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Improving high school students' perceptions of mathematics through a mathematical modelling course

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Literature shows there is support for adding connection and relevancy in mathematics for students through the use of real-world context and data in mathematical modelling. A teaching unit on mathematical modelling was designed within the context of future affordable housing for the local surrounding area. The teaching unit was implemented, and data were collected to address the research question: 'How does exposure to mathematical modelling influence students' perceptions and understandings of mathematical modelling?' Data were collected through pre- and post-teaching unit surveys and post-teaching unit student interviews. Pre- and post-surveys were used to establish any changes in students' perception towards mathematics, understanding of mathematical modelling and perceived relevance of mathematical modelling use to their own lives. Student interