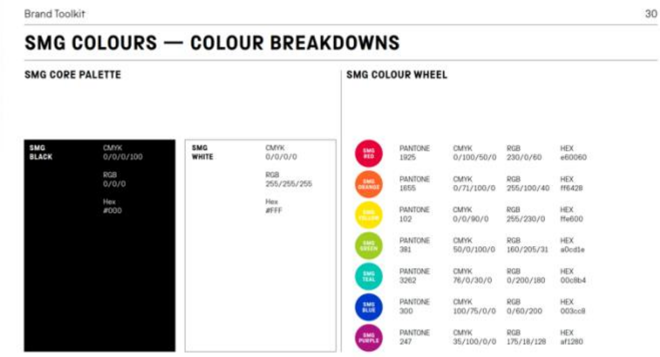


Figure 0-7: Brand Toolkit Page 30 (Science Museum Group., 2018)

Figure 0-8: Brand Toolkit Page 31 (Science Museum Group., 2018)

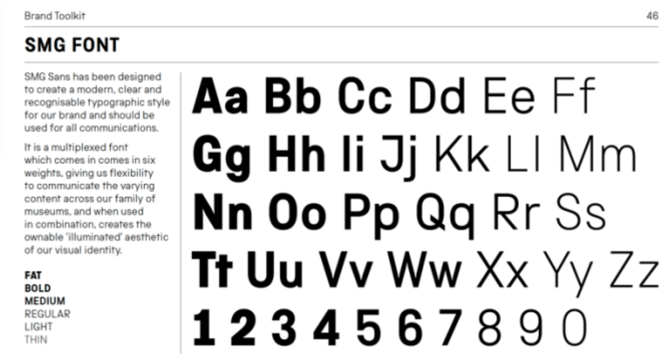


Figure 0-6: Brand Toolkit Page 46 (Science Museum Group., 2018)

Figure 0-1: Brand Toolkit Page 101 (Science Museum Group., 2018)

Appendix I. **Data Collection Sheet**

Prototype:

Enjoyment or surprise expression (e.g. "Wow, aha, ooo")	**Reading text aloud**	**Strategic talk** (e.g. "You have to scan this code here")	**Connection and linking**			**Positive cognitive/ perceptual talk** (e.g. "So that's what a crank is!")	**Total**
			Activity or event (e.g. "I remember when we went to…")	**People or place** (e.g. "your Grandad used to work with engines")	**Object, action or skill** (e.g. "That looks like …" "It moves like my bike")		
Change in mindset, indication of engagement. Feeling comfortable 'this place is for me'.	Indication that parent/carer or participant feels the language is accessible. Indication of sharing.	building confidence and ownership. Developing skills.	Extending the reach of the experience. Making connection with their own life.	Helping people recognise that they know people who use science. Science is shaped by everyone in society.	SC principle = Linking to everyday life. Building on existing knowledge. Meeting people 'where there are'.	SC principle = Building confidence. Promoting science talk. Evidence of meaning-making.	
			x 2	x 2	x 2	X 2	

Dwell time (seconds):

Notable statements:

How many stars would you give this experience?
What was your favourite thing about it?
What do you think could be done better?

Appendix J. **General Learning Outcomes for Power Hall (DRAFT)**

Power Hall GLOs for the Gallery and Top-level Sections

Context

After a recent focused period of content and interpretation work we are now in a position to refine the top level learning outcomes for the gallery, in line with the four key STEM engagement approach we have developed (STEM literacy, Skills, People and Everyday examples).

Gallery Learning Outcomes

Visitors to the Power Hall will:

- Understand that Manchester's engine-driven ideas and industry changed the world forever
- Develop their understanding of how engines work and impact our lives
- Recognise and/or relate to the diversity of people and roles that shape our ongoing relationship with engines
- Enjoy using the skills that underpin the process of creative problem-solving to explore the gallery and programmes
- Reflect on their own relationship with energy and their agency to shape it

Section by Section

East Threshold

Visitors will:

- Be excited by the industrial atmosphere created by the sensory installation and authentic machinery
- Understand that Manchester's engine-driven ideas and industry changed the world forever
- Develop a sense of anticipation and curiosity to explore

Making More

Visitors will:

