INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
8–9 SEPTEMBER 2022, LONDON SOUTH BANK UNIVERSITY, LONDON, UK

AN INTEGRATED APPROACH TO STEM AND SUSTAINABILITY EDUCATION WITHIN THE NEW ZEALAND CONTEXT

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ABSTRACT
There is a need for science, technology, engineering and mathematics (STEM) skills to prepare young people for a rapidly changing future. However, it has been argued that it is not enough to only teach STEM in isolation; pressing global concerns call for sustainability to be of the highest priority and an integral part of learning. One way to integrate STEM and sustainability concepts is through hands-on activities that reflect real-world problems and contextualise students' learning. This study examined the learning that occurred when a group of 49 primary school students aged between 9 and 13 undertook an engineering design challenge within a New Zealand classroom context. Four key findings emerged: first, the primary level students participating did not have a sound understanding of sustainability; second, participants were able to apply and relate their learning to a real-life context; third, the participating students preferred activities that were hands-on and practical in nature and finally, an integrated approach enabled the students to be engaged and enjoy themselves while learning. The research presented is not intended to present a novel approach for teaching STEM topics, nor be a critique of the New Zealand Curriculum, rather it highlights the application of a STEM programme integrated with sustainability in a specific context within New Zealand.

Keywords: Education, STEM, primary education, sustainability

1 INTRODUCTION & CONTEXT

Demand for science, technology, engineering and maths (STEM) skills are expected to increase over the next 20 years. The need to have technically literate professionals who can think critically and creatively is key to solving the complex problems at present and in the future [1]. But how are we to produce STEM and sustainability-literate, critical thinking, creative problem solvers who are acutely aware of the social, economic and environmental implications of their solutions? This research considers the role of education as a tool to improve STEM and sustainability education for primary school aged students in an Aotearoa, New Zealand (NZ) context.

Declining STEM results among NZ's young people demonstrate a need for renewed focus and attention to STEM-based education. The latest Trends in International Mathematics and Science Study (TIMSS)[2] reported that NZ students' science and maths achievement is significantly lower than Australia, England and the United States. Similar observations are made by the Organisation for Economic Co-operation and Development (OECD) Programme for International Student Assessment (PISA) [3]. The TIMMS and PISA reports indicate an opportunity to improve STEM skills and understanding in primary school students. It is difficult to be declarative about NZ students' understanding of sustainability, as it is not a prescriptively assessed subject within the NZ curriculum as a distinct element.

Nearly 17% of the NZ population identify as Māori [4]; the indigenous population. Māori culture and knowledge is unique to NZ [5], where the Māori worldview has been, and continues to be, integral to society. Where materialism, dualism and anthropocentric views often serve as the dominant view on the human-environment relationship in western societies [6], Māori views focus on reciprocity and interdependency between people and planet, stemming from their origin narrative. This worldview introduces the idea of *whakapapa* (genealogy) and provide Māori with *tikanga* (right ways of doing things), whereby humankind and the planet shares the same *mauri* (life essence) rather than ruling over the land, humans are inherently related to the earth and are expected to guard over it through a principle called *kaitiakitanga* (guardianship) [7, 8]. The concept of *kaitiakitanga* promotes sustainability and intergenerational equity, endeavouring to ensure that all parts of the ecosystem are in “as good or better state than when they were found” [8]. It is pertinent, given the importance of Māori culture to NZ that such beliefs, values and practices, particularly those that relate to sustainability, are upheld. This cultural landscape of NZ further supports the notion of emphasising sustainability learning in education.

Research suggests that the earlier students are exposed to STEM based concepts, the greater engagement and increased motivation they foster towards these subjects [9]. In a review carried out by Tytler et al. [10] the different factors that get students into the STEM pipeline from primary school to secondary school were explored. This included students’ attitudes towards the subjects, specifically their interest and self-efficacy. These factors were found to be influenced by teachers and the methods of teaching, as well as their socioeconomic backgrounds, and expected future pathways. The focus on attitudes is a prevalent topic in available literature [11, 12] particularly dealing with negative attitudes that can manifest early on towards STEM subjects. Accordingly, this body of work focusses on primary school based students as early engagement to these concepts have been shown to be vital. The English-medium New Zealand classroom is guided by the New Zealand curriculum which is amongst the most flexible and ambiguous in the world [13]. When compared to curricula such as the Cambridge International Curriculum or International Baccalaureate which are prescribed and methodical in nature, the New Zealand curriculum places a high priority on ‘student-centred pedagogies, flexible skills derived from generic core competencies, and inquiry-based learning’ [14]. Revised and released in 2007, the current New Zealand curriculum highlights the core learning objectives for each subject in the ‘back end’ of the curriculum (English, the Arts, Health and Physical Education, Languages, Mathematics and Statistics, Science, Social Sciences and Technology). The approaches to teaching those objectives as well as the values and purpose of the curriculum is detailed in the ‘front end’ of the curriculum. This front end is particularly unique in its inclusion of five key competencies, a vision statement, a set of principles and values and a section on effective pedagogy [13]. Teachers are given the flexibility to address learnings in key subject areas using this front end to design and deliver content and assessments. The aim is to develop well-rounded, confident, connected, actively involved, lifelong learners. While this allows teachers and other learning professionals a large amount of scope and autonomy when it comes to what and how they teach, it can also generate confusion and frustration pertaining to the way they teach it as each school relies on the curriculum as a framework as opposed to a set of instructions [15]. Debate abounds as to the efficacy of this approach, but literature also supports the flexibility of the curriculum allowing for a unique and novel approach to teaching that allows students to be a part of the learning and engage with theoretical and academic concepts on a deeper level [16]. McDowell & Hipkins [17] found schools that incorporate both the back and front ends of the curriculum simultaneously seemed to generate more engagement in students than those who focussed on a traditional teacher-centred pedagogy. This was achieved by implemented project-based learning, student-led inquiry; personalised learning; play-based learning; team teaching; flexible use of time and space; and multilevel/age classes or groups. However, there are split opinions with some schools remaining ‘traditional’, keeping each area of the curriculum separate, citing a variety of reasons including timetabling issues, superficial subject coverage and a lack of cohesion between the different dimensions of the school inhibiting integration of subject matter. Overall though it has been argued that the prevailing integration provides students with opportunities to build meaningful relationships between learning areas and improved engagement. That said only just under half of teachers agreed or strongly agreed that student learning outcomes are better.

2 INTEGRATING STEM AND SUSTAINABILITY

The principle behind integrating STEM education is to connect real-world problems through a comprehensive class unit that combines some or all of the STEM disciplines [18]. This is to allow connected learning for students which is meaningful and relevant [18]. A multitude of studies highlight this multidisciplinary integration by facilitating design-based activities that make connections to real-life problems [19]. Creating a cohesive integrated STEM lesson is difficult due to the challenging nature of these concepts for students in primary school. However, there are successful examples that link environmental problems as the context for a design experiment. The success of a design-based challenge is captured in the lesson plan proposed by Moore et al. [18]. The benefit of this type of lesson plan is the integrated nature of teaching the content through a given context, which provides the students an opportunity to present their design to the class and learn from the discussion. The application of a STEM and sustainability-based programme can be considered a success based on student engagement [10] be it behavioural engagement, emotional engagement and cognitive engagement as discussed by Van Uden et al. [19].

The contextual literature has pointed to STEM education being particularly pertinent for NZ primary aged students. Given the indigenous history and the underlying Māori worldview, integrating STEM and sustainability knowledge, is unique and relevant to the NZ context. This, partnered with the flexibility of the New Zealand curriculum, leads to an opportunity: utilising the NZ curriculum to teach STEM concepts in a way that integrates sustainability, community and project-based learning. The research was guided by four main questions:

1. How important do students perceive sustainability to be and how comfortable are they defining what it means?
2. How do students apply science concepts to an engineering design activity?
3. What are the students' preferred ways to learn?
4. How enjoyable is an integrated science, engineering and sustainability activity for primary school students in a classroom context?

3 METHODOLOGIES

The research sought to identify whether young people responded well to a hands-on challenge that integrated principles of engineering, science and sustainability in a formalised setting. Several primary school age appropriate engineering design challenges were considered and ultimately an egg drop challenge was selected. Students were tasked with a design and build activity to keep a raw chicken egg intact when dropped from a height. The activity was selected because it is a widely known and trialled activity that allows for the integration of science concepts through an engineering design process. This challenge was adapted to be founded on waste reduction and closed loop designs that is relevant in a New Zealand context. The study was carried out at a local primary school in two senior classes *Raupō* (year 5 and 6, aged between 9 and 11 years old, 24 participants) and *Totara* (year 7 and 8, aged between 11 to 13 years old, 21 participants).

