

University of Southern Queensland

School of Engineering

Designing Interactive Engagement Activities for Multi-Year
Mechanical Engineering Programs: A Mixed Methods Evaluation

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ABSTRACT

This dissertation investigated the effectiveness of mechanical engineering outreach activities in engaging students across various educational levels and influencing their career aspirations. The study encompassed a comprehensive review of existing literature, theoretical frameworks, and practical implementations to evaluate how outreach programs best foster interest in mechanical engineering.

The literature review highlighted the significant role outreach programs play in promoting Science, Technology, Engineering and Mathematics (STEM) awareness and shaping students' attitudes toward careers in these fields. The review also identified challenges such as the lack of systematic evaluation mechanisms to identify the long-term impact of outreach programs on tertiary transitional rates. The dissertation presented a conceptual design for outreach activities tailored to four separate grade levels, from interactive, hands-on experiences for younger students to complex, technology forward exposure for older students.

Key findings suggested that targeted outreach activities can significantly impact students' interest in engineering, provided they are presented with age-appropriate content. The study also highlighted successful examples of outreach programs and provides recommendations for improving the frameworks for outreach program design. Future research recommendations included longitudinal studies to track the long-term effects of outreach activities and the development of innovative evaluation methods, supported by collaborate efforts and institutional stakeholders. Overall, this project contributed to a deeper understanding of how mechanical engineering outreach activities can effectively engage students and promote interest in the engineering field.

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Nicholas Shields



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CHAPTER 1

INTRODUCTION

Universities have always sought to attract students for their academic pursuits, a task particularly more involved in the field of engineering given the array of majors available. Interaction with university staff from these majors can aid in shaping students' understanding of the requirements and prospects involved. These interactions focus to promote awareness of STEM and contribute to motivating learners (J. Vennix et al. 2017). Engaging students can take various forms, including compulsory on-campus experiences, voluntary open days, and off-campus activities. Academics often tailor these activities to showcase the cutting-edge research in their field, yet they may inadvertently deter certain demographics with overly technical content.

This project aims to develop an interactive outreach activity specifically designed for mechanical engineering that can adapt to different age groups and events. This design will be heavily grounded in the literature for what engages certain age groups and demographics. Additionally, this research will delve into what factors facilitate the successful transition from outreach participation to enrolment in engineering programs.

Typically, students are exposed to engineering based activities in conjunction with their school curriculum. Project-based learning such as this can increase participation going forward (S. Sánchez-Cambronero et al. 2021). Although, these students are already actively interested in STEM studies. There is a reduction in interest from students to pursue tertiary studies in engineering, generally declining over the first years of high-school and continuing throughout (J. Kennedy et al. 2018). There is a rising importance for a framework for engineering outreach activities available to Australian students. International research finds that a combination of sharing expertise, interactive work-shop activities, and exposure to the work environment promote interest in STEM. However, the critical feature is a student's opportunity to connect with a person out of the school environment (J. Vennix et al. 2018). The Australian National University's (ANU) Department of Nuclear Physics have found success in their outreach activities by exposing local students to research projects of international quality. These students are seen to continue into relevant education and choose ANU as their institution (A. Mitchell et al. 2020). There is value in investigating Australian university outreach practices in different fields of study.

CHAPTER 2

LITERATURE REVIEW

For engineering education, outreach activities serve as a vital conduit for promoting STEM awareness amongst potential students during their formative years. These activities encompass various interventions aimed at enhancing the communication of STEM education whilst motivating learners (J. Vennix et al., 2016). The success of outreach activities can be found in surveys and interviews with participants and providers. With this, alongside literature review, a comprehensive definition of STEM outreach can be found: the dissemination of STEM content beyond conventional student-teacher relationships to stakeholders, such as students, aimed at fostering understanding, awareness, and interest in STEM disciplines (R. Tillinghaust et al., 2020).

Alternatively referred to as ‘Engagement Activities’ and ‘School-University Partnerships’, these initiatives array from large scale programs such as the Science and Engineering Challenge in Australia reaching 15,000 school students per year, to more localised efforts such as the Australian National University Research School of Physics’ annual on-campus demonstrations to groups of 20-30 students ranging from ages 14-18 (E. Eilam et al., 2016; A. Mitchell et al., 2020). The outreach approach may involve more creative design, such as an escape room concept within an engineering education setting. Such innovative methodologies highlight the versatility of outreach activities in catering to diverse audiences and enhancing STEM engagement (R. Ross et al., 2020). N. Fitzallen et al. (2016) explores the experience of university engineering students delivering STEM outreach programs, citing benefits of social and responsibility skillset building. Similarly, L. Ward et al. (2015) of the University of Tasmania provides a “proof of concept in terms of the utility of engineering activities as a way of engaging students in learning about scientific disciplines”, demonstrating the way in which these programs delivered by university students can expose middle school students to hands-on activities beyond the regular curriculum.

Despite its importance, outreach activities face challenges such as funding constraints and reliance on volunteer efforts (S. Chapman et al., 2017). Additionally, J. Gore et al. (2017) notes the absence of systematic evaluation mechanisms for assessing the effectiveness of outreach activities in higher education participation among students. Mostly, outreach activities have

focused on overcoming barriers for students from low socio-economic backgrounds. Addressing the benefits of outreach activities remains crucial for advancing STEM education.

2.1. Student Decision Making

2.1.1. Decisions Students Make Prior to University

The decision-making process for choice of university degree is influenced by a myriad of factors. Often influenced by academic performances, analysis reveal a strong correlation between students' enjoyment and proficiency in school subjects to their inclination towards pursuing related disciplines at the university level (L. Dawes et al., 2015). An independent study of Queensland school students revealed extra-curricular activities also played an important role in subject selection for year 11 and 12 (S. Reed et al., 2020). Moreover, the timeline to make these choices unfolds differently for each student. Timing for STEM outreach activities is crucial with 60% of students in year 10 having a broad area of study, 80% decided on a specific degree between year 11 and 12, and 73% having chosen universities to attend in year 12 (L. Dawes et al., 2015). However, J. Gore et al. (2017) contests the assumption that career aspirations for Australian students take shape around year 10, but rather significant interest is often expressed as early as year 7, rising and falling towards the very end of high school.

M. Gosper et al. (2013) predicts that due to current students' reliance on technologies in their daily lives, there is expectation that a more diverse set of technologies will play an integral role in their university experience. Factors such as perceived ease of degree, job opportunities, and wage expectations are further reasons driving degree selection, with some disparity between male and female students across various disciplines (J. Lopez-Bonilla et al., 2012). Furthermore, students' socioeconomic backgrounds and geographical proximity to university campuses play pivotal roles in shaping their educational aspirations. Challenges persist for students in remote areas, who face the dilemma of relocating for study or forgoing further education due to limited local opportunities (N. Zacharias et al., 2018).

2.1.2. Demographics and Age Considerations

Outreach programs have been tailored to ensure responsiveness in reaction to the disparities present with age and gender demographics. Within STEM education, male students are overrepresented in physics and engineering studies, while female students show more interest in fields such as health and arts (J. Vennix et al., 2016; L. Ward et al., 2015).

Data from The Organization for Economic Cooperation and Development (OECD) countries reveal that there are significant differences in the career expectations among 15-year-old boys and girls, with 5% of girls estimated to be in careers of engineering, compared to 18% in their male counterparts (L. Ward et al., 2015). A study over 64 schools in New South Wales saw among females, the predominant occupation of interest was arts (18%) and teaching (16%), whereas engineering was most favoured amongst males (7.5%). Additionally, engineering was a top 2 choice of students from non-English-speaking backgrounds (J. Gore et al., 2017). J. Vennix et al. (2017) identifies in their outreach activities run in the United States and Netherlands that out of 729 high-school students that males were well over-presented at 77.1%. In Australia, although female participation in tertiary education is more than half of all enrolments (57%) females are significantly less present in science and engineering disciplines, reporting there are 0.6 female engineering graduates for every male graduate (S. Chapman et al., 2017).

Understanding the capabilities of each age group is also key in designing effective outreach activities. For instance, programs targeting younger students focus on hands-on, interactive experiences with low levels of theory to foster curiosity. As the demographic ages, activities slowly increase emphasis on practical applications and career pathways in STEM fields (J. Gore et al., 2017). Thus, the best outreach programs will not categorize themselves solely as STEM or engineering programs. Instead, they will attempt to appeal to participants who exhibit traits of “Independence, adaptability, comprehension of diverse few points, and an interest in innovation” (S. Cheryan et al., 2015). By dismantling stereotypes that confine engineering to specific demographics, these engagement initiatives can potentially gain the participation of underrepresented minorities and point them towards an engineering career path (T. Petray et al., 2019).

2.1.3. Content of Activities as Age Group Progress

As students advance through age groupings and year levels, outreach activities adjust to their changing needs, considering factors such as comprehension levels, interests, as well as STEM career aspirations. Research from R. Tillinghaust et al. (2020) finds elementary aged outreach programs often focus on enhancing fundamental skill, primarily focused on fostering curiosity in STEM subjects. As they move into middle school, more complex concepts are introduced with incorporation of team or project-based learning. In these grades, the effects of peer influence begin to play a larger role in career interests. High school marks the final transition into formally selecting a tertiary path, thus the engagements offered provide insights into various STEM career pathways, collaborating with industry professionals.

In designing an outreach activity, understanding the attitudes of students towards engineering is vital. These attitudes vary widely across different year levels, with declines seen over the first year of high school. Links to this decline are found in the students' association with usefulness as well as personal capabilities in the field (J. Kennedy et al., 2018). Figure 1 are the results of 5925 New South Wales students, in year 3,5,7, and 9 cohorts nominating occupations of interest over consecutive years (2012-2015):

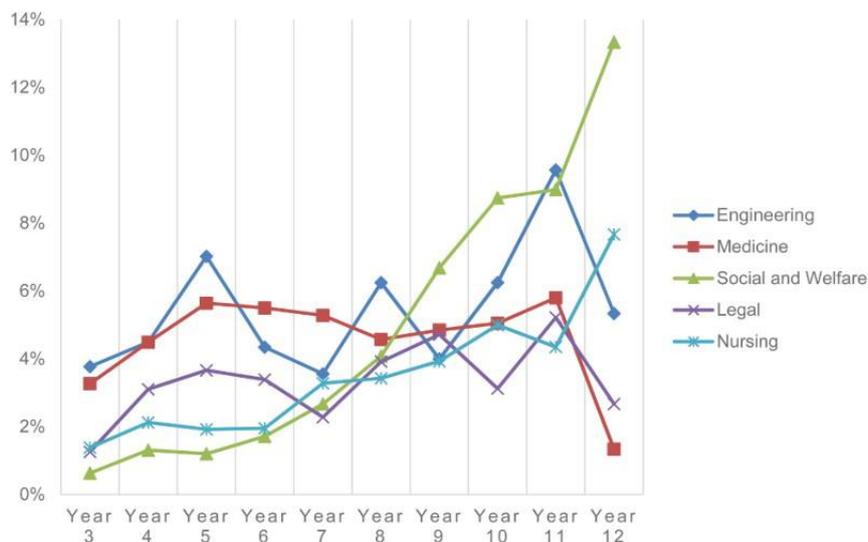


Figure 1: Variation of Career Aspirations Across 64 NSW Schools (2012 – 2015) (J. Gore et al., 2017)

The variation and large decrease in levels during the final years of schooling are accounted to an ongoing assessment by students of their abilities and relative achievements, as well as understandings on what is required in certain tertiary study and careers (J. Gore et al., 2017).

2.2. Outreach Activities for Engineering

2.2.1. University Efforts to Promote STEM Education

The efforts by university-led initiatives have shown to have a noteworthy impact on students' career aspirations. These initiatives have been identified as potential solutions to the decline in tertiary student enrolments in STEM, and when local institutional support is limited the advancement of STEM-careers is hindered (K. Sadler et al., 2016). L. Dawes et al. (2015) states amidst the current climate, it is essential that universities play a large role in strengthening partnerships with schools in informal settings to show the significance and feasibility of pursuing STEM careers as a viable career option.

Institutions such as the University of Melbourne have been long committed to outreach activities, with the aim to engage participates and entice enrolment in these disciplines (R. Schmid et al., 2012). In addition to interactive activities, the Endeavour program provides student engagement with industry professionals, a key component of engineering education (S. Male et al., 2019). The University of Southern Queensland's HeadStart Program incentivises an early adoption of tertiary STEM education by providing credits to their larger academic certifications through introductory courses. This program is designed to run alongside their secondary school subjects, targeting those with an already strongly solidified idea of career aspirations (University of Southern Queensland, 2024). The Australian National University's Department of Nuclear Physics operate 10-15 outreach events per year, commonly to groups of 20-30 students ranging from 14-16 years of age (A. Mitchell et al., 2020). An outreach activity from L. Ward et al. (2015) involved 57 grade 6 students undergoing learning activities in ordinary classroom settings but being facilitated by local university students of the STEM Education and Outreach Team, showcasing their projects. Programs such as the Science and Engineering Challenge (SEC) are run out of the University of Newcastle since 2000, with the mission "through the provision of meaningful, hands-on experiences we aim to inspire more young people to make a difference in the world by choosing a career in science and engineering" (S. Reed et al., 2020). Long term evaluation of this program report that of the high school physics students that participated, 51.9% reported SEC influenced their decision to study STEM subjects. Furthermore, 30.9% of the University of Newcastle's first year engineering students indicated that SEC significantly impacted their choice to pursue an engineering degree (S. Reed et al., 2020).

2.2.2. Institutional Strategies for Attracting Students to Engineering Programs

The various strategies institutions employ to attract enrolment of students into engineering programs focus on continued engagement and interest. One key aspect of attracting students through outreach activities is to provide hands-on learning experiences and exposure to real-world applications in a positive learning environment (J. Vennix, et al., 2016). For example, the Endeavor program at the University of Melbourne engages final year engineering students with industry members, academics, and school students, in which they publicly demonstrate their design projects. Additionally, this program sends engineering students to primary and secondary schools throughout Victoria to provide interactive classroom presentations (R. Schmid et al., 2012). Outreach activities have been a core function of institutions such as the Australian National University's Department of Nuclear Physics, making contributions to secondary-level physics education through on-campus demonstrations of cutting-edge equipment, as well as local school visits opening relationships between academics and students (A. Mitchell et al., 2020).