- Be amazed by the scale and variety of engines made in Manchester
- Use their senses and skills to actively engage with the phenomena on display
- Develop their understanding of how engines work and affect people's lives

On Demand

Visitors will:

- Understand that the shift to power networks and distribution provided a blueprint for the system we all use today
- Value the process of trial and error as vital to the process of creative problem-solving
- Reflect on humans' ever-increasing demands for power and their role as a consumer

Connecting

Visitors will:

Power Hall Learning Outcome development

Draft Learning Outcomes (v4 Jan 2020 doc)	Outputs of our STEM Engagement approach workshops	Proposed Learning Outcomes
Visitors to the Power Hall will: • Understand that these engines have impacted our lives in the past and still have relevance today • See the diversity of people who have used and maintained these engines over time • Recognise themselves on gallery • Engage with the science behind engines • Identify and use Power Hall skills • Feel that engineering is something they could do too through making and tinkering • Use their creativity and problem solve through hands-on opportunities • Use their whole body to experience the building and collections • Be impressed by the size and age of the building • Discuss, debate and respond to content on gallery	• **Supporting STEM Literacy,** furthers my understanding of concepts and phenomena I experience in the real world • Provide an accessible introduction to the key concepts that underpin how engines work • Highlighting **Transferable skills**, gives me a tangible connection between technical objects and human stories that I can use & develop • We will focus on a set of core transferable skills which fuel creative problem-solving to frame the technical skills represented in the collections and programmes. • **People like me**, both today and in the past, have shaped their world, and I can too. • Contribute to a sense of place which visitors can identify with and feel a personal connection to. • **Everyday examples** enable me to make personal connections with the people, skills and STEM content in the Power Hall and feel that it is for me. • Encourage visitors to take an active role in personalising their gallery experience with their own examples.	Visitors to the Power Hall will: • Understand that Manchester's engine-driven ideas and industry changed the world forever • Develop their understanding of how engines work and impact our lives • Be surprised by the diversity of people and roles that shape our ongoing relationship with engines • Enjoy using the skills that underpin the process of creative problem-solving to explore the gallery and programmes • Actively reflect on their personal dynamic relationship with engines and their agency to shape it

Appendix K. **Fieldwork Visit to Thinktank – Birmingham Science Museum. Date: 19.02.20**

Reason for Visit: An award-winning science museum with extensive interactive exhibits throughout four floors along with an outside science garden/play space, it also includes a planetarium and Birmingham themed ‘Kids' City’. Their Industrial Revolution-themed ‘Power Up’ section houses, amongst other engines, the Smethwick Engine, the world’s oldest working steam engine. After undergoing extensive restoration, it is now ‘steamed’ for public viewing six times per year – 19^{th} February being one of these special days. The researcher was interested to see how this ‘Power Up’ area of the museum used digital interpretation to engage their audience in the subject of engineering, mechanics and problem solving.

Experiences: The steaming of the Smethwick Engine was extremely atmospheric, and the hypnotic movement of the machines and mechanisms was certainly mesmerising. As expected, the exhibition area quickly got very hot and quite noisy. Unfortunately, there was no formal explainer team talking to the crowd of visitors or presenting machines during the visited time. Engineers/technicians were visible but not going out of their way to talk to people. This meant that the visitors relied heavily on gallery interpretation displays and interactives. Most of the interactives focused on the theme of industrialisation via steam engines, particularly about the canals, as shown in Figures 5 and 6 below:

Figure 0-9: How a lock works interactive animation

Figure 0-10: City to sea interactive journey

The exhibition contained two interactives that were used to show directional changes in force. These were very effective, non-digital, hands-on experiences. One, shown in the images below (Figure 7), focused on the piston's linear movement being transferred into rotary movement via a crank and flywheel. Visitors ‘pumped’ the lever up and down to work the crank which turned the flywheel which was connected to a rotating 'machine'. Apart from the lever, the rest of the interactive was behind glass with interpretive text applied to it.

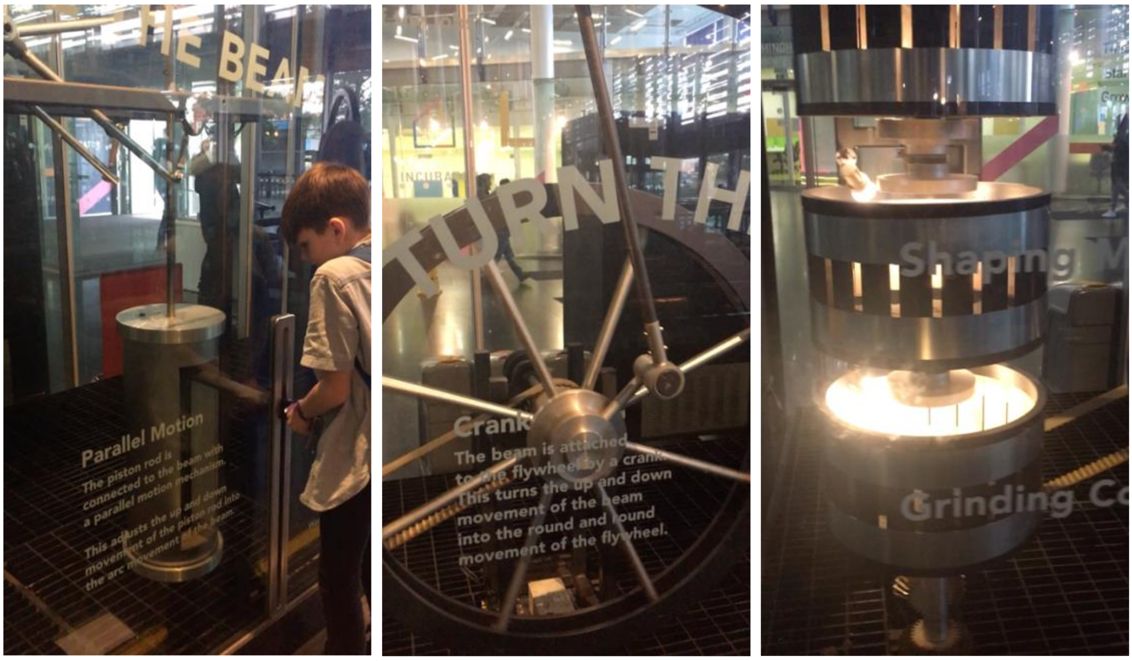


Figure 0-11: ‘Turn the Flywheel’ interactive interpretation.

Visitors were clearly enjoying the physicality of pumping the crank, although it was noted that many were not paying too much attention to the chain reaction they were creating. This may have been because the machines were set back from the glass and the large scale meant that the association between the different elements was not always clearly apparent. In general, the researcher perceived this to be a good physical interactive but felt the scale was a little too much for younger visitors to make the connections between parts. It was also considered that the ‘machine’ at the end of the process could have been more obvious and tangible rather than the spinning cylinders which did not carry too much relevance.

The second interactive to show forces and changes in direction was a simple but robust reciprocating vertical pump handle attached to a rotational gear drive. Visitors moved the handle up and down to see how the linear motion can be transformed into rotational motion through gears (See Figure 8).

Figure 0-12: Linear to rotational force via gears interactive

In a separate interactive, it was interesting to see the Thinktank's interpretation of the boiler turning water to steam and steam into force. This is a process that has already consumed much thought during the study through sketches and ideation. In this process, visitors moved a lever up and down to pump bellows in a furnace at the base of a boiler structure behind the glass. This action turned lights on to create a fire effect in the 'firebox' which in-turn caused bubbles to rise on a digital screen above it. Within a few seconds, polystyrene balls in a cavity (boiler) above the screen started to bounce about.

To continue the process visitors moved along to turn a physical valve. As they did so, a cylinder with a rising piston activated and had pieces of polystyrene bouncing around inside to represent the steam forcing the piston up.

The researcher considered this to be a clever representation of the process, and because the boiler was close to the glass, it made it easier to understand what was happening. The polystyrene may be a little confusing to some visitors, but the bellow pumping gave a good sense of the physical exertion required to start and maintain an engine. The points of interaction were well thought out and positioned carefully for accessibility.

Figure 0-13: Firebox, boiler and piston interactive interpretation

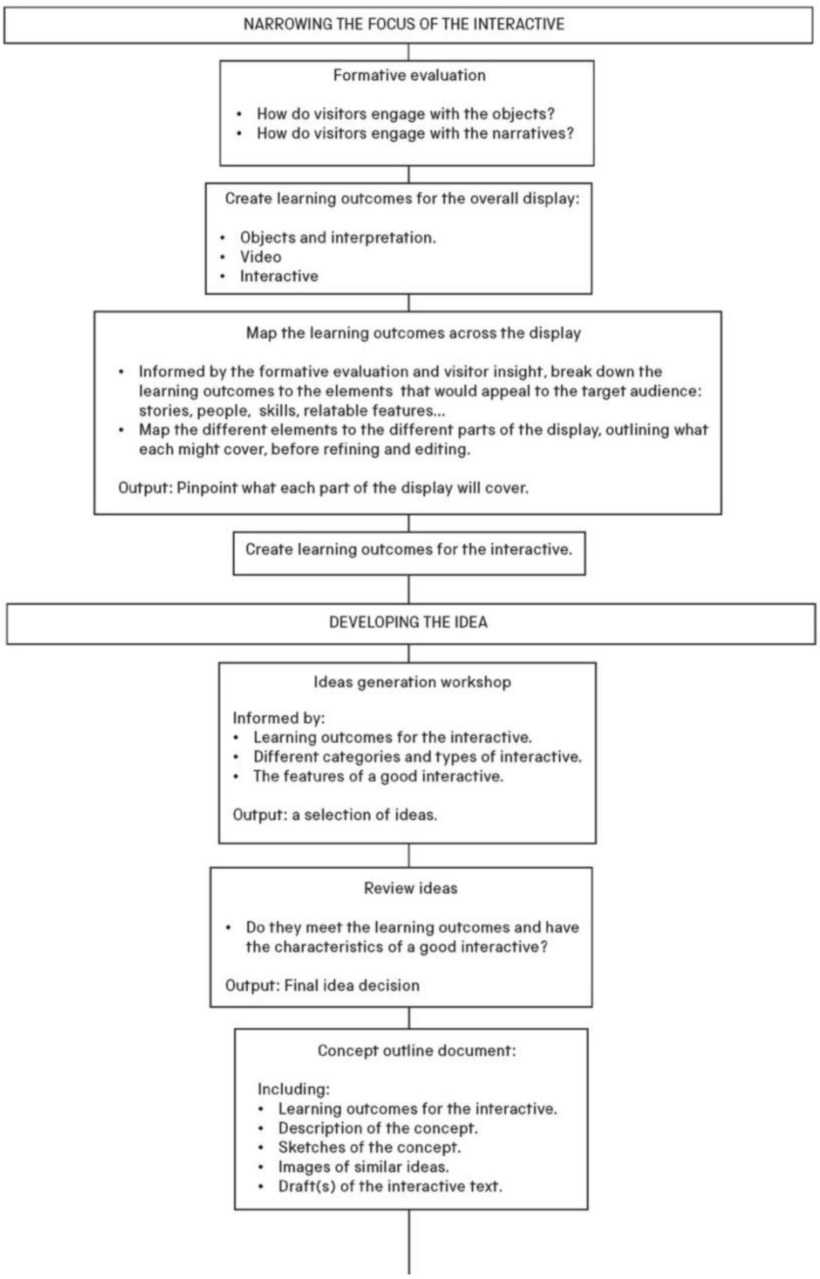
On the floor above the Power Up gallery in the area entitled ‘We made it’ there was a range of machine-themed exhibits and interactives. One of particular interest was a magnetic based interactive on the theme of gear trains.

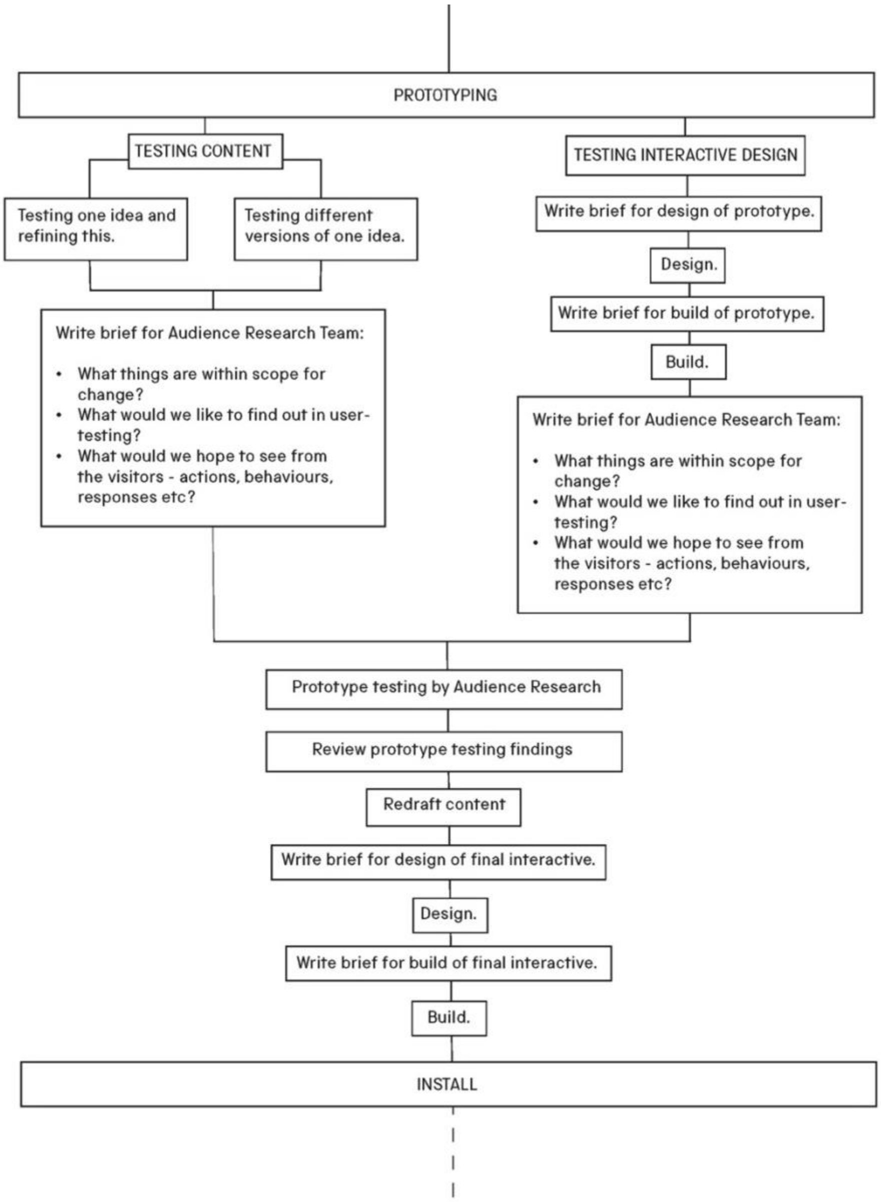
Users were instructed to look for the red light to signify which gear they were about to concentrate on. They then had to create a gear train from the driver gear (in a fixed position on the left side of the board) to a fixed position gear on the opposite side of the board (indicated by the red light). This interactive had clearly had a lot of use and visitors seemed to be enjoying ‘tinkering’ with it but it was noted that this was often done in an experimental way without following the instructions positioned separately, above the display board as shown in Figure 10. The different lights offered five different options for the gear train which helped to add variety, but it was felt that the understanding about the functionality of gears could be lost in this interactive. The ‘So what?’ question is not clearly answered, and the user may not get a clear grasp of any change in speed, torque or direction of force.

Figure 0-14: 'Connect the gears' interactive interpretation.

Appendix L. **SIM Sample Interactive Development Work-flow**

DEXTRALOG: INTERACTIVE DEVELOPMENT PROCESS




PROTOTYPING
TESTING CONTENT
TESTING INTERACTIVE DESIGN
Testing one idea and refining this.
Testing different versions of one idea.
Write brief for design of prototype.
Design.
Write brief for build of prototype.
Build.
Write brief for Audience Research Team:
• What things are within scope for change?
• What would we like to find out in user-testing?
• What would we hope to see from the visitors - actions, behaviours, responses etc?
Write brief for Audience Research Team:
• What things are within scope for change?
• What would we like to find out in user-testing?
• What would we hope to see from the visitors - actions, behaviours, responses etc?
Prototype testing by Audience Research
Review prototype testing findings
Redraft content
Write brief for design of final interactive.
Design.
Write brief for build of final interactive.
Build.
INSTALL

Appendix M. **Use Scenario**

Use Scenario: Noah and Preliminary Example Three – Interactive Gears and Belts

Noah sees a number of visitors already using the activity and waits his turn by the first station [Gears] which quickly becomes free. He does not look for any text instruction or signage but sees two large cogs on a screen with a black and white factory video scene above them. He begins by experimenting and sliding a bar up and down. He notices that this changes the size of one of the gears on the screen display. Changing the size of the gear makes the video of factory workers tending to a cotton loom go faster or slower. He notices headphones at the side of the display and puts them on. He smiles when he can hear the machine sounds and background music getting faster. He experiments again by sliding the lever and making the video and sounds run slower - when it reaches slow motion, he finds this more entertaining. He calls out to his sister to come and try. She puts on the second pair of headphones and listens - she takes over the slide control. They then notice another button which they press. This changes the video footage and displays an opposing gear train/system. They are able to make a prediction about what will happen and experiment with the different scenarios.

The quick rewards of this interactive and intuitive interface encourage Noah to move along to the next interactive as soon as it becomes free [Belts]. This time there are 3 buttons to press and a black handle to turn. Noah and his sister are both able to interact with this display. The buttons control the size of a machine wheel attached to the belt on the digital display (small, medium or large). When the wheel is small an animation of a person on a treadmill will run fast, when the machine wheel is set to ‘medium’ the man jogs slowly, when the wheel is set to ‘large’ the man walks. At first the buttons are pressed, and they notice the size of the wheel change but are puzzled why nothing is really happening on the display screen. To make the animation work Noah figures out that he must turn the black handle. As he winds the handle the treadmill animation runs. After experimenting, he notices it’s harder to turn the handle when the wheel is set to ’small’ and he shouts this discovery out to his sister. They switch positions to try this out. They set the wheel to ‘large’ which makes the resistance less and the person run faster on the treadmill.

Noah moves on to the third panel [Power]; he sees a large image of a wind turbine with a close-up image of some gears. In front of the display is a disk-type object. He sees the word 'spin'. He tentatively spins the disk and sees the blades of the wind turbine slowly start to move. He spins again with more confidence to make the blades turn a full revolution - he realises the gears are turning too. Dotted lights travel down the wind turbine and lead to an image of a large bulb which glows faintly - he hears a 'sizzle' sound. He sees text information change on the screen but pays little attention to it, he notices three buttons on the 'interface' flash. The buttons are labelled small, medium and large. Noah presses the small button. The smaller of the two gears (the 'driven gear' – attached to the generator) on the display lights up to attract his attention - he notices it has changed size to a much smaller gear. He spins the dial, and the blades turn faster - this time, brighter dotted lights travel down the wind turbine and into the image of the bulb which glows brightly and plays a rewarding ding sound! He presses the button that says 'large' this changes the graphic of the gear attached to the generator to a larger circumference, this driven gear glows and attracts his attention. He spins the dial to see what happens this time. The blades and gears turn but now the lights traveling down the turbine are very faint and the bulb flickers with a faint on/off sizzle.

Appendix N. **Pilot Questionnaire Results: Prototype 3 (Informal Session 2)**

Group No.	How does this experience make you feel about steam engines?	Do you think this information is connected to your life? Why do you think that?	Is there anything you particularly liked about it?	Is there anything you disliked about it?	Do the engines make you think of anything or anyone that you are familiar with today? If so, what?
1	We think they are interesting. I know I'd like to learn a bit more.	Probably some of the concepts are very relevant to today.	We liked how it moved and that it's nice and simple.	Not really.	This makes me think of my old teacher at school
2	They're quite mesmerising.	Those animations make me think of things we're familiar with, which is quite surprising.	The graphics are nice and modern, it's something a bit different.	A couple of the noises were a bit too loud.	It makes me think of our neighbour. He is always tinkering in the garage, he used to be an engineer I think.
3	I'm not sure.	It makes me think of chains on a bike, and also it looks a bit like a train.	I like the noises best	I think it needs to be much bigger.	It makes me thinks of spanners and tools and metal.
4	Dad likes them best.	I think it's connected to how things move and how lots of things have an engine like cars and trains.	I like that it's fun to play with.	No nothing.	My dad and grandad, they worked with engines all the time.
5	I'm interested in them.	Not really to connected to modern times. But it's good to understand how it used to work.	It makes it seem very simple and the little pictures are really sweet.	It's a bit small.	It's made me think of a car engine and the wheels turning.
6	I'd like to see some real ones in action to know a bit more.	Yes, it's connected to the way things used to be. It's important because that's how we make progress.	It's all nice but do like how the different parts light up.	No	It has made me think about my bike.

7	This design makes them feel quite modern.	Well I can see how different bit of the bigger engine might be connected to other things and we haven't even noticed before or made that connection.	We liked the buttons to press, it makes it feel quite interactive.	I would maybe like to see a real engine to compare it with.	Not really
8	I think I can understand things a bit better when it's laid out simply like this.	No really connected to my life right now. But I suppose they might still use 9machines for making clothes and things.	I like how it just suddenly comes to life!	No	Makes me think of trains and the train ride we went on.
9	It makes them look quite fun.	I'm not sure. I suppose it's connected to cars and bikes and trains.	I love the noises and sound effects. It's very fun to play with. I like that there is not too much to read.	It made me jump.	My teacher at school
10	I think they are interesting	We think it looks like a bike system. A little bit 'make-believe' but familiar.	We liked the animated parts and the noises.	No	Makes me think of my childhood and messing around with bikes and inventions – and grease!

Appendix O. **Pilot Questionnaire Results: Prototype 4 (Informal Session 3)**

Group No.	How does this experience make you feel about steam engines?	Do you think this information is connected to your life? Why do you think that?	Is there anything you particularly liked about it?	Is there anything you disliked about it?	Do the engines make you think of anything or anyone that you are familiar with today? If so, what?
1	I didn't think I was interested but I am now. It seems simpler than I thought.	Yes definitely, it's all about inventions and engineering and that important to everything.	I liked how it's made us think a bit differently and work together.	No nothing.	It's made us think about dancing – probably not what was meant to happen hey!
2	Not sure, it's not something we have thought about before now.	I suppose so, I think the industrial revolution is what first springs to mind.	The illustrations are lovely, I would like to see them bigger.	It was a bit fiddly to use but I have never done AR before.	It makes me think the engine is alive a bit like chitty chitty bang bang
3	I'm not sure.	Yes definitely, it's the way machines work – or used to work.	I like the AR part that was a nice surprise.	Nothing	The governor model makes me think of a sycamore seed.
4	It's made us think a bit differently. I think they are more interesting than we had imagined	I think it's connected to how any type of machine moves	I like the little person that appears and finding the right image makes it more fun.	No nothing.	The girl reminds me of a little magical elf or something!
5	Maybe that there is more than meets the eye.	The movement is similar to lots of things and riding a bike	The leaflet is nice, and model is really fun to make.	It took a while to get the AR to work.	It's made me think of craft club at school.
6	Not as boring as I thought.	Connected to making thing spin around in circles.	I like that I understand what a governor does now – did not even now what one was before.	Just having one might cause an argument.	It has made me think about the last time we made something together using a kit at home. It was a paper town model

7	It's made us think of them outside the box. More than meets the eye.	Definitely, it was so easy to explain this governor to the kids.	I liked that it made us move around and do things together.	No	It made us think of just dance on the PlayStation.
8	It's made them a bit more exciting.	Not really but it was fun.	I really like the craft activity and he (the child) concentrated so hard.	No	It has actually made me think we haven't been out on our bikes for ages.
9	I never thought of them at all before now, but the kids seem interested, so that must be good	It about how engines used to be but I think that relates to new inventions too.	I love that you have something to take home.	It might be too hard for the little one to do on his own.	Well my dad used to repair stuff and was good at working on engines.
10	It's made me think that there is probably a lot more I don't know. But we would like to see a real one working.	Definitely, I love how it can be related to a fairground ride and the model is makes it easy to understand.	Obviously, the model/crafty bit but also that it's a bit like a treasure hunt, my kids love that type of thing.	Maybe that we have to use a phone.	It did make us think about a fairground swing.