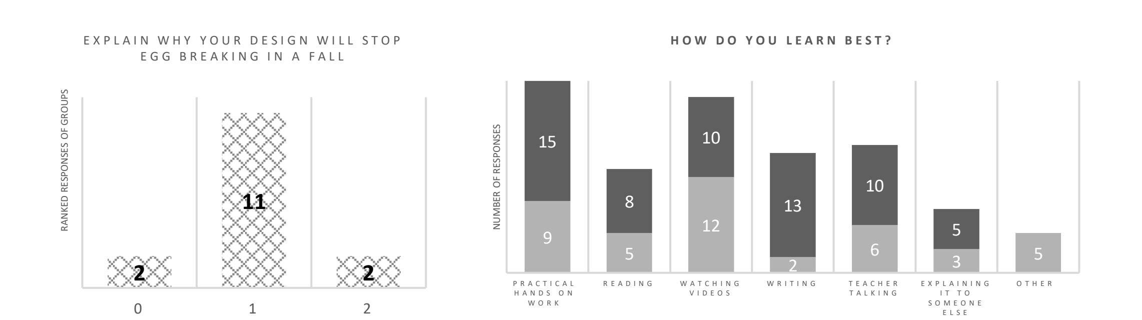
The research is descriptive in nature; accordingly, the primary form of data collection was two surveys involving Likert scales and open choice questions which could be ranked. As Likert scale survey methods are susceptible to self-reporting bias [19] the open questions were also analysed using content analysis by coding the responses to identify how well the STEM and sustainability content was understood. In-class observations were also used to provide a reference check for how well students were relating to the STEM and sustainability concepts. Audio recordings were also used for the researcher's reference to ensure the class discussions were transcribed correctly.

The research was conducted in three sessions. The first was an information-based session; setting the scene and establishing assent and consent for students who wished to participate. As young people were involved, the study was conducted following extensive review by university ethics committee with appropriate permissions and consent sought from participants and their guardians. Two further sessions were designed using the "Good Engineering Unit" conceptual framework outlined by Moore et al. [18]. These sessions involved researchers setting the context through presentations in the format of "fun facts". Environmental sustainability was discussed with a focus on waste produced in NZ including discussing materials and their lifecycles. This progressed to integrating science concepts; forces, gravity and drag were explored via discussion and illustrative demonstrations. Once these sessions were completed the design and build challenge was undertaken: the students organised themselves into groups of two to four students and used provided recycled materials to construct a device that protected an egg when dropped from a 2-storey structure. The third session began with a presentation of the final designs with each group presenting their device for discussion where students could justify their choices and relate their explanation to the theoretical concepts introduced in the second session. At the end of these sessions' participants were asked to complete the short questionnaires.

4 RESULTS & DISCUSSION

The egg drop challenge appeared to be an enjoyable hands-on learning activity that was able to integrate STEM and sustainability teaching practically. Utilising the principles of the lesson plan by Moore et al., [18] the participants were able to contextualise the science and sustainability concepts that were explained to them before applying them to a challenge that produced tangible outcomes (i.e. the egg either cracked or survived). Presenting their solutions to the challenge, discussions were used to cement understanding of concepts.

When considering how important students perceive sustainability to be and how comfortable are they defining what it means; it would appear to be evident that the students felt that sustainability was important but didn't necessarily have confidence regarding what the term means specifically. The participants' response to the survey question "I think sustainability is important" was majority positive. This response is promising that sustainability amongst younger generations is perceived to be important. Although it raised two strands of thinking; does the strength in their response to sustainability being important translate to them being more engaged in sustainability issues, and therefore make more environmentally conscious decisions? Or was it simply because they thought it was the answer we wanted to hear? The results in Figure 2 indicate it may be the latter as when asked if "comfortable explaining what sustainability is" most gave a disagree or neutral response with very few indicating that they felt comfortable they could do so. This lack of understanding for the term was confirmed in the open-ended question, "do you think your design is sustainable?". From the content analysis rankings over half of the group responses were given a 0 for this question, this reflected a response which had no attempt at explanation or an unrelated explanation. No groups provided a response referencing how their design could utilise the cradle-to-cradle design approach and what made the materials used in their design sustainable (or not), which would have ranked higher. When considering how students apply the science concepts to the engineering design activity; this question is addressed by the ranked question results documented in Figure 5. This open-ended question resulted in a great variety of responses which were ranked using content analysis. Rankings were from 0 to 2 and were based on the inclusion or relation of a design feature to relevant scientific or other theoretical information taught either earlier in the session or in the session prior. Most groups stated information about a theoretical concept but did not link these to their design. Two groups, however, did relate design features to one or more theoretical concepts covered in the previous sessions with justification achieving a higher rank. These results would appear to suggest the students did have a grasp of science and engineering concepts in the context of the task.



Figures 1, 2, 3, 4 & 5 (Clockwise from top left): results of surveys and ranked questions (light grey indicates year 7&8, dark grey indicates year 5&6 and pattern indicates mixed groups)

However, the most notable application of science concepts to the engineering activity was through the class discussion. The participants were able to explain their design intent with respect to the learned scientific principles and were open to criticism offered by peers. To the extent of unprompted justifications of their design choices or taking the feedback on board for changes they would make if they had to do it again. The success of the class discussion was unexpected as initially researchers had reservations about how well the respondents would take discussions of their designs. In practice the class discussion was constructive, giving students the opportunity to justify their designs and provided another opportunity to expand on the class discussion and reiterate key scientific principles. The respondents illustrated cognitive engagement in the class predictions of whether the design would protect the egg or not. For example, participants justified that the egg would survive as the design had a parachute with a bigger surface area to increase drag and slow down the descent.

When considering what are students preferred ways to learn; this is addressed by the results demonstrated in Figure 4. Collectively, the most popular learning option for “Practical hands-on work" followed closely by “Watching videos” at 52%. Ranked third and fourth was “Teacher talking” and “Writing”. The least popular learning option was “Other” with 12% of the total votes. As this was an open-ended option, it is not entirely unexpected that it did not generate many responses amongst the numerous options available. The second least popular option selected was “Explaining it to someone else”. However, from recordings it is evident that many did enjoy this in discussions, indicating that there is perhaps difficulty in the degree of self-awareness or reflection and indeed that there may be flaws with the wording and or nature of the survey itself. The younger participants (those in year 5 and 6) prefer hands-on work when in the classroom, while the year 7 and 8 participants preferred watching videos. Collectively these were the top two choices amongst the entire cohort. The biggest variation between the age group of participants was their response to “Writing”, this was ranked third for year 5 and 6 participants, compared to last for years 7 and 8. These responses indicate a variation between the two cohorts. Conclusions drawn from these findings could point towards adapting the styles of teaching to better suit students as they get older. However, these results are a snapshot and do not show whether the year 5 and 6 participants would change their preferences, as they get older, in the same trend as the year 7 and 8 participants. It could instead be preferences that are retained as the participants get older.

When considering what are students preferred ways to learn; this final question was answered through survey response as well as recorded observations. The survey questions that specifically asked their thoughts on the challenge returned majority positive responses; these have not been plotted as chart as they were overwhelming positive with all participants indicating that they enjoyed the challenge. Additionally, when asked “would like to do more science and engineering activities” this was again a majority positive response. While this could indicate an improvement it is difficult to separate out these observations from general enthusiasm for a challenge which felt fun, although the fact it felt fun to the students is in itself a positive indication for incorporating this type of activity in STEM and sustainability education at a primary level.

Observation indicated students were behaviourally engaged, Participants were actively involved in the lesson and on task which meets the definition by Van Uden et al. [19]. The participants listened to teachings, were all involved in planning and constructing their designs, as well as discussing and presenting. To an extent this also shows emotional engagement, as the participants were giving us their full attention and from our observation seemed to be enjoying themselves. Particularly in the testing session, the students were very excited to see if their eggs landed safely. Further research into the extent of student engagement in an integrated engineering design activity in comparison to typical classwork would need to be done in a longitudinal study with a much larger sample size to draw more conclusive results. In such a larger scale study it would also be pertinent follow up over longer timelines to determine any influence on further education and career pathways.

5 CONCLUSIONS

This research aimed to identify whether an integrated STEM and sustainability programme would work in a New Zealand context. Based on a qualitative analysis of primary school students through an egg drop challenge, it can be concluded that integrating STEM and sustainability through a hands-on engineering design challenge is effective in driving engagement and enthusiasm. However, further research is required to definitively state that in a wider New Zealand context the same conclusion could be reached and determine the generalisability of the work. It would be useful for a further study to explore the extent of knowledge New Zealand primary level students have about sustainability. This research is limited by its focus on a small sample size from within one geographic community, but the methods could be applied more generally in a large scale study. New Zealand schools are varied (e.g., traditional pedagogical methods, lower decile, Māori medium or rural schools for example) and consequently adapt the curriculum to meet their community’s needs. In order to properly capture this a longitudinal, multi-school study would be required to determine whether an integrated programme of

STEM and sustainability could work in a wider New Zealand context. While acknowledging the above, the results would appear to indicate that first, the students participating did not have a sound understanding of sustainability. Second, participants were able to apply and relate their learning to a real-life context facilitated through a constructive class discussion. Third, the participating students preferred activities that were hands-on and practical in nature. Finally, an integrated approach enabled the students to be engaged and enjoy themselves while learning with behavioural, emotional, and cognitive engagement.

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