Moreover, institutes have aimed to broaden participation in engineering by targeting underrepresented groups, such as females or those who do not identify with the STEM archetype. By reimagining STEM beyond the traditional boundaries with showcase of the different opportunities within engineering, these outreach programs attempt to overcome stereotypes and attract a more diverse pool of students (B. Bond, 2016; T. Petray et al., 2019). The LasterTag activity developed by the Department of Engineering at La Trobe University had successfully attracted thousands of students to participate in a hands-on experience, soldering electronic devices and engaging in team skirmishes, mixing both theoretical and practical application with team challenges to increase an interest in engineering (R. Ross et al., 2017). This program saw 97% of participants finding the activity "highly enjoyable", with 55% of students who had previously been uncertain about pursuing engineering as a career indicating they were strongly more interested in studying engineering as a result (R. Ross et al., 2017).

Research indicates that certain characteristics of these outreach activities shape student perceptions and learning outcomes. Long form problem-based programs were observed to provide a more effective learning environment and better cohesion within teams as well as with teachers, as opposed to those with a short duration (J. Vennix et al., 2016). Additionally, placements in industry were apparent as to be the only effective exposure to

practices in engineering that in an activity setting would be irrelevant. Providing opportunity for practical experience through internships and industry collaborations showcase the relevance and application of engineering education in a real-world environment, as well as develop networks to enhance security in employability (S. Male et al., 2019).

2.2.3. Factors Influencing Interest in Mechanical Engineering

Research indicates that students' attitudes towards STEM subjects vary widely across different stages of schooling. However, exposure to these disciplines, such as engineering, can significantly impact student's intentions to continue studying in these fields (J. Kennedy et al., 2018). S. Chapman et al. (2017) emphasises that these interests are largely accounted for by their formal education, from early schooling to secondary schooling. However, highlighting the importance of extracurricular activities, real world experiences and industry linkages outside of the classroom as critical avenues for STEM engagement.

Providing insight by professional engineers does reflect positively on interest in engineering, with documented instances of mechanical engineering students providing outreach to promote the field alongside relative disciplines (R. Tillinghaust et al., 2020). The influence of teachers and parents also emerges as a significant factor shaping student's selection of engineering studies at universities (L. Dawes et al., 2015). L. Dawes et al. (2015) also touches on how as avid customers of technology in today, youth are more ambitious to be the creators and innovators of these advancements in the future.

Mechanical engineering is a diverse field that touches on several technical areas, each appealing to different student interests. Activities that require students to create mechanical designs are seen to motivate learning of STEM concepts that make these technologies possible (T. Moore et al., 2013). However, E. Shahali et al. (2016) suggests students that show a keen interest in engineering theory, wishing to partake in relative activities further, are those later in their schooling years as the younger demographic find a challenge in understanding these concepts.

2.3. Transition from Outreach Participation to Enrolment in Engineering Programs

The transition from participation in STEM outreach activities to enrolment in tertiary education within engineering is not heavily documented due to the length of time required to obtain results. Understanding the situation of transition rates, as well as the factors that influence the desired transition into engineering are essential for designing outreach activities, so we look at the available information to provide insight. Research indicated that outreach activities play a significant role in shaping students' attitudes towards STEM careers (J. Vennix et al., 2016).

A statistical analysis from L. Dawes et al. (2016) found that students who chose engineering at university based this decision on what they enjoyed and excelled at school, with enjoyment having the highest correlation. Furthermore, STEM outreach activities were a critical influence on university and degree choice earlier in high school than later. 80% of participants who engaged in these activities had decided on the specific degree during year 11 to 12, with 73% choosing the university to pursue this endeavour (L. Dawes et al., 2016).

Despite the importance of outreach efforts, there are other challenges that persist in achieving growth in engineering enrolments that may need to be addressed in conjunction. Those educated in STEM have become an economic priority for Australia as 75% of employers seek skills relative to the field, also identifying them as the most innovative. (B. Bentley et al., 2022). However, the state of engineering enrolments does not reflect the requirements of the Australian population, even with numerous efforts of engagement programs and initiatives (D. Corrigan et al., 2019).

P. Briggs et al. (2023) accounts this decline to the poor engagement of students with the associated subjects for STEM education, such as mathematical literacy. Figure 2 shows the number of Australian school students studying intermediate to advanced mathematics:

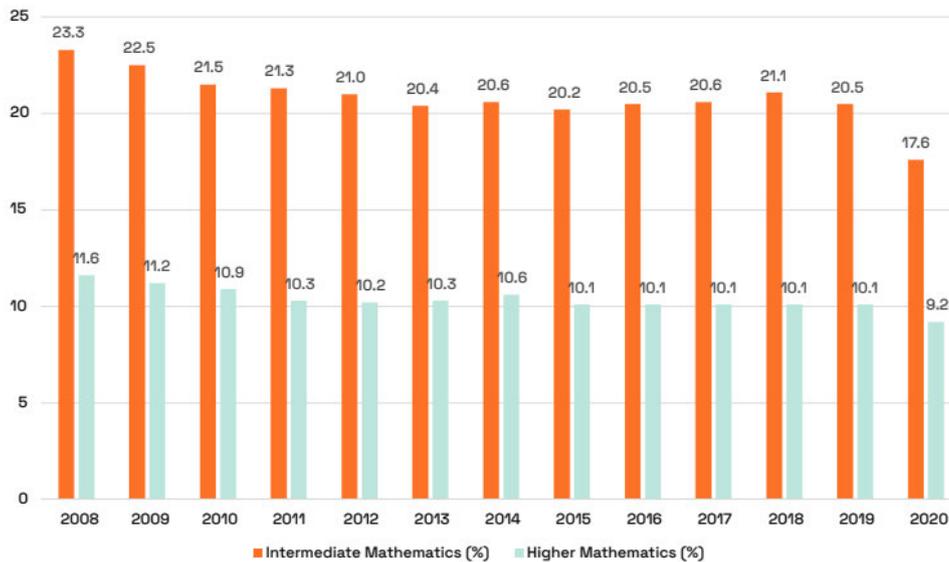


Figure 2: Number of Australian Students Studying Intermediate to Advanced Mathematics (2022) (P. Briggs et al., 2023)

Given that engineering degrees require a higher competency in mathematics, a fall in enrolment numbers can be accounted for this challenge. Outreach activities that foster an interest in learning the pre-requisite subjects will result in higher study levels (P. Briggs et al., 2023).

2.4. Current Outreach Activities and Programs

Various outreach activities are currently active and reported to successfully promote STEM education by fostering interest in engineering among students. Here is a list of a select amount of outreach activities in greater detail.

2.4.1. School Engagement (University of Southern Queensland)

The University of Southern Queensland offers various engagement opportunities for future students. Such events range from workshops and curriculum-centred activities to tailored presentations during normal school hours. Furthermore, upon request current university students may attend career days hosted by the secondary school. These

initiatives aim to inspire academic youth and raise their aspirations for tertiary education (University of Southern Queensland, 2024). The UniSQ Head Start program is an academic extension initiative for year 10 to year 12 students. This program allows these students to take university level courses whilst completing their high school education, providing flexibility alongside their school commitments, earning credits towards a UniSQ degree and fostering an early understanding of what will be involved in their tertiary education endeavours.

2.4.2. Science and Engineering Challenge (University of Newcastle)

The Science and Engineering Challenge (SEC) is a nation-wide outreach program founded by the University of Newcastle, providing immersive and hands-on experiences for students with the aim to in “make a difference in the world by choosing a career in science and engineering” (S. Reed et al., 2020). The cohorts for SEC are year 9 and 10 students for the challenge segment, with year 5 and 6 students included in the ‘discovery day’ (University of Newcastle, 2024). This program involves activities designed to encourage teamwork, problem-solving, and creativity. Reaching approximately 15,000 students per year, the SEC has found large success in encouraging the continued pursuit of STEM education in its participants (E. Eilam et al., 2016).

2.4.3. Endeavour Program (University of Melbourne)

The Endeavour program, hosted by the University of Melbourne’s School of Engineering, offers a platform for final-year engineering students to showcase their designs projects to an audience of school students as well as industry members and academics. Running for over a decade, the annual Endeavour Expo is held in October to provide a hub for STEM engagement amongst all its attendees. In addition to the exhibition the Endeavour program conducts interactive classroom presentations for both primary and secondary schools across Victoria. Considered quite a large-scale event, the Endeavour program has garnered strong relationships with the university and its possible enrollers from local schools (R. Schmid et al., 2012; University of Melbourne, 2024).

2.4.4. ANU Outreach Initiatives

The Australian National University (ANU) Department of Nuclear Physics has been actively engaged in outreach initiatives for several years, recognizing the importance of its role as a national institution in supporting the advancement of education. As a leading

research university, ANU acknowledges its responsibility to contribute not only to academic research but also to the broader educational landscape in Australia, ensuring that students across the country have access to the latest advancements in STEM (Australian National University, 2024).

Their Department of Nuclear Physics plays a pivotal role in these outreach efforts. One of their key initiatives is hosting on-campus events that showcase advanced technologies and research to secondary school physics students. These events, which are held annually, offer students a unique opportunity to engage with the latest scientific advancements (Australian National University, 2024). A highlight of this event is the demonstration of the Heavy Ion Accelerator Facility (HIAF), a research tool used by physicists to study the structure of matter at the atomic level. The HIAF demonstration provides students with a rare glimpse into real-world applications of nuclear physics, sparking curiosity and deepening their understanding of the subject (A. Mitchell et al., 2020).

2.4.5. LaserTag Activity (La Trobe University)

Developed by the Department of Engineering at La Trobe University Victoria, the LaserTag Activity is an educational initiative designed to engage high school students with engineering concepts in a fun and interactive manner. Participating students are provided with the opportunity to assemble LaserTag devices and utilise these in gameplay scenarios. The primary objective of the LaserTag activity is to not only provide an enjoyable experience but also to foster interest and enthusiasm in engineering and STEM disciplines through practical application. As a result of their participation, a notable finding indicates that a considerable percentage of students who were previously uncertain about pursuing engineering as a career reported increased interest after engaging in the activity (R. Ross et al., 2017). R. Ross et al. (2020) have also adapted this outreach design framework into escape room activities with the same overall objectives.

2.5. Evaluation Methods

Evaluating the effectiveness of outreach activities is crucial for understanding their impact on student engagement and learning outcomes. This section presents a review of literature on the various evaluation methods commonly employed in similar engagement activities, including qualitative, quantitative, and mixed-method approaches.

2.5.1. Qualitative

Qualitative methods offer deeper insights into student experiences by capturing open-ended responses, interviews, and observational data. These approaches help illuminate the reasons behind students' engagement or disengagement, as well as the specific aspects of the activity that sparked their interest (N. Sardana et al., 2023). This data collection method can be in the form of program observations, informal interviews, and collaborative discussions (S. Chapman et al., 2017). Furthermore, valuable qualitative data can also be obtained from the instructors, with Sadler et al. (2016) interviewing staff members to identify both the factors that contributed to the success of the activities and the obstacles faced. Often, qualitative questions focus on measures other than career aspirations, such as general enjoyment of the activities or their perspectives of stakeholders involved in delivering these programs (S. Reed et al., 2020).

2.5.2. Quantitative

Quantitative methods, such as pre- and post-activity surveys or Likert-scale questionnaires, are commonly used to collect measurable data on shifts in interest and perceptions. These methods provide an objective way to assess whether specific learning outcomes have been achieved and track changes in student attitudes over time (N. Sardana et al., 2023). An example of this is the STEM Career Interest Survey (STEM-CIS), a Likert-scale style survey developed to measure interest in STEM classes and careers, particularly in middle school students (M. Kier et al., 2013). In practice, engagement activities such as one conducted by E. Mohd Shahali et al. (2016), are seen to adapt the STEM-CIS framework to better obtain subject specific data relative to their outreach program. Studies utilising such quantitative tools can publish precise figures that reflect changes in participant attitudes, such as C. Chalmers et al. (2014), reporting 94.4% of participants of Queensland University of Technology's robotics outreach program

considered continued study in STEM subjects, and S. Illingworth et al. (2015) reporting a 46% higher chance of pursuing a science-based career after the event.

2.5.3. Mixed Methods

Mixed methods, which combine both quantitative and qualitative approaches, offer a more comprehensive understanding of how activities influence students. By integrating numerical data with narrative feedback, mixed-method evaluations can uncover not only how much interest has shifted but also why these changes occurred (N. Sardana et al., 2023). K. Litchfield et al. (2015) implements a mixed methods approach, combining variable-oriented analysis with multiple logistic regression models from responses to a national survey, to aid in investigating motivations to study engineering for members of Engineers Without Borders. Although there is often a preference for quantitative data in published research, adopting a mixed approach to explore engineering education is regarded as essential for future studies (M. Borrego et al., 2013). M. Howell Smith et al. (2019) finds that a pure mixed methods approach, which is one that is not qualitatively or quantitatively dominant, is the most insightful technique when obtaining data. However, executing this balance can be challenging and is not easily achievable in most instances.

2.6. Literature Conclusion

While this literature review provides valuable insights into STEM education and some certain characteristics of what makes a successful outreach activity, there is a notable gap in the literature regarding the effective design of outreach activities tailored specifically to mechanical engineering students, as well as the transition rate of student participants. Long term evaluation of these outreach programs is absent in the literature, limiting the ability to determine whether outreach has an impact beyond initial enjoyment of programs. Future research should focus on developing interactive outreach activities specifically for mechanical engineering and exploring the implication of including engineering in STEM education. However, there is valuable literature available to incorporate aspects into a theoretical outreach activity design, as well as set goals of fostering interest that may increase future enrolment.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

This methodology outlines a series of conceptual designs guiding the development of engagement activities for mechanical engineering. These programs will be centred around the mechanical engineering discipline to illustrate the relative engineering principles.

The target audience for these activities have been segmented into the following grade groupings; primary school, 7-8, 9-10, and 11-12. The intent behind these selections is firstly mirroring the engagement programs already offered by the University of Southern Queensland. Furthermore, from the review of literature it is found that these grade levels are critical in identifying and exposing those who have an inherent interest in STEM. Primary students require an introduction to the field, while those towards the end of their schooling have a firm idea on the career path they wish to pursue. As our target audience ages, the literature suggests evolving the concepts with more complex, cutting edge, and industry relevant topics can have a greater influence on a continued path in engineering. The designs will intend to take advantage of these models.

3.1. Project Goals

The aim of the research project is to develop an interactive engagement activity specifically designed for mechanical engineering students across a set of differing grade levels. These activities should successfully facilitate the transition from outreach participation to enrolment in tertiary mechanical engineering programs. The purposes of these events are to either foster an interest in the field of STEM, or further encourage those already desiring a career in the field by giving access to more advanced engineering concepts.

To accomplish these goals the following objectives will be undertaken in the design:

- A design of outreach activities that will involve a demonstration or student task that introduces a progressing level of STEM concepts and theory. These programs will be at an appropriate complexity for each target audience.
- A set of manuals that will encompass these tasks will be created to facilitate the undergoing of these activities.
- A development of framework for the collection of both the quantitative and qualitative data that will allow insight on the effectiveness of outreach activities in transition rates.

It is important to note that this research project will reach to the extent of trial design of engagement activities, and not the physical testing of design with large student groups. As this design will be heavily grounded in the relative literature, it will hope to add to the structure for future development of outreach activities for universities.

3.1.1. Existing Literature

The key findings from the literature show that effective design and strategy of outreach programs provide participants with hands-on learning experiences and exposure to real-world applications (J. Vennix et al., 2016). Additionally, programs that engage students with industry professionals and demonstrations of cutting-edge technology promote a continued pursuit in STEM academics, ultimately leading the tertiary endeavours in the field (R. Schmid et al., 2012; A. Mitchell et al., 2020). Furthermore, mixing both theoretical and practical application with team challenges had found near unanimous enjoyment by those involved (R. Ross et al., 2017). Our design will aim to incorporate as many of these successful concepts found to justify its development and implementation.

3.2. Design of Engagement Activities

To effectively design engagement activities tailored to different educational levels, we have identified key methods from the literature that demonstrate success in fostering interest in STEM and mechanical engineering. The following table summarizes these methods:

Table 1: Key Engagement Methods for Outreach Activities

Method	Description
Hands-on, interactive demonstrations	Activities that encourage physical interaction with engineering concepts, such as building simple machines or conducting basic experiments that illustrate motion and forces. This stage emphasises exploration through play, to better stimulate curiosity about STEM.
Narratives in theory	It is suggested that narrative-driven activities enhance engagement and help students relate to engineering concepts on a personal level.
Simple engineering challenges	Designing basic challenges to develop problem-solving skills and foster teamwork among students. There is value in collaborative challenges, especially among young learners.
Guided enquiry and exploration	Encouraging students to ask questions and explore answers through experimentation. This can be implemented through project-based learning.
Team projects	Implementing group projects where students collaboratively design and build solutions to real-world problems, fostering cooperation and communication skills, and reinforcing learning outcomes via peer interaction.
Engineering design processes	Teaching basic principles of the engineering design process, allowing students to conceptualize, prototype, and test their designs. These design principles can build an understanding of how engineers approach problems.
Exposure to advanced tools	Providing students with access to industry-standard tools, such as Computer-Aided Design (CAD) software and 3D printing technology, to create and visualize their designs. Furthermore, exposure to the latest innovations in technology by industry professionals and academics.

Real-world simulations	Engaging students with contextual learning that simulates real-world engineering challenges, fostering a deeper connection between theoretical concepts and practical applications.
Critical thinking and analysis	Incorporating activities that require students to analyse data and evaluate on their engineering design choices, testing their higher order thinking skills.
Industry collaboration and mentorship	Partnering with industry professionals to provide mentorship opportunities, guest lectures, or collaborative projects that connect students with real-world engineering practices.
Complex design challenges	Challenging students with tasks that require in-depth planning, teamwork, and execution of engineering solutions, such as creating prototypes for innovative products or addressing societal issues through engineering.

3.2.1. Primary

Introducing young students to the world of mechanical engineering requires a carefully crafted approach that presents theoretical concepts in an accessible and engaging way. At this early educational stage, students are more likely to absorb new information when it is delivered through active engagement and simple hands-on activities rather than in-depth theoretical instruction. The cognitive development of primary school-aged children suggests that they learn best through doing, making involvement in practical tasks far more effective than passive learning methods. As such, activities designed for this demographic typically introduce fundamental STEM concepts like the laws of motion, friction, and speed, but these ideas are integrated into tasks that allow for creativity, exploration, and imagination.

The goal of these early activities is not to overwhelm students with complex engineering theories but to subtly communicate these principles into playful and captivating projects. Rather than explaining the equations governing motion, activities might involve designing and testing simple devices where students can intuitively grasp the relationship between theory and application through observation and experimentation. This approach aligns with established research on early STEM education, which emphasises that children are more likely to develop a lasting interest in engineering if they are allowed to explore these subjects in a fun, pressure-free environment. The pedagogical framework for teaching

primary students is rooted in constructivist learning principles, where knowledge is constructed through direct involvement and meaningful social interaction. By encouraging hands-on participation and collaboration, these activities create an environment where students learn by doing and interacting with both their peers and the materials at hand. In this sense, the role of the educator shifts from being a traditional instructor to a facilitator. Moreover, these early activities can also build essential skills, such as teamwork and communication. Through group activity, students learn the importance of working together to solve challenges, sharing ideas, and supporting one another's efforts. These skills are invaluable not only in engineering but in all aspects of life.

At this stage, however, certain key engagement methods that are more suitable for older students are intentionally omitted. For instance, inquiry-based learning, which relies on students posing and answering their own questions, may be less effective for younger learners who lack the foundational knowledge to frame such inquiries effectively. Primary students often need more structure and guidance in understanding new concepts, and while exploration is encouraged, it must be balanced with clear instruction to ensure students do not become frustrated or overwhelmed by too much independence. Additionally, younger students are less able to grasp purely theoretical ideas without concrete examples or tangible experiences to ground their understanding. Cognitive research suggests that primary students benefit most from learning that is directly tied to real-world experiences or physical actions, which is why activities that allow them to "see" mechanical principles in action, such as building simple machines, are prioritized over abstract discussions.

Advanced technological tools, such as Computer-Aided Design (CAD) software, are not typically introduced at this stage because the students lack the necessary computer skills and abstract thinking capabilities required to effectively engage with these tools. While CAD software becomes an essential engagement method in later stages, especially in middle and high school, for primary students, the focus remains on tactile and sensory learning experiences. Introducing such technology too early might not only overwhelm young learners but also take away from the creativity and tangible problem-solving opportunities that physical construction provides at this age.

For this grouping fostering curiosity and a sense of wonder about the world is more important than achieving mastery of engineering concepts. The objective is to create positive associations between problem-solving and enjoyment, laying the foundation for

a deeper interest in mechanical engineering as students mature. By engaging students in activities that allow them to creatively solve problems, experiment with ideas, and see the tangible results of their efforts, they begin to see engineering as a dynamic and enjoyable discipline. It is this sense of excitement and possibility, rather than a focus on correctness or precision, that will inspire young learners to continue exploring engineering as they advance through their educational journey. By blending practical learning with a sense of fun and exploration, educators can foster an early interest in STEM fields, building a foundation for future learning while ensuring students enjoy the process. The aim is not to create experts at this stage but to ignite the spark of curiosity that will grow into a passion for mechanical engineering as students advance in their studies.

3.2.2. Grades 7-8

As students' progress into middle school, their cognitive abilities expand, allowing them to grasp more complex ideas. This developmental growth makes it possible to introduce basic engineering hypotheses and experimentation, encouraging students to start investigating the underlying principles behind the processes they observe. At this stage, the focus begins to shift slightly more towards exploration and guided inquiry, as students can better comprehend scientific questioning and testing. While hands-on activity remains an essential component of the learning process, middle school students are also encouraged to delve deeper into understanding the 'why' behind the mechanics, moving beyond simple construction to actively exploring the forces at play. At this level, concepts such as basic mechanical systems, become principles that will provide students with a foundation for understanding more advanced topics in later years, and the activities designed for this demographic are intended to allow for experimentation and creative problem-solving. Students might plan and experiment with different designs, asking questions about how certain principles influence their creations. Through this practice students begin to develop critical thinking and analytical skills essential for future engineering endeavours.

Group challenges are particularly effective for middle school students, as this age group tends to benefit from social interaction and collaboration. Working in teams to solve engineering problems promotes not only technical understanding but also skills such as communication, teamwork, and leadership. These skills are invaluable in engineering, where collaboration is often key to success. Research highlights the positive impact of

group-based learning in STEM education, noting that students who engage in collaborative projects are more likely to develop a positive perception of STEM fields and continue their studies in these areas.

However, despite the increasing complexity of the activities and the capacity for theoretical exploration, certain advanced engagement methods remain inappropriate for this age group. Complete independent inquiry-based learning, where students fully direct their own learning through asking questions and pursuing their own experiments, should not be fully utilized at this stage. While students are encouraged to experiment and explore, they still require structure and guidance from instructors to help them frame their questions and conduct meaningful investigations. Without this support, students may struggle to fully grasp the scientific principles behind their activities. As such, guided inquiry where instructors provide a framework for exploration but allow students to make decisions and experiment within that structure remains the preferred method.

The use of advanced mathematical modelling or simulations is still generally not introduced at this stage, as middle school students may not yet have the mathematical background necessary to fully engage with these tools. While students are encouraged to consider basic calculations related to their designs, complex mathematical analysis or simulations may overwhelm students and detract from the hands-on, exploratory nature of the activities. The focus is on building intuition and a basic understanding of mechanical systems rather than delving into rigorous quantitative analysis, which is more suitable for older students. Additionally, industry collaboration or mentorship is not commonly used to great extent with this demographic. While this approach is highly effective for high school or university-level students, where real-world application and career preparation are crucial, middle school students are generally not yet ready to interact with professional engineers or handle the complexities of industry-driven projects. Instead, the emphasis remains on providing a supportive learning environment where students can safely experiment, make mistakes, and learn through trial and error without the pressure of professional expectations.

Students in this age range are encouraged to make the connection between theory and application, to understand how the mechanical systems they design relate to broader engineering principles. The goal is not only to foster creativity and problem-solving skills but also to begin laying the groundwork for more complex engineering knowledge.

Activities that allow students to tinker with designs and ask questions about why certain configurations work better than others help to cultivate an engineering mindset. Despite the absence of some more advanced engagement methods, the activities aim to foster skills that will be highly beneficial for future engineering endeavours. In addition to building technical knowledge, group challenges and guided inquiry promote skills such as communication and teamwork. The ability to work collaboratively, explain ideas clearly to peers, and revise designs based on feedback are all important aspects of engineering practice, and middle school is an ideal time to begin developing these competencies.

3.2.3. Grades 9-10

Grades 9-10 represent the most formative years for students as they begin selecting subjects that will guide their future career paths. During this period, students transition from exploring broad engineering concepts to focusing on specific areas of interest, and their engagement activity design must reflect this. The activity model for this age demographic shifts towards developing a deeper understanding of engineering principles while introducing the application of advanced tools. This is essential as students benefit from tasks that not only challenge their design skills but also engage them in critical thinking and analysis. The emphasis moves beyond hands-on activities and simple experimentation, focusing instead on equipping students with the tools and knowledge necessary to solve complex engineering problems.

To meet these educational needs, activities for this group should expose students to cutting-edge technologies such as CAD software, 3D printing, and simulation tools. These advanced tools give students the ability to visualise and refine their designs in ways that were not previously available to them. By working with CAD software, students can digitally model mechanical systems, test their designs through simulations, and iterate on them before physical construction. This process promotes iterative design principles, an essential skill in engineering, where designs are seen to continuously refine based on feedback and testing. Contextual learning is particularly important at this stage, as students are better able to understand how theoretical knowledge can be applied to real-world challenges. Activities that focus on solving practical problems help bridge the gap between abstract theory and tangible outcomes. By analysing how different engineering principles affect the performance of their designs, students develop a more comprehensive understanding of mechanical systems and the impact of their choices. This deeper

engagement with engineering content will aid students in making informed decisions about their subject selections as they approach the final years of schooling. Project-based learning becomes particularly valuable during grades 9-10, where students engage in longer-term projects that require planning, design, prototyping, and testing. By working through a complete design process, students not only develop technical skills but also gain experience in managing complex projects.

Fully independent research-based projects, those conducted at university-level or advanced high school engineering courses, are typically not employed at this stage. While students are encouraged to engage in guided inquiry and exploration, they still need a structured environment that provides clear goals and expectations. Without such guidance, students may struggle to effectively manage complex projects or may fail to connect the theoretical principles they have learned with practical outcomes. The balance between freedom and structure is crucial at this stage, and while students are encouraged to explore, they do so within a framework that helps them stay on track and make meaningful progress.

Additionally, collaboration with industry professionals may be beneficial but is often limited. Students at this age may not yet have the maturity or technical knowledge required to fully benefit from industry driven projects or mentorship programs. While they can use advanced tools like CAD and 3D printing, they are still building foundational knowledge and may not yet understand the broader context of how these tools are applied in professional engineering environments. It is best to have students work within simulated real-world scenarios that are designed to mimic industry challenges without the need for direct professional collaboration. This approach allows them to develop a sense of real-world engineering processes while still receiving the instructional support necessary to succeed. Furthermore, advanced theoretical instruction that involves higher-level mathematics and engineering theory is typically restrained at this stage. While students are introduced to more complex engineering principles, the focus remains on application rather than deep theoretical exploration, which is more appropriate for senior students or university-level learners. Instead, activities are designed to reinforce practical engineering skills and provide students with the tools they need to experiment and innovate within their current knowledge base.

The activity model for grades 9-10 is designed to give students a more comprehensive understanding of mechanical engineering while introducing them to advanced tools and technologies that they will likely encounter in future careers. By exposing students to CAD software, 3D printing, and simulation tools, and integrating critical thinking and contextual learning, these activities lay the groundwork for more specialised study in the final years of high school and beyond. While more advanced engagement methods, such as independent research projects, industry collaboration, and complex theoretical instruction, are not yet suitable, the activities at this stage challenge students to deepen their understanding of engineering concepts and apply them in increasingly meaningful ways. This blend of technical skill building and real-world problem solving prepares students for their final years of schooling, where they will further refine their interests and begin selecting the subjects that will shape their future academic and professional paths.

3.2.4. Grades 11-12

In the final years of schooling, most students have solidified their career aspirations, with many having already chosen the subjects that align with their future goals. For those participating in outreach activities related to mechanical engineering, it is likely that they have a well-established interest in the field. This creates a unique opportunity to engage students at a more advanced level, both in terms of content and the methods used to deliver that content. The activities designed for this age group must reflect a more progressed level of engagement with mechanical engineering principles, preparing students for the challenges they will face in tertiary education and professional practice. The focus shifts away from igniting curiosity and creativity, which was essential in earlier stages, and towards refining the technical knowledge and skills they need to succeed in higher education and professional environments. These activities should mirror real-world engineering projects, requiring detailed planning, execution, and critical analysis. The intent is to simulate the type of work students will encounter in both their future studies and professional engineering roles.

For instance, a project might involve designing and optimizing a mechanical component using Computer-Aided Design (CAD) software, performing Finite Element Analysis (FEA) to assess its performance under stress, and then iterating on the design based on the results. This introduces students to the iterative design process that is fundamental to engineering, where prototypes are tested and improved in cycles to achieve the best

possible outcome. Advanced technologies and tools will play a significant role in these activities. Students should be introduced to cutting-edge engineering software which are commonly used in professional engineering environments. By mastering these technologies, students not only build technical proficiency but also gain an advantage as they enter tertiary education or seek early career opportunities. Additionally, these tools provide students with a deeper understanding of the theoretical frameworks that underpin mechanical engineering. For instance, when students use FEA to simulate the stresses and strains on a mechanical component, they directly apply concepts from mechanics of materials and structural analysis, reinforcing their theoretical knowledge through application.

One of the key elements at this stage is the opportunity for students to collaborate with industry professionals. This collaboration provides invaluable insights into real-world engineering practices, allowing students to experience firsthand how theory is applied in professional contexts. Through this type of exposure students can learn about current industry challenges, technologies, and methodologies, bridging the gap between academic knowledge and practical application. Industry collaboration is also particularly effective at this stage as it exposes students to the realities of engineering careers, helping them solidify their interest in mechanical engineering and providing them with professional networks that can support their transition.

Activities emphasise independent problem-solving and critical thinking, with students expected to take full ownership of their projects from initial design to final presentation. Through projects requiring detailed planning and iterative refinement, students build confidence and expertise needed to tackle complex engineering challenges. Unlike earlier stages, where hands-on activities are predominant, senior students focus on mastering theoretical frameworks and digital design tools essential in professional engineering. While group work previously promoted creativity and collaboration, the emphasis now shifts to individual mastery, as students prepare for higher education's self-directed nature. Independent problem-solving becomes critical, with activities revolving personal design and analysis, fostering self-sufficiency and readiness for the autonomy required in tertiary studies.

The outreach activities for students in their final years of schooling are specifically designed to help them transition from high school to higher education and professional

engineering careers. Focus is on technical precision, advanced tool proficiency, and individual mastery of mechanical engineering concepts. The decrease in hands-on and creativity driven tasks reflects the students' evolved focus; they are less interested in exploration and more focused on preparing for the demands of tertiary education. By exposing students to industry-standard technologies and requiring them to solve complex, real-world engineering problems, these activities ensure that students develop the confidence and competence necessary to succeed in their future studies and careers.

3.3. Development of Instructor Manuals

The activity manuals, tailored for both the student participants and instructors, will play a critical role in facilitating the successful execution of the engagement activity designs. These manuals will clearly outline the learning objectives, activity steps, and relevant theory, alongside technical explanations and example mathematical breakdowns of the analytical methods involved. If required before conducting an experiment, instructors will have a worked example of the math used to predict theoretical outcomes, allowing students to compare these with their actual results. This will deepen their understanding of how theory relates to practice. The manuals will also include the necessary instructions for conducting the activities, sections on data collection, performance reflection, and key engineering principles. Diagrams or visual aids may be necessary to better communicate the mechanical engineering principles being explored, as well as the tasks that will be executed.

User manuals will be provided to students, containing a portion of theory but primarily focusing on open spaces for calculations, data collection, and analysis. These manuals will guide students through performing the activity, recording results, and critically thinking on the concepts being explored. By engaging directly in these tasks, students will solidify their understanding of mechanical engineering concepts through application and reflection.

3.4. Evaluation Techniques

An evaluation process is required to assess how well the activities have used researched techniques to engage students, enhance their understanding of mechanical engineering concepts, and inspire a continued interest in STEM education. This information will be the basis of the result to identify strengths and weaknesses in the design, allowing for informed adjustments that will aid in an improved framework for future outreach programs. The data will attempt to be collected through a combination of qualitative and quantitative methods, through participation feedback via a pre and post questionnaire. To obtain quantitative data instruments such as a rating scale will be made use of for different aspects of their activity design, and with what will require a higher degree of analysis, the qualitative data will be gathered from open ended opinions based on participant experiences.

The intention behind questioning the students before and after the event is to accurately measure changes in their knowledge, attitudes, and interest in the topic. The first survey will establish a baseline while the concluding survey will hope to reveal the impact of the outreach efforts. This feedback will furthermore offer insight into the perceived value of the activities, highlighting areas for improvement. Additionally, other evaluation techniques will involve observational assessments made by the instructor to which they can monitor student engagement and interactions. This method provides a real time understanding of how these tasks are being received, and whether the intended learning outcomes are being achieved. These techniques have been chosen as they provide a comprehensive understanding of the effectiveness of the activity design both qualitatively and quantitatively, further allowing the research to refine outreach program models.

The evaluation of our outreach activities will employ a mixed methods approach, specifically a convergent parallel design. This methodology involves the simultaneous collection of both qualitative and quantitative data, allowing us to gain a comprehensive understanding of the effectiveness of our activities (refer to figure 3). By conducting analyses on both data sets concurrently, we can compare the results to provide a better interpretation of our findings. A sequential mixed methods design was considered but ultimately rejected, as it requires a phased data collection approach that would necessitate returning to participants with additional questions or follow-up phases, which is impractical in the context of this project. Collecting all data at once ensures that we can accurately capture initial and post-event responses in a single setting.

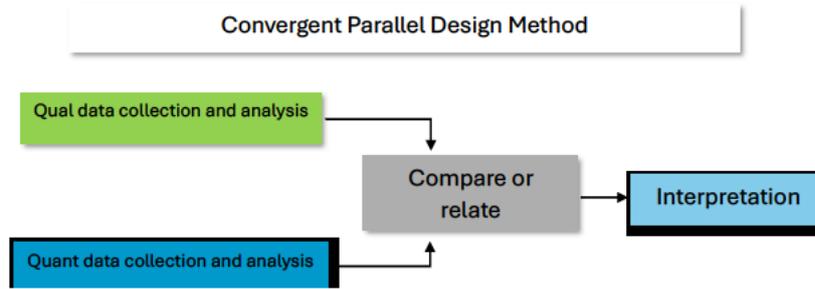


Figure 3: Convergent Parallel Design Method

One of the primary strengths of this mixed methods design is that it combines the advantages inherent in both types of data. The quantitative component will yield generalizable results, offering statistical insights into trends and pattern. Conversely, the qualitative data will enrich our understanding of the contextual factors surrounding student experiences. Integrating these two data types will not only enhance the robustness of our findings but also facilitate a deeper understanding of how the outreach activities influence students' perceptions and engagement in mechanical engineering. By triangulating the results from both quantitative and qualitative analyses, we aim to create a well-rounded evaluation that accurately reflects the impact of our engagement strategies and informs future program improvements.

3.5. Resource Requirements

The following list outlines the resources required to complete the research project and the details associated. The allocation of these resources at certain stages of the project can be found the schedule section of the methodology. These resources may be subject to change as new requirements arise.

- **Human Resources:** Three key personnel are required: the activity designer and documenter, the engagement activity participant, and the project supervisor to assist and collaborate on the endeavour.
- **Materials and Supplies:** Physical adaptations of these activity designs may require certain materials and products, dependant on the tasks at hand.
- **Equipment:** The main resource requirement is in computer hardware and software. Completing both the design and documentation of this project will need computer

facilities. Additionally, certain software and their accompanying licenses such as Office Word, AutoCAD, and internet accessibility are necessary.

- Facilities: A workspace to undergo the needed tasks is essential, such as a home office. Furthermore, an online meeting platform, such as Microsoft Teams, will be utilised to allow collaboration during the project timeline.

3.6. Limitations

Whilst the design of these activities aims to engage students into the aspiration of tertiary education in mechanical engineering, there are a set of limitations to be aware of when approaching this project. The segmentation of age groups may require further adjustments if implemented in real-world applications. Although it is found in literature to be beneficial to expose more complex ideas as the demographic matures, it could potentially exclude those who struggle with certain engineering concepts or are just beginning to develop an interest in the field. Additionally, the advanced technologies proposed for use in the design will mirror those available at the University of Southern Queensland, limiting the applicability these outreach activities at other institutions. As not all participants will have access to the suggested equipment, it is assumed for this project that they will be able to utilise these technologies. Lastly, allowing for long period feedback on the activities and their impact on interest in tertiary education in STEM would greatly aid in the future improvement of this model. However, as the extend of this project is the conceptual design and trial execution, there are limitations in collecting data for making these adjustments.

3.7. Schedule

This schedule outlines the timeline for the conceptual design of the engagement activities, along with the resources that are needed for each stage. It is structured to ensure timely completion of each phase of the design process, from the initial planning to the finalisation and presentation. See **Appendix A** for the full schedule table.

3.8. Risk Assessment

For this project it is important to outline the risks and hazards that may be associated with all aspects involved. Fortunately for this conceptual design the extent of risks follows similarly to that of office ergonomics. See **Appendix B** the submitted and approved risk assessment via SafeTrak.

3.9. Methodology Conclusion

This research project aims to design an effective engagement activity from the literature found that is tailored for mechanical engineering in the ambition to facilitate the transition from outreach participation to enrolment in the relevant tertiary education. To achieve this goal, the project will focus on three main objectives: conceptual design of outreach programs, creation of instructor manuals, testing and iteration, and the development of a framework to assess the effectiveness of activities in influencing transition rates.

While the project aims to provide comprehensive conceptual designs, it is important to note its limitations. These limitations identified may require attention as the design process moves forward. However, despite these constraints the project holds promise in contributing to the structure for future development of engagement activities for universities. By incorporating successful models found from existing literature and aligning these to the requirements of each target audience, the project seeks to lay a foundation for future research and design.

CHAPTER 4

ACTIVITY DESIGNS

This chapter will provide the description for all engagement activity designs, giving insight into their objectives, the engineering concepts that will be introduced, as well as justification for these choices. These designs will be the first iteration being given to participants. Once we have received data from our mixed method evaluation, alterations can be suggested for future iterations. The manuals that accompany these activities can be found in the Appendix as directed.

4.1. Primary: Hot Wheels Ramp – Exploring Motion and Weight

In this activity for primary school students, we focus on building a strong foundational interest in mechanical engineering concepts using Hot Wheels cars. The activity is designed to be simple yet highly engaging, using accessible materials and play-based learning to introduce students to core engineering principles. By allowing students to physically interact with objects, observe real-time outcomes, and make basic predictions, this activity encourages hands-on learning and exploration. Furthermore, the use of familiar objects like toy cars ensures that students are comfortable with the materials and can focus on experimentation. This accessibility is vital, as it removes any intimidation associated with more complex or abstract engineering tools. The success of similar STEM outreach programs discussed in the literature, such as La Trobe University's LaserTag activity, demonstrates the effectiveness of using familiar, enjoyable tasks to introduce engineering principles in a way that resonates with younger audiences.

The activity's primary objective is to immerse students in a highly engaging, tactile experience where they can intuitively grasp the basic principles of motion, mass, and force. Focus is on fostering curiosity about the physical world, helping students begin to form connections between everyday experiences and the mechanics behind them. This experience sets the stage for more formal education in science and engineering, sparking early interest in STEM fields.

Key Engagement Methods:

- *Interactive demonstrations:* Students at this age are highly tactile learners. By providing physical objects like Hot Wheels cars, we are adhering to the constructivist learning principles that emphasise learning through doing. Students in this demographic are in the preoperational stage of cognitive development, where they understand the world largely through sensory experiences and direct interactions with their environment. The act of launching a car and visually witnessing how different factors affect its movement helps solidify abstract concepts like force and motion.
- *Exploration through play:* Literature suggests that play-based learning is essential for this age group as it reduces pressures to comprehend engineering principles and instead encourages exploration and experimentation. The playful nature of this activity makes it easy for students to engage without feeling as though they are in a formal learning environment. This is crucial as the goal at this stage is not mastery of complex engineering concepts, but rather sparking an enduring interest in learning about how the world works.
- *Narrative-driven engagement:* By framing the experiment as a quest to figure out which car can travel the farthest, we are introducing a narrative element to the activity. As previously noted, narrative-based learning can aid in making abstract concepts more relatable and memorable for young learners. Students personalise the learning experience, giving them a sense of ownership and excitement over the discoveries they make.
- *Collaboration and teamwork:* Even in primary education, social learning plays a critical role in enhancing comprehension and engagement. While students will each launch their own cars, there will be opportunities to work in small groups to compare results and discuss outcomes. Social learning theory suggests that observing and interacting with peers can enhance understanding, especially in environments where students are encouraged to discuss their observations and form collective conclusions. This activity facilitates peer-to-peer learning, allowing students to articulate their understanding of motion and weight, which reinforces the concepts being explored.

This activity was selected based on research that highlights the importance of early exposure to STEM concepts in a context that feels fun and accessible. The Hot Wheels ramp provides

a visually stimulating and engaging way for students to observe the relationship between mass and motion, without the need for complex theoretical explanations. This ties directly into our design framework, which emphasises that for younger students, fostering interest is more important than imparting deep technical knowledge at this stage. While the concepts of friction, mass, and force are introduced in very simple terms in this activity, they serve as a foundation for more advanced engineering education.

For the relative manuals for this activity, please see **Appendix C** and **D**.

4.2. Grades 7-8: Hot Wheels Ramp – Trajectory Theory

As students' progress to grades 7-8, their cognitive and analytical abilities allow for a deeper engagement than the concepts introduced in primary school. This activity revisits the Hot Wheels ramp but introduces a more rigorous exploration of trajectory, weight, and the effects of angle and release height. The activity integrates theoretical mathematics, requiring students to predict outcomes using basic physics equations and then test their predictions through experimentation. This progression helps students bridge the gap between intuitive understanding and formal scientific reasoning.

Students will explore how weight, angle, and release height affect the distance travelled by a toy car, and they will be introduced to basic calculations involving velocity and distance. The activity aims to teach students how to apply theoretical knowledge to real-world situations and to encourage critical thinking through hypothesis testing and analysis of results.

Key Engagement Methods:

- *Guided inquiry and exploration:* At this stage, students are beginning to develop the ability to form and test hypotheses in a structured way. As discussed previously, guided inquiry is a critical engagement method for this age group because it encourages independent thought while still providing a framework to support learning. In this activity, students will hypothesise how changes in the car's weight or the ramp's angle will affect its speed and trajectory. They will then conduct experiments to test these predictions, learning to refine their hypothesis based on the results they observe.

- *Integration of theoretical analysis:* One of the main ways this activity builds on the primary school version is by introducing simple mathematical models to help students predict outcomes. Basic physics equations, such as those for velocity and distance, allow students to make predictions before conducting their experiments. This aligns with the design framework, where we explore the importance of connecting hands-on activities with theoretical learning.
- *Collaboration and teamwork:* Like the primary school version, this activity includes a strong collaborative element. Students will work in small groups to perform their experiments, discussing their predictions and comparing results. However, the focus in this age group shifts towards more structured teamwork, where students take on defined roles such as data recorder and experimenter. This structured collaboration mirrors the collaborative nature of real-world engineering projects and helps students develop essential teamwork and communication skills.
- *Problem-solving and critical thinking:* This activity also introduces a higher level of problem-solving and critical thinking, as students must not only conduct the experiment but also analyse their results and discuss their observations. This iterative process mirrors the engineering design process, where initial prototypes are tested, refined, and improved upon based on performance data. By encouraging students to think critically about the relationship between their theoretical calculations and the experimental results, we are fostering the development of higher order thinking skills that are crucial for success in STEM fields.

The design of this activity aligns with the cognitive development of middle school students, who are ready to engage with more abstract concepts and formalised scientific methods to a certain extent. The inclusion of theoretical mathematics challenges students to think more deeply about the principles at play, while the hands-on nature of the activity ensures that learning remains engaging and accessible. As previously noted, middle school students benefit from activities that blend practical experimentation with theoretical learning, as this helps them understand how abstract concepts apply to real-world scenarios.

At this stage of development, students are beginning to form deeper connections between what they learn in the classroom and how it applies in the real world. By introducing mathematical models and requiring students to make predictions, we encourage them to view

engineering not just as trial and error, but as a discipline that balances theory with practical application. This is a vital shift in thinking for students who are beginning to consider their future studies and careers. While primary activities focused more on building curiosity and basic understanding, this activity takes students one step further by engaging their analytical and reasoning skills. By blending these, this activity sets the stage for future learning, where students will engage in more complex, self-directed projects that require a deeper understanding of both theory and practice. This activity scaffolds their learning by introducing them to the idea that engineering is a process of inquiry, experimentation, and refinement, preparing them for future STEM coursework and potentially even careers. Additionally, this activity helps students develop confidence in their ability to solve complex problems, reinforcing their interest in pursuing further studies in engineering or related fields.

To view the relative manuals for this activity, please see **Appendix E** and **F**.

4.3. Grades 9-10: Introduction to CAD and Mechanical Design

Participants in grades 9-10 are introduced to Computer Aided Design (CAD) software, focusing on developing their skills in designing mechanical components. The aim of this activity is to expose students to the tools and features of CAD, allowing them to create 3D models of simple mechanical parts such as gears, brackets, or other basic components. This introduction to CAD lays the foundation for understanding the role of design in mechanical engineering, emphasising precision, spatial awareness, and the importance of visualisation in the engineering process.

The primary objective of this activity is to familiarise students with CAD software by guiding them through the process of creating 3D models of mechanical components. By the end of the activity, students will have learned how to navigate the software's user interface, use basic tools like sketching, extrusion, and dimensioning, and understand the importance of accuracy and detail in mechanical design. The goal is to introduce students to the world of digital design in engineering, encouraging them to think critically about how physical objects are conceptualised and created.

Key Engagement Methods:

- *Exposure to advanced tools:* One of the central engagement methods for this age group is exposure to industry-standard tools. By using CAD software, students gain practical experience with a powerful tool used in professional engineering settings. Although the activity is limited to modelling without simulations, this initial exposure is vital for helping students develop a comfort level with the software, preparing them for more advanced tasks in the future. This also introduces students to the role of CAD in mechanical engineering, where design precision is paramount before any physical prototyping occurs.
- *Engineering design principles:* This activity immerses students in the early stages of the engineering design process. They begin by conceptualising mechanical components like gears or brackets, and then using CAD to translate their ideas into digital 3D models. Students will focus on creating accurate, detailed models, which requires them to understand the importance of geometrical constraints and tolerances in engineering. This emphasis on precision mirrors real-world engineering practices, where even small errors in design can lead to significant issues during manufacturing.
- *Interactive Digital Learning:* Although the activity is digitally focused, it maintains the interactive learning approach that is still critical at this developmental stage. Students are actively engaged in creating their own designs, manipulating objects in a 3D space, and using CAD tools to refine their models. This engagement with digital objects helps students build spatial awareness and problem-solving skills, as they learn how to manipulate dimensions, shapes, and features within the CAD environment.

This activity was chosen based on the cognitive development of students in grades 9-10, who are ready to transition from hands-on physical learning to digital-based problem-solving. At this stage, students can understand abstract concepts like design accuracy, geometry, and the relationship between 2D sketches and 3D models. The decision to focus on modelling without simulations was made to keep the activity accessible to students who are new to CAD while allowing them to build foundational skills in digital design. By focusing on the design aspect, students learn to appreciate the complexity and precision required in mechanical engineering, even before simulations or physical testing come into play.

For the relative manuals for this activity, please see **Appendix G** and **H**.

4.4. Grades 11-12: Designing Mechanical Components – Finite Element Analysis

In this final engagement activity, students in grades 11-12 will build upon their foundational knowledge of Computer-Aided Design (CAD) by engaging in more complex design tasks. They will not only design mechanical components, such as brackets or gears, but also perform Finite Element Analysis (FEA) to test the structural integrity of their designs under various conditions. This activity bridges the gap between digital design and real-world mechanical performance, helping students understand how engineers validate and refine designs before manufacturing. The goal of this activity is twofold: first, to enhance students' skills in designing mechanical components, and second, to introduce them to Finite Element Analysis (FEA), a critical tool in mechanical engineering for assessing stress, strain, and deformation in materials. Students will design a mechanical component and use FEA to analyse how their design performs under applied loads. The goal is to simulate real-world conditions and teach students how engineers use FEA to ensure that components can withstand the forces they will experience in use.

Key Engagement Methods:

- *Advanced exposure to industry-standard tools:* Students in their final years of high school are ready for advanced exposure to the tools and technologies used by professional engineers. In this activity, 3D modelling and Finite Element Analysis (FEA) is a powerful feature that allows students to simulate how their components will respond to forces, stress, and deformation.
- *Engineering design and validation process:* Students will go through a more rigorous version of the engineering design process in this activity. They will start by designing a component, ensuring that it meets the outlined specifications, and then subject it to FEA to validate their design. This process introduces students to the concept of design validation, where engineers use simulations to test how their components will perform under real-world conditions before they are improved and finally built.

- *Critical thinking and problem-solving through analysis:* FEA requires students to think critically about the material properties, forces, and constraints involved in their design. By performing stress and strain analysis on their components, students learn how to interpret data from simulations and use that information to refine their designs. This encourages higher-order thinking, as students must evaluate whether their component will fail under certain conditions and make the necessary adjustments to improve its structural integrity. This aligns with the engagement methods discussed, where problem-solving and critical analysis are key to developing students' engineering mindset.
- *Bridging theory and real-world application:* One of the primary learning outcomes of this activity is helping students connect theoretical principles of mechanics, such as stress, strain, and load distribution, with their real-world applications. FEA allows students to visualise how their designs behave under different conditions, helping them understand abstract mechanical engineering concepts in a tangible way.

Students at this stage are preparing for higher education or entry into the workforce, and thus need exposure to the full engineering design process. CAD design, combined with FEA, offers a comprehensive platform for teaching both the creative and analytical sides of mechanical engineering.

This activity is designed to give students a comprehensive understanding of the entire design and validation process. By introducing them to FEA, we equip them with a critical tool for analysing and improving their designs, helping them build confidence in their ability to solve complex engineering problems. These skills will serve them well in both higher education and future careers, where they will need to combine creative design with rigorous analysis to develop innovative engineering solutions.

For the relative manuals for this activity, please see **Appendix I** and **J**.

4.5. Activity Evaluations

To accurately measure the impact of these activities on student interest, understanding, and engagement with mechanical engineering, a mixed-methods evaluation approach will be employed. This method combines both quantitative and qualitative data collection and analysis, ensuring a comprehensive understanding of the outcomes of the activities. These question sets will ask of the students both before and after the activity, to better isolate the designs specific impact. The inclusion of both numerical data and open-ended responses allows for a stronger evaluation, addressing both the measurable and experiential aspects of student engagement. By integrating both quantitative data, with the use of Likert-scale responses, and qualitative data, such as open-ended feedback, this method captures a wide range of student experiences and attitudes.

The quantitative aspect of the evaluation will focus on numerical measures of student engagement, interest, and perceived learning outcomes. To assess this a five-point Likert-scale will be used. The Likert scale will range from 1 to 5, providing a clear, quantifiable measure of student attitudes. This method is ideal for capturing changes in interest or confidence, as it allows tracking trends across a large group of participants and identify key areas where the activities are particularly effective, or where improvements may be needed.

In addition to the Likert-scale responses, qualitative data will be collected through open-ended questions at the end of each evaluation form. These questions will encourage students to reflect on their personal experience with the activities and provide more nuanced feedback. This qualitative feedback is crucial for gaining insight into the experiential aspects of the activities. These are elements that cannot be fully captured by numerical data alone. Open-ended questions allow for more exploratory feedback, providing valuable context for the quantitative data. Students' reflections will help identify aspects of the activities that particularly resonated with them or areas that may require further development.

4.5.1. Mixed-Methods Data Integration

Once the data collection is complete, the quantitative and qualitative results will be integrated to form a comprehensive evaluation of the activities. This mixed-methods integration will provide a better understanding of the overall effectiveness of the outreach efforts, combining the numerical insights from the Likert scale with the personal reflections captured in the open-ended responses.

The quantitative data from the Likert scale will be analysed using basic statistical methods, identifying trends across different activities or age groups, and determining the overall effectiveness of the activities in fostering interest in mechanical engineering. The qualitative data will be analysed through thematic coding, identifying common themes and patterns in the student responses. This approach allows us to explore the subjective experiences of the students in greater depth, highlighting both the strengths and areas for improvement in the activities.

By combining these two methods, we ensure that the evaluation captures both the measurable impact of the activities and the individual student experiences that provide richer context to the numerical data. The mixed-methods approach was chosen for its ability to capture both the breadth and depth of student engagement. The Likert-scale offers clear, comparable data that can be easily quantified, while the open-ended responses provide deeper insight into students' individual experiences, allowing us to identify any unexpected outcomes or themes. This combination is essential for understanding the full impact of the outreach activities, ensuring that our evaluation is not only comprehensive but also actionable, providing clear directions for future program development.

The evaluation survey for each activity can be found at the beginning and end of each user manual.

4.6. Preliminary Evaluation of Design

Based on prior research, it is anticipated that outreach activities tailored to different age groups will effectively foster interest in mechanical engineering. Previous studies show that engaging students through hands-on, interactive experiences with relativity to real-world applications significantly impacts their intention to pursue STEM fields. For primary students, activities that emphasise fun and curiosity-driven learning are likely to spark initial interest in engineering. For middle school students, activities that introduce basic engineering concepts are expected to solidify their interest and encourage exploration of engineering careers. The literature supports the idea that introducing practical applications and team-based projects at this age can significantly influence a student's career aspirations in STEM fields. The two activity designs proposed strongly correlate to this structure, and it would be anticipated that feedback received would justify its model. Giving these students a

task with instantaneous payoff, with a greater engineering concept being taught, will likely entice participants into the further inquiry into the topics that STEM has to offer.

For students in grades 11-12, outreach activities that incorporate advanced engineering concepts and tools, such as the CAD software from the activity design, are expected to resonate more effectively with their developing skill sets. These students are at a critical juncture where they begin to make more definitive decisions about their future career paths. Therefore, providing them with activities that simulate real-world engineering practices and challenges will allow them to gain insight into the standards at the tertiary level. This early expose can solidify intentions and answer any queries about what is expected of them if their pursuit continues.

There are identifiable challenges that outreach programs, such as the designs proposed, may face during implementation. One of the major challenges identified in the literature is funding constraints, which can impact the scale and quality of outreach activities, as limited financial resources may restrict the ability to conduct these outreach programs. Addressing this challenge will require innovative approaches to resource management and potential partnerships with industry stakeholders to ensure the sustainability and effectiveness of the outreach activities. Furthermore, the need for systematic evaluation of outreach activities is another significant challenge. Without robust evaluation mechanisms, it can be difficult to measure the impact of outreach programs have on the overall transition to tertiary education. Developing and implementing comprehensive evaluation frameworks will be essential for assessing the effectiveness of outreach activities and ensuring they meet their intended goals.

The preliminary insights drawn from existing literature suggest that well designed outreach activities that incorporate aspects that focus on age-appropriate content have the potential to significantly impact student interest in mechanical engineering. The results will include validating these predictions with real-world data and refining the outreach strategies to optimise their effectiveness, in hopes to build a well-researched framework for future design.

CHAPTER 5

RESULTS AND DISCUSSION

The designed engagement activities were conducted with participants across different age groups, and data was collected using a mixed-methods evaluation approach. This included both Likert-scale questions to gather quantitative data and open-ended responses to capture more detailed reflections on each activity. The following tables present the collected data, with slight rewording of the open-ended responses for clarity and ease of understanding. These responses provide insight into how the key engagement methods impacted student interest, understanding, and engagement with mechanical engineering concepts.

5.1. Participant Responses to Engagement Activities

Table 2: Mixed-Methods Responses to Engagement Activities

Activity 1: Participant #1	
Pre-Activity Responses	Post- Activity Responses
<p>Likert-Scale: 1. Excitement: 5 2. Interest in learning how objects move: 4 3. Enjoy testing things: 5</p> <p>Open-Ended: 4. “I think I will learn why cars move faster or slower based on how heavy they are and how steep the ramp is. I’m curious to see what makes a car go far.” 5. “The most fun part will be launching the cars and seeing which one goes the farthest. I like doing experiments like this.”</p>	<p>Likert-Scale: 1. Increase in interest: 4 2. Understanding of weight and movement: 4 3. Fun level: 5</p> <p>Open-Ended: 4. “I really enjoyed launching the cars and watching how far they would go. I thought the heaviest car would always go the farthest, but I learned that it depends on more than just weight.” 5. “I learned that heavier cars don’t always go the farthest because things like the angle of the ramp and friction are important too. It was cool to see how different factors affect how cars move.”</p>
Activity 1: Participant #2	
Pre-Activity Responses	Post- Activity Responses
<p>Likert-Scale: 1. Excitement: 3 2. Interest in learning how objects move: 3 3. Enjoy testing things: 4</p>	<p>Likert-Scale: 1. Increase in interest: 3 2. Understanding of weight and movement: 4 3. Fun level: 4</p>

<p>Open-Ended: 4. "I think I will learn how to make a car go fast by changing how I push it or maybe by changing how the ramp is set up. I'm interested in figuring out what makes one car faster than the other." 5. "Launching cars will be fun because I like seeing how fast things can go, especially when they go off ramps."</p>	<p>Open-Ended: 4. "I liked seeing which car went the farthest, but it was surprising how much difference the ramp angle made. I thought weight was the only thing that mattered, but now I know that how steep the ramp is also affects it a lot." 5. "I learned that changing the height of the ramp makes a big difference in how far the cars go. I didn't realise that something like the ramp angle would affect it so much. It was fun figuring that out."</p>
Activity 2: Participant #1	
Pre-Activity Responses	Post- Activity Responses
<p>Likert-Scale: 1. Comfort using math to predict: 2 2. Belief that weight/angles affect travel: 4 3. Interest in calculating movement: 3 Open-Ended: 4. "I think it's interesting how you can use math to figure out how far something will go. I've never really thought about how math can help predict where something will land, so I'm curious to see how accurate it is." 5. "I want to see how changing the angles works because I think the angle of the ramp will really affect how far the cars travel. I want to test different angles to see what makes the car go the farthest."</p>	<p>Likert-Scale: 1. Help in understanding math and movement: 4 2. Understanding of weight/angles: 4 3. Comfort using math to predict: 4 Open-Ended: 4. "I learned that math can help you predict how far things will go if you know the angle and weight. It was cool to use numbers to guess how far the car would go, and it was pretty close to what I thought it would be. I didn't expect it to be that accurate." 5. "I liked figuring out the best angle for the ramp because it made the cars go the farthest. It was fun trying out different weights and heights to see what worked best. I also learned that math can really help in predicting things like speed and distance, which was something I didn't know before."</p>
Activity 2: Participant #2	
Pre-Activity Responses	Post- Activity Responses
<p>Likert-Scale: 1. Comfort using math to predict: 3 2. Belief that weight/angles affect travel: 3 3. Interest in calculating movement: 2 Open-Ended: 4. "I think it will be cool to see how math works with the cars. I'm not sure how it all fits together yet, but I'm interested in learning about how the math we use can make predictions about movement." 5. "I'm excited to see how changing the weight of the cars affects how far they go, and I'm looking forward to testing different setups with the ramp."</p>	<p>Likert-Scale: 1. Help in understanding math and movement: 3 2. Understanding of weight/angles: 3 3. Comfort using math to predict: 3 Open-Ended: 4. "I learned that weight and angle both matter a lot when it comes to how far the cars go. It was interesting to see how changing just one thing, like the angle, can make a big difference in the distance the car travels. I didn't expect that the changes would be so noticeable." 5. "I liked testing the cars and trying to beat my predictions with the math. I'm still not super comfortable with using math to predict everything, but it was cool to see how the angles and weights affected the cars in real time. I think I need more practice to really get it though."</p>

Activity 3: Participant #3	
Pre-Activity Responses	Post- Activity Responses
<p>Likert-Scale:</p> <ol style="list-style-type: none"> 1. Confidence in designing with software: 2 2. Interest in learning mechanical design: 4 3. Belief that digital tools help engineers: 4 <p>Open-Ended:</p> <ol style="list-style-type: none"> 4. “I think I’ll learn how to create objects and parts using SolidWorks. I’m interested in how engineers use software to design things before they actually build them. I think it will be a challenge to get everything right, but I’m excited to try.” 5. “It might be hard to get the design just right because I’ve never used 3D software before, but I think it will be a good way to see how engineers solve problems.” 	<p>Likert-Scale:</p> <ol style="list-style-type: none"> 1. Confidence in using SolidWorks: 4 2. Understanding of design precision: 5 3. Interest in using CAD tools: 5 <p>Open-Ended:</p> <ol style="list-style-type: none"> 4. “It was definitely hard to learn SolidWorks at first because there are so many options and tools to figure out, but once I got used to it, I was able to create my designs a lot faster. It made me appreciate how important it is to be precise when designing parts.” 5. “I understand why engineers need to be really careful with their measurements because even a small mistake can cause problems. This activity made me more confident in using CAD software, and I want to keep practicing so I can get better at designing more complex parts.”
Activity 4: Participant #4	
Pre-Activity Responses	Post- Activity Responses
<p>Likert-Scale:</p> <ol style="list-style-type: none"> 1. Comfort with testing designs digitally: 3 2. Importance of testing designs: 5 3. Interest in learning testing and analysis: 4 <p>Open-Ended:</p> <ol style="list-style-type: none"> 4. “I think I’ll learn how engineers make sure their designs are safe and can handle stress before they actually build them. I’ve heard of FEA before, and I’m curious to see how it works.” 5. “It might be hard to understand all the data from testing, but I think it will be interesting to see how a design performs in a simulation before it’s built.” 	<p>Likert-Scale:</p> <ol style="list-style-type: none"> 1. Understanding of design testing: 5 2. FEA tool’s usefulness: 5 3. Confidence in using simulations: 4 <p>Open-Ended:</p> <ol style="list-style-type: none"> 4. “I learned how engineers use testing tools like FEA to check if their designs can handle pressure and forces before they actually build them. It was really interesting to see how stress points showed up on my design and to think about how that would work in real life.” 5. “I would make the design stronger based on the FEA results I got because I saw areas where it might fail under too much stress. This activity made me realise how important it is to test things before building them, and I feel more confident now using simulations to analyse designs.”

5.2. Interpretation of Results

The following section will interpret the results of the data collected from the designed engagement activities. A convergent parallel design is used, in which both quantitative and qualitative data were collected simultaneously and analysed in tandem. By comparing the Likert-scale responses with the open-ended reflections from the participants, we can draw comprehensive conclusions about the effectiveness of the key engagement methods employed in the activities. This mixed-methods approach allows us to integrate both numerical and experiential insights, ensuring that our evaluation captures the full scope of participant experiences.

5.2.1. Activity 1: Primary

The Likert-scale responses from both participants (P#1 and P#2) reveal generally high excitement levels for the activity, particularly for P#1, who rated their excitement as a 5 before the activity. P#1 also demonstrated a solid interest in learning how objects move, with a 4 out of 5 on that measure. After the activity, both participants indicated an increased understanding of how weight affects movement, with both rating their understanding as a 4. This suggests that the hands-on, play-based learning method was effective in enhancing their conceptual understanding of weight and movement. Both participants also rated the activity highly in terms of enjoyment (P#1: 5, P#2: 4), reflecting the success of using a play-based learning approach, which aligns with our expectations from literature. The high enjoyment ratings suggest that tactile, interactive activities the one conducted can effectively engage primary students and stimulate curiosity.

In the open-ended responses, P#1 and P#2 both emphasised the enjoyment they derived from launching the cars and experimenting with different variables, such as ramp angle and car weight. P#1's response, "I thought the heaviest car would always go the farthest, but I learned that it depends on more than just weight," reflects a shift in understanding and highlights the educational impact of the activity. This matches their Likert-scale response of an increased interest, suggesting that the play-based method helped explain basic physics concepts. Similarly, P#2's qualitative response, "I didn't realise that something like the ramp angle would affect it so much," shows a deeper grasp of how different factors affect motion. The qualitative data reinforces the quantitative measures, as both participants acknowledged learning about the effects of weight and ramp angle.

Converging the Likert-scale data and open-ended responses indicates that the hands-on, play-based learning method was successful in increasing both engagement and conceptual understanding for primary students. The participants' positive enjoyment ratings and reflections on what they learned suggest that tactile experimentation, paired with exploratory learning, effectively nurtures curiosity and builds foundational knowledge in mechanical engineering concepts. This outcome is consistent with literature in STEM outreach, which highlights the importance of interactive, play-driven engagement methods at this developmental stage.

5.2.2. Activity 2: Grades 7-8

In this activity, both participants expressed low levels of comfort using math to predict movement before the activity, with P#1 rating it as 2 and P#2 as 3. Post-activity, P#1 showed an increase in comfort, raising their score to 4, and P#2 remained at a middle score of 3. This suggests that there is evidence that integration of theoretical math with hands-on experimentation improves the confidence in applying mathematical concepts to physical movement. However, this is inconclusive due to P#2's response. The understanding of the relationship between weight, angles, and movement was similarly inconclusive. Both participants rated their understanding the same post-activity, suggesting that combining theory and hands-on learning was not as effective in promoting deeper comprehension, but rather enforcing current understanding.

P#1's qualitative feedback showed direct appreciation in the application of theoretical concepts to a real-world problem, aligning with the literature on the importance of applied learning in STEM education. P#1's enjoyment of figuring out the best angle for the ramp shows that they were not only engaged by the activity but also motivated by the challenge of applying theory to practice. P#2 also acknowledged the educational value of the activity, stating, "I learned that weight and angle both matter a lot when it comes to how far the cars go." Although P#2 did not express the same level of increased comfort in using math, they noted the importance of hands-on experimentation in reinforcing their understanding of theoretical concepts. The qualitative data suggest that while math may still pose a challenge for some students, incorporating physical experimentation makes abstract concepts more accessible.

The Likert-scale data and qualitative reflections indicates that integrating theoretical math with hands-on exploration has an inconclusive effect on increasing mathematic ability, but

rather an aid to sustain current levels. While the quantitative ratings show a slight improvement in participants' confidence and knowledge of engineering theory, the qualitative data reveals that the combination of theory and physical experimentation is key to deepening comprehension. The activity successfully bridged the gap between abstract math and tangible outcomes, allowing students to see the practical applications of the theories they were learning.

5.2.3. Activity 3: Grades 9-10

P#3 initially reported low confidence in designing objects using SolidWorks, with a pre-activity confidence rating of 2. However, by the end of the activity, their confidence increased to a 4, showing a significant boost in their ability to use the software. P#3 also indicated a high interest in continuing to use CAD tools in the future, indicating that the exposure to digital design had a strong positive impact. P#3 also rated their understanding of precision in mechanical design as 5 after the activity, which was a key learning objective for this age group. This shows that the use of industry-standard CAD tools not only increased their skills but also heightened their awareness of practices in mechanical engineering.

The open-ended responses highlight the challenges they faced initially but also their growing confidence as the activity progressed. Their comment, "It was definitely hard to learn SolidWorks at first because there are so many options and tools to figure out," reflects the initial difficulty many students face when learning new software. However, the increase in their confidence is supported by their statement, "Once I got used to it, I was able to create my designs a lot faster." The response "This activity made me more confident in using CAD software, and I want to keep practicing" aligns directly with the goals of this activity, confirming that the use of CAD software met the educational objectives of improving both skill and enticed further learning and exploration of engineering design.

The integration of the quantitative and qualitative data reveals that exposure to digital design tools was highly effective in increasing student confidence and understanding of mechanical design. The quantitative increase in confidence, paired with P#3's qualitative reflections, suggests that using industry-standard software fosters both practical skills and an appreciation for the demands of real-world engineering.

5.2.4. Activity 4: Grades 11-12

P#4's comfort with testing designs digitally increased from a pre-activity rating of 3 to a post-activity rating of 4. Additionally, they rated their understanding of the importance of testing designs as 5 both before and after the activity, confirming that they already had and understanding about the critical role of design validation in mechanical engineering. The FEA tool was also rated highly useful, indicating that P#4 found the activity's focus on testing and analysis to be very valuable. The increase in P#4's confidence in using simulations shows that the activity helped them become more comfortable with applying FEA.

P#4's qualitative reflections further demonstrate their deepened understanding of the importance of FEA. Their comment, "It was really interesting to see how stress points showed up on my design and to think about how that would work in real life," indicates that the activity successfully bridged the gap between digital simulation and real-world application, as well as enticing further investigation into these practices. P#4's realisation that they would need to strengthen their design based on the FEA results shows that the activity helped them engage with the iterative process of design improvement, a core engineering skill. This appreciation of FEA's importance, particularly in testing designs before building them, is evident in their comment, "This activity made me realise how important it is to test things before building them." This is supported by their post-activity Likert-scale ratings, reinforcing the effectiveness of this design testing and validation method.

The combination of the quantitative and qualitative data shows that introducing students to more advanced engineering practices, such as FEA, was highly effective in fostering both practical skills and conceptual understanding. P#4's increased comfort with simulations and their reflections on how FEA enhances design testing demonstrate that the activity successfully taught critical engineering principles, particularly the importance of design validation. This activity designs seem to not only enhanced technical skills but also deepened the students' understanding of how industry professionals ensure their designs can withstand real-world application.

5.3. Framework for Outreach Activity Design

The evaluation results provide key insights for refining our outreach activity framework. By integrating participant feedback, we can identify which engagement methods were effective and where improvements are needed. This section outlines how the findings shape future activities, reinforcing successful methods and proposing a refined framework for ongoing development.

5.3.1. Reinforced Methods

The evaluation results have supported key elements of our framework. Firstly, the activity designed for the younger demographic proved highly effective, highlighting the value of play-based, tactile learning. Participants showed increased interest and enjoyment, aligning with research on the benefits of kinaesthetic learning for primary-aged students. The framework should continue prioritising simple, interactive experiments using familiar objects to introduce mechanical engineering concepts. Furthermore, for middle school students, activities combining math with physical experiments confirmed the effectiveness of integrating theory with hands-on learning. Students gained confidence in using math to predict outcomes, though results suggest more support may be needed to ensure all students feel comfortable with the associated theory. The framework should maintain this blend, offering additional guidance when necessary. Finally, activities using CAD and FEA highlighted the importance of exposing an older demographic to industry-standard tools. Students reported increased confidence and understanding, reinforcing the need to continue introducing digital modelling and simulation.

5.3.2. Adjustment of Methods

While much of our framework was supported by the data, some areas need refinement to better meet the needs of all students and improve the effectiveness of future outreach activities. The data from grades 7-8 suggest that not all students were comfortable with integrating mathematical theory into hands-on experiments. Although many appreciated the challenge, some struggled with mathematical concepts, indicating the need for more support. Future activities should include step-by-step guidance, breaking down complex ideas and providing clear examples of how theory connects to physical outcomes. Group work or peer support could also help build confidence in applying theoretical knowledge.

Additionally, the results show that while hands-on learning and digital tools were generally effective, different learning styles require varied engagement methods. It is found that learning new software can be challenging at first. To accommodate diverse preferences, the framework should include tutorials or videos for visual learners and offer more guided practice before advancing to complex tasks. This will help reduce frustration and increase engagement.

5.3.3. Proposed Framework for Outreach Activity Design

Based on the evaluation results, the proposed framework for future mechanical engineering outreach activities integrates key engagement methods supported by the data while incorporating adjustments to address identified areas for improvement:

1. Hands-On Learning for Early Engagement

- *Target Group:* Primary and early middle school students.
- *Engagement Method:* Activities should prioritise tactile, hands-on learning, using familiar objects to introduce mechanical concepts in a playful and engaging way. The focus should be on experimentation and exploration, allowing students to manipulate variables with ease to observe outcomes.

2. Applied Learning for Conceptual Understanding

- *Target Group:* Middle school students.
- *Engagement Method:* Activities should blend theoretical concepts with practical application, ensuring that students can see the real-world implications of abstract ideas. Hands-on experiments should be paired with guided mathematical analysis to encourage students to apply theory to predict outcomes.

3. Digital Design and Iterative Problem-Solving

- *Target Group:* High school students.
- *Engagement Method:* Introduce students to industry-standard tools such as CAD software and simulation tools like FEA. Activities should focus on iterative design processes, allowing students to create, test, and refine their designs using digital tools.

4. Support for Diverse Learning Preferences

- *Target Group:* All students.
- *Engagement Method:* Offer varied instructional material to accommodate different learning preferences. This may include visual aids, written guides, and peer support to ensure that all students can engage meaningfully with the content.

5.4. Final Discussion and Future Study

While this research project has provided valuable insights into the design and effectiveness of mechanical engineering outreach activities, several areas for future study have emerged that could help deepen our understanding of these programs and their long-term impact.

One significant limitation of this research was the small sample size, with only one or two participants involved in each activity. While this data offers a useful starting point, conducting these activities on a larger, more diverse group would allow for a more robust evaluation of the effectiveness of key engagement methods. A larger participant pool would also enable a more detailed analysis of how peer interaction affects learning and engagement, particularly in group-based activities where collaboration is encouraged. Future studies should focus on increasing the number of participants to gather more comprehensive data on group dynamics and collective problem solving, which are critical components of engineering practice.

As noted in the evaluation section, collecting qualitative data from younger students presented some challenges. The open-ended responses from primary students were often brief and less detailed compared to those from older participants. This raises questions about the reliability and depth of qualitative responses from younger age groups. Future research could explore alternative methods for eliciting more detailed reflections from younger students.

While this research successfully captured immediate reactions to the engagement methods employed, it does not provide insight into the long-term effects of these activities on students' educational and career trajectories. A major area for future study is the impact of outreach activities on transition rates to university engineering programs. Long form studies

that track participants from outreach activities through to their university enrolment could provide critical data on the lasting influence of these programs on students' academic and career decisions. However, due to the scope and resources available for this project, long-term tracking was not feasible. Future research should aim to collaborate with educational institutions to perform these long-term evaluations. This would require institutional support and consistent follow-up with participants over several years to accurately measure the enduring impact of these outreach efforts.

Overall, while this research has highlighted the potential of well-designed outreach activities to foster interest in mechanical engineering, there remains several promising avenues for further investigation. Expanding participant numbers, refining methods for younger students, and conducting long-term studies on the transition to tertiary education will all contribute to a more comprehensive understanding of how mechanical engineering outreach can shape the future of STEM education.

CHAPTER 6

CONCLUSION

This dissertation explored the design, implementation, and evaluation of outreach activities aimed at fostering interest in mechanical engineering among students of different age groups. By employing a variety of engagement methods, ranging from hands-on, play-based learning for younger students to advanced digital design and analysis tools for older students, the research sought to understand how different approaches impact student interest and engagement with mechanical engineering concepts.

Through a mixed methods evaluation, combining both quantitative Likert-scale responses and qualitative open-ended feedback, the study provided insight into the effectiveness of these activities. The results demonstrated that hands-on learning and experimentation are particularly effective for younger students, promoting curiosity and foundational understanding of mechanical principles. For middle school students, integrating theoretical math with physical experimentation proved valuable in enhancing both confidence and comprehension. In the case of high school students, exposure to industry-standard tools highlighted the importance of digital design and simulation in developing both practical skills and an understanding of real-world engineering processes. However, the study also revealed areas for further improvement. The small sample size limited the ability to generalise the findings, and the qualitative responses from younger students highlighted the need for alternative methods to better capture their reflections. Additionally, while the research provided immediate insights into student engagement and learning, it did not address the long-term impact of these activities on students' academic and career trajectories. Future research should focus on expanding the participant pool, refining data collection methods for younger students, and conducting longitudinal studies to assess the long-term effects of outreach activities on university enrolment and career paths in mechanical engineering. Collaborations with educational institutions will be essential for undertaking such research.

This project shines light on the potential of well-designed outreach activities to inspire and educate students, highlighting the importance of early engagement in STEM education. The findings contribute to the growing body of research on effective outreach in engineering and lay the groundwork for further exploration into how these activities can be optimised to support the next generation of engineers.

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APPENDICES

Appendix A: Project Schedule

Task	Details	Resource Requirements
Discussion of Design Ideas	From the literature review, we can discuss what factors are necessary in the effective design of engagement activities and begin to theorise ideas that fit these models.	<ul style="list-style-type: none"> - Project Supervisor - Internet - Microsoft Teams - Home office - Office Word
Methodology Writing and Submission	To justify what the plan of action is for the design of these activities, the methodology will be created to outline how the project will be approached given the literature.	<ul style="list-style-type: none"> - Office Word - Home office
Conceptual Design of Activities	Once the roadmap and framework are set, the initial design of the activities can commence.	<ul style="list-style-type: none"> - Office Word - Internet - Home Office - AutoCAD
Discussion and Editing of Conceptual Designs	After building the first iteration of the engagement activity designs, a discussion can be held to identify the changes needed, as well as the strong aspects to bring forward.	<ul style="list-style-type: none"> - Project Supervisor - Internet - Microsoft Teams - Home Office
Finalisation of Conceptual Design	The final conceptual design should be completed after all feedback has been considered. This may require further research into the literature, or a restructure of any predetermined aspects that may have been seen as best practice.	<ul style="list-style-type: none"> - Office Word - AutoCAD - Home Office - Internet
Writing User Manuals	Given the conceptual design is finalised, we can move towards building the user manuals that will facilitate the execution of these activities. These again will be subject to discussion and editing to produce the best final product.	<ul style="list-style-type: none"> - Office Word - Internet - Home Office - Project Supervisor - Microsoft Teams

Testing of Activities	With the final design and user manuals complete, a set of trial runs can be performed to collect the necessary survey data for evaluation,	<ul style="list-style-type: none"> - Activity Equipment - Activity Environment - Participants - Office Word
Draft Dissertation Writing and Submission	A draft dissertation that will include all aspects of the research project tasks will be formulated. This will include everything to date and be the basis for presentation to peers and academics.	<ul style="list-style-type: none"> - Office Word - Internet - Home Office - Project Supervisor
Presentation of Final Project	A presentation of the complete research project will be made at UniSQ in front of peers and academics. This presentation will intend to effectively communicate the design, findings from literature, and all processes relative to the project. Feedback will be acquired to further improve the research project before finality.	<ul style="list-style-type: none"> - Project Supervisor - University Auditorium - University Peers - University Academics
Final Dissertation Revision and Submission	After acquiring feedback from the presentation, a final dissertation will be submitted to the university for review. This final dissertation will aim to be the most comprehensive and well worked version.	<ul style="list-style-type: none"> - Office Word - Project Supervisor - Internet - University Academics

Appendix B: SafeTrak Risk Assessment

4774	RISK DESCRIPTION			STATUS	TREND	CURRENT	RESIDUAL
	ENP4111 - Design of Interactive Mechanical Engineering Engagement Activities			Live		Low	Low
RISK OWNER		RISK IDENTIFIED ON		LAST REVIEWED ON		NEXT SCHEDULED REVIEW	
Nicholas Shields		20/05/2024		20/05/2024		20/05/2025	
RISK FACTOR(S)	EXISTING CONTROL(S)	CURRENT	PROPOSED CONTROL(S)	TREATMENT OWNER	DUE DATE	RESIDUAL	
Computer Station Risks: - Body Stressing injuries from home office work.	Control: - Ensure furniture and computers are set up ergonomically and are suited to the task. - Stand up, sit less, move more. - Take intermittent breaks.	Low	No Control:			Low	
Home Office Environment Risks: - Physical injuries from home hazards i.e. slips, trips, falls.	Control: - Check that the workspace is free of clutter and trip hazards and has adequate ventilation.	Low	No Control:			Low	
Home Office Environment Risks: - Inadequate lighting.	Control: - Check the level of illumination and location of lighting fixtures are suited to the activity. Lighting level should be sufficient for visual tasks to be completed without eye strain.	Low	No Control:			Low	
Other Home Hazards: - Fire	Control: - Ensure smoke detectors are installed, regularly checked, and a fire extinguisher or other retardant is accessible.	Low	No Control:			Low	
Other Home Hazards: - Electrical Fault	Control: - Electricity supply and any electrical appliances used while homeworking should be well maintained and regularly checked.	Low	No Control:			Low	
Other Home Hazards: - Noise Pollution	Control: - Eliminate loud damaging noise. Low levels of music and shut off external sound when necessary.	Very Low	No Control:			Very Low	

Design of Interactive Mechanical Engineering Engagement Activities Risk Assessment (SafeTrak, 2024)

Appendix C: Hot Wheels Ramp – Exploring Motion and Weight:

Instructor Manual

Primary School Students

Hot Wheels Ramp – Exploring Motion and Weight

Instructor Manual

Introduction:

In this activity, students will explore the basic concepts of motion and weight by launching Hot Wheels cars down a ramp. The objective is to observe how different weights impact the distance each car travels, sparking curiosity in mechanical engineering principles through a hands-on experience.

Theory:

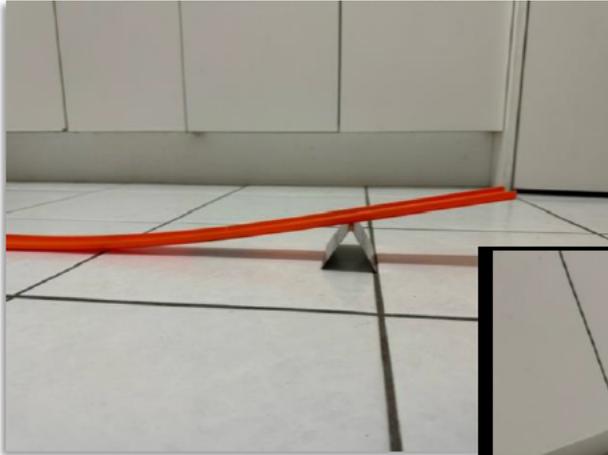
- *Motion and Weight:* Motion refers to the movement of objects. The distance an object travels is influenced by factors such as weight, force, and surface resistance.
- *Gravity and Force:* As cars roll down the ramp, gravity acts on them, creating motion.
- *Basic Concept of Friction:* Friction between the wheels and ramp affects how far the cars will go.

Materials Required:

- Hot Wheels cars of various weights
- A sturdy ramp (i.e. propped up hot wheels track)
- Measuring tape
- Notebooks for students to jot down their findings

Preparation Steps:

1. Set up the ramp in a secure location.
2. Mark a starting line using masking tape.
3. Gather cars of differing weights and have them weighed for the activity.



Task Instructions:

1. *Introduce the Activity:* Briefly explain the goal to find out if heavier cars travel farther than lighter ones.
2. *Prediction Phase:* Have students predict which car will go the farthest.
3. *Launch Phase:* Allow each student to release a car from the starting line and observe the results.
4. *Measurement Phase:* Use the measuring tape to record how far each car travelled. Encourage students to record their observations.
5. *Discussion:* Guide students in comparing their predictions to the results. Prompt them to think about why some cars went farther than others. Ask students to think about how speed and weight might connect to distance. Encourage questions about real-life examples, like how weight affects motion and trajectory.

Conclusion:

Summarise the observed results. Highlight that weight and surface resistance influence how far objects travel. Explain how this exploration is a fundamental part of understanding mechanical engineering concepts in a fun, real-world context.

Appendix D: Hot Wheels Ramp – Exploring Motion and Weight: User Manual

Primary School Students	
<h3 style="margin: 0;">Hot Wheels Ramp – Exploring Motion and Weight</h3> <p style="margin: 0;">User Manual</p>	
<p>For today’s activity, you will be using hot wheels cars and a ramp to investigate the effects of weight on motion and trajectory. This activity will help you understand how these factors are related.</p>	
<p>Pre-Activity Survey</p> <p>Please fill out the following survey before beginning the exercise!</p>	
Pre-Activity Questions	
<p>How excited are you about learning with toy cars in this activity?</p>	<p>(1 = Not excited, 5 = Very excited)</p> <p>1 2 3 4 5</p>
<p>Do you enjoy doing activities where you get to test and explore things yourself?</p>	<p>(1 = Strongly disagree, 5 = Strongly agree)</p> <p>1 2 3 4 5</p>
<p>How interested are you in learning how objects move?</p>	<p>(1 = Not interested, 5 = Very interested)</p> <p>1 2 3 4 5</p>
<p style="text-align: center;">What do you think you will learn from this activity?</p> <hr style="border: 0; border-top: 1px solid black; margin-bottom: 5px;"/> <hr style="border: 0; border-top: 1px solid black; margin-bottom: 5px;"/> <hr style="border: 0; border-top: 1px solid black; margin-bottom: 5px;"/> <hr style="border: 0; border-top: 1px solid black; margin-bottom: 5px;"/>	
<p style="text-align: center;">What do you think will be the most enjoyable part of this activity?</p> <hr style="border: 0; border-top: 1px solid black; margin-bottom: 5px;"/> <hr style="border: 0; border-top: 1px solid black; margin-bottom: 5px;"/> <hr style="border: 0; border-top: 1px solid black; margin-bottom: 5px;"/> <hr style="border: 0; border-top: 1px solid black; margin-bottom: 5px;"/>	

Predictions

Before you begin, let's make some predictions.

Weigh and write down the mass of each vehicle

Car 1 = _____g

Car 2 = _____g

Car 3 = _____g

Car 4 = _____g

Car 5 = _____g

List the order you think the cars will travel, from farthest to shortest

Why do you think the cars will perform this way?

Post-Activity Survey

Please fill out the following survey after finishing the exercise!

Post-Activity Questions

How much did this activity increase your interest in learning about how things move?

(1 = Not at all, 5 = A lot)

1 2 3 4 5

Did working with the toy cars help you understand how weight affects movement?

(1 = Strongly disagree, 5 = Strongly agree)

1 2 3 4 5

How fun was it to test and explore the movement of the cars?

(1 = Not fun, 5 = Very fun)

1 2 3 4 5

What did you enjoy most about the activity?

What new things did you learn about how objects move?

Appendix E: Hot Wheels Ramp – Trajectory Theory: Instructor Manual

Grade 7-8 Students

Hot Wheels Ramp – Trajectory Theory

Instructor Manual

Introduction:

In this activity, students will explore how the angle, weight (mass), and height of release affect the trajectory and distance travelled by a Hot Wheels car. They will make predictions using a physics-based formula involving the car's mass and compare these to the actual results.

Theory:

- *Trajectory and Motion:* Trajectory is the path an object takes as it moves through space. By adjusting variables like ramp angle and car mass, students will observe the relationship between these factors and the distance travelled.
- *Energy Conservation:* Gravitational Potential Energy (GPE) is the energy held by the object when elevated. As the object travels down the ramp, GPE is converted to Kinetic Energy (KE). Using conservation of energy, we can estimate the initial velocity at the base of the ramp, and subsequently the horizontal distance (range).

Range Prediction Formula:

1. Determine the Initial Velocity (u_o):

The weight of the object alone doesn't directly influence the range, but rather the initial release velocity does. You'll need to calculate or estimate the initial velocity of the object as it leaves the ramp. Assuming friction is negligible, you can use energy conservation principles:

$$GPE = KE$$

Using the height of the ramp (h) from which the car starts its motion, we can estimate the initial velocity (u_o) when it launches off the ramp:

$$mgh = \frac{1}{2}mv^2$$

Solving for u_o

$$u_o = \sqrt{2gh}$$

1. Calculate Time of Flight

Once you have the initial velocity (u_o) use the angle of trajectory (θ) to find the horizontal (u_{ox}) and vertical (u_{oy}) components of the velocity:

$$u_{ox} = u_o \cos\theta$$

$$u_{oy} = u_o \sin\theta$$

The time the object spends in the air depends on its vertical motion. Using the formula for vertical displacement and assuming it will land roughly at the same vertical level it was launched from, we get:

$$t = \frac{2u_{oy}}{g}$$

2. Calculate Range

Finally, use the time of flight (t) and horizontal velocity (u_{ox}) to find the range (R):

$$R = u_{ox} \cdot t$$

Substituting time of flight from the previous step:

$$R = u_{ox} \cdot \frac{2u_{oy}}{g} = \frac{u_o^2 \sin 2\theta}{g}$$

This final formula will give us the range given our initial speed estimate based on the height of the ramp. Note, this theoretical formula neglects friction associated with mass of the vehicle. We will investigate the impact of this aspect on our recorded trajectory results.

Materials Required:

- Hot Wheels cars of various weights
- A sturdy adjustable ramp (i.e. propped up hot wheels track)
- Measuring tape
- Protractor
- Calculator
- Notebooks for students to jot down their findings

Preparation:

1. Set up the ramp to our first trial angle.
2. Measure the mass of each vehicle.



Task Instructions:

1. *Introduce the Activity:* Explain that they will observe how ramp height and angle affect distance, as well as the possible impact of mass. Run them through the development of our trajectory formula.
2. *Calculate Initial Predictions:* Have students measure the mass and height. Guide them to calculate the predicted range.
3. *Experiment Phase:* Let students release the different cars at the test angles and record actual distances.
4. *Data Comparison and Discussion:* Students should compare calculated predictions with actual results and discuss any discrepancies.

Conclusion:

Prompt students to think about how factors such as mass and friction influence results. Discuss how real-world conditions often lead to differences from theoretical predictions. Encourage them to explore real-world scenarios where similar calculations apply. Emphasise the importance of understanding these factors in engineering applications.

Appendix F: Hot Wheels Ramp – Trajectory Theory: User Manual

Grade 7-8 Students

Hot Wheels Ramp – Trajectory Theory

User Manual

In this activity, you will investigate what factors affect a car's trajectory when launched from a ramp. You will predict the car's range using a formula and then compare your results to see how close your predictions are.

Pre-Activity Survey

Please fill out the following survey before beginning the exercise!

Pre-Activity Questions

How comfortable are you with using math to predict how things will move?	(1 = Not comfortable, 5 = Very comfortable) 1 2 3 4 5
Do you think adjusting weights and angles affects how far something can travel?	(1 = Strongly disagree, 5 = Strongly agree) 1 2 3 4 5
How interested are you in learning how objects move?	(1 = Not interested, 5 = Very interested) 1 2 3 4 5

What do you think is the most interesting thing about how objects move?

What are you most excited to try in this activity?

Prediction Formula

We will first predict the flight range of our vehicle, that we will use to identify our discrepancy to real world results.

Mass of vehicle: _____ kg

Ramp Height (h): _____ m

Ramp Angle (θ): _____ Degrees

Formula for Velocity:

$$u_o = \sqrt{2gh}$$

Formula for Range:

$$\frac{u_o^2 \sin 2\theta}{g}$$

Predicted Range of Car 1: _____ m

Repeat this calculation for all our test vehicles at both trajectory angles.

Observation and Results

		Calculated Range	Actual Range	Discrepancy
Angle: _____ Degrees	Car 1 _____ g			
	Car 2 _____ g			
	Car 3 _____ g			
Angle: _____ Degrees	Car 1 _____ g			
	Car 2 _____ g			
	Car 3 _____ g			

Did the actual distances differ from your predictions?

Yes / No

What factors might have influenced your results? What was the biggest influence?

Post-Activity Survey

Please fill out the following survey after finishing the exercise!

Post-Activity Questions

How well did this activity help you understand how to use math to predict movement?

(1 = Not at all, 5 = A lot)

1 2 3 4 5

Did adjusting the weights and angles help you see how those changes affect distance?

(1 = Strongly disagree, 5 = Strongly agree)

1 2 3 4 5

How comfortable do you now feel using math to predict the movement of objects?

(1 = Not comfortable, 5 = Very comfortable)

1 2 3 4 5

What did you learn about the relationship between weight, angles, and movement?

What part of the activity did you enjoy the most and why?

Appendix G: Introduction to CAD and Mechanical Design: Instructor Manual

Grades 9-10

Introduction to CAD and Mechanical Design

Instructor Manual

Introduction

For this activity, students will be introduced to the basics of Computer-Aided Design (CAD) software and mechanical design principles. The objective is for students to create a simple model of a mechanical component, discuss how changes to the design can impact functionality, and understand how CAD tools are essential in engineering design.

Theory:

- *Introduction to CAD:* CAD software allows engineers to create precise drawings and models of mechanical components. These models are used to visualise and test designs before they are manufactured.
- *Engineering Design Process:* The engineering design process can be generalised into a set of steps:
 1. *Conceptualisation:* Brainstorming ideas and defining the purpose of the design.
 2. *Modelling:* Using tools, such as CAD, to create a visual representation of the design
 3. *Testing and Iteration:* Making changes to improve the model to better meet the predetermined criteria.
- *Dimensions and Tolerances:* Engineers must ensure that designed parts fit within specified limits to function correctly.
- *Forces and Stresses:* Understanding how certain forces may be applied to a part dependant on its design and application.

Materials Required:

- Computers with CAD software available (i.e. CREO, SolidWorks, AutoCAD).
- Notebooks for sketching.

Preparation:

- Ensure all computers have the necessary CAD software (whichever is available) is installed and open.
- For the exercise, prepare a simple prompt (e.g. “Design a bracket, wheel, or small gear) to guide the students.
- Alternatively, have engineering drawings available that the students can recreate. Make use of available tutorials to acquire design examples.

Task Instructions:

1. *Introduce CAD and Mechanical Design Concepts:* Explain how CAD is used in mechanical engineering, referring to the theory.
2. *Sketching Phase:* Before using CAD have students sketch their design idea, thinking about dimensions, size, and functionality.
3. *CAD Modelling Phase:* Guide students through basic CAD functions: drawing shapes, extruding, and creating simple assemblies.

Teaching Tips:

- Encourage students to explore how to modify dimensions and see how changes effect the design.
- Provide guidance on CAD shortcuts and tips to help students navigate the software.
- Encourage students to ask questions about why certain dimensions or shapes may perform better under stress.

Conclusion:

Summarise the importance of CAD in real-world engineering. Explain how digital modelling can help engineers visualise and refine designs before physical prototyping.

Appendix H: Introduction to CAD and Mechanical Design: User Manual

Introduction to CAD and Mechanical Design

User Manual

In this activity, you will learn how to use CAD software to create a simple model of a mechanical part. You will see how changes to your design can impact how it works, which is an essential skill in mechanical engineering.

Pre-Activity Survey

Please fill out the following survey before beginning the exercise!

Pre-Activity Questions	
How confident are you in your ability to design objects in 3D using software?	(1 = Not confident, 5 = Very confident) 1 2 3 4 5
Do you think designing objects digitally can help engineers solve problems?	(1 = Strongly disagree, 5 = Strongly agree) 1 2 3 4 5
How interested are you in learning how engineers design mechanical parts?	(1 = Not interested, 5 = Very interested) 1 2 3 4 5
What do you expect to learn by designing objects digitally? _____ _____ _____ _____	
What challenges do you think you might face in this activity? _____ _____ _____ _____	

Sketch Phase

Use the following space to draw your design. Make sure to label the key dimensions for the component.

Reflection

What changes did you make to improve your model?

How important is dimension precision and tolerances in design?

How do you think CAD can help engineers in the design process?

Post-Activity Survey

Please fill out the following survey after finishing the exercise!

Post-Activity Questions

How much did this activity increase your confidence in using SolidWorks to design mechanical parts?

(1 = Not at all, 5 = A lot)

1 2 3 4 5

How well did you understand the importance of precision in designing mechanical components?

(1 = Not at all, 5 = Very well)

1 2 3 4 5

How interested are you in continuing to use CAD tools in the future?

1 = Not interested, 5 = Very interested)

1 2 3 4 5

What was the most challenging part of using CAD software to create your design?

How do you think this activity helped you understand the design process in mechanical engineering?

Appendix I: Designing Mechanical Components – Finite Element Analysis: Instructor Manual

Grades 11-12

Designing Mechanical Components – Finite Element Analysis

Instructor Manual

Introduction:

This activity will task students to deepen their understanding of CAD modelling and learn to conduct Finite Element Analysis (FEA) on a mechanical component they design. This activity aims to demonstrate how engineers use FEA to predict how parts will perform under stress, helping students connect theoretical knowledge with practical applications.

Theory:

- *Introduction to FEA:* FEA is a computational method used by engineers to predict how a component will react to forces, heat, vibrations, and other physical effects. FEA divides a complex structure into small elements and calculates stresses and strains within each one.
- *Mechanical Principles:* In application, components will be subjected to stress and strain. Stress is the reactive force applied to a material, while strain is the deformation in response to stress.
- *Engineering Design Process:* This activity will provide a snapshot into the advanced process that includes conceptualising, detailed modelling, testing (via FEA), and iterative design improvements based on test results.

Materials Required:

- Computers with CAD software available (i.e. CREO, SolidWorks, AutoCAD) that have FEA capabilities.
- Access to a materials library within the software.
- Notebooks for sketching.

Preparation:

1. Ensure all computers have the necessary CAD and FEA tools activated, with the appropriate materials library.
2. Provide a design prompt (make use of CAD tutorials for design examples) or let students choose a component type relevant to mechanical engineering applications.

Task Instructions:

1. *Introduce FEA and Mechanical Design Process:* Explain the process of designing and testing a component in the digital space. Refer to real world applications, and the intent of using such processes.
2. *Design Phase:* Have students sketch and then create a 3D model of their component in CAD, considering the material and forces it will experience. Ask them to specify its function what that types of forces it may experience in real-world use.
3. *FEA Setup and Execution:* Guide students in setting up an FEA simulation, including choosing material properties, applying force and boundary conditions, and running the analysis.
4. *Analysis and Iteration:* Students should analyse the FEA results, identify high-stress areas, and iterate their design to improve performance. Encourage them to adjust their design model to investigate its impact. Discuss how these changes can alter the stress distribution and possible component durability. Suggest that students explore different appropriate materials and see how each effects the FEA results.

Conclusion:

Wrap up by discussing the importance of FEA in modern engineering, as it allows for precise testing and adjustment of designs. Communicate how this iterative design approach is essential for creating safe and reliable products in many engineering fields, such as automotive and aerospace.

Appendix J: Designing Mechanical Components – Finite Element Analysis: User Manual

Grades 11-12	
<h2 style="margin: 0;">Designing Mechanical Components – Finite Element Analysis</h2> <h3 style="margin: 0;">User Manual</h3>	
<p>In this activity, you will design a mechanical component in CAD and use Finite Element Analysis (FEA) to predict how it will perform under stress. This process will hope to give insight into how engineers design and test components digitally before manufacturing.</p>	
<p>Pre-Activity Survey</p> <p>Please fill out the following survey before beginning the exercise!</p>	
Pre-Activity Questions	
How comfortable are you with the idea of testing your designs digitally using simulations?	(1 = Not comfortable, 5 = Very comfortable) <div style="text-align: center; font-weight: bold; letter-spacing: 10px;">1 2 3 4 5</div>
Do you think it's important to test designs before they are built?	(1 = Strongly disagree, 5 = Strongly agree) <div style="text-align: center; font-weight: bold; letter-spacing: 10px;">1 2 3 4 5</div>
How interested are you in learning how engineers test and refine their designs using analysis tools?	(1 = Not interested, 5 = Very interested) <div style="text-align: center; font-weight: bold; letter-spacing: 10px;">1 2 3 4 5</div>
<p style="text-align: center;">What do you think you'll learn from testing your design using FEA?</p> <hr style="border: 0; border-top: 1px solid black; margin: 5px 0;"/> <hr style="border: 0; border-top: 1px solid black; margin: 5px 0;"/> <hr style="border: 0; border-top: 1px solid black; margin: 5px 0;"/>	
<p style="text-align: center;">What do you think will be the most difficult part of analysing your design?</p> <hr style="border: 0; border-top: 1px solid black; margin: 5px 0;"/> <hr style="border: 0; border-top: 1px solid black; margin: 5px 0;"/> <hr style="border: 0; border-top: 1px solid black; margin: 5px 0;"/> <hr style="border: 0; border-top: 1px solid black; margin: 5px 0;"/>	

Sketch Phase

Use the following space to draw your design. Make sure to label the key dimensions for the component. Identify points the forces that will be applied in real-world application.

What is your material selection for this component? And why have you chosen this?

What areas of your component do you expect the largest stress? What are its critical points?

Now follow your instructor to model and apply a Finite Element Analysis (FEA) on your design in the CAD software!

Max Stress Observed: _____ MPa

Strain and Deformation Observed: _____

Revised Results:

Max Stress Observed: _____ MPa

Strain and Deformation Observed: _____

Reflection

What were the differences between your predictions and the FEA results?

Note any modifications you made to your component. Describe what adjustments you made and why.

What did you learn about how stress and strain impact your design?

How did FEA help you improve your design?

How could this process be useful in real engineering projects?

Post-Activity Survey

Please fill out the following survey after finishing the exercise!

Post-Activity Questions

How much did this activity increase your understanding of how engineers test designs before manufacturing them?

(1 = Not at all, 5 = A lot)

1 2 3 4 5

How well did the FEA tool help you see the strengths and weaknesses of your design?

(1 = Not at all, 5 = A lot)

1 2 3 4 5

How confident are you in your ability to use simulations to analyse designs in the future?

(1 = Not confident, 5 = Very confident)

1 2 3 4 5

What did you learn from testing your design using FEA?

What improvements would you make to your design based on the analysis results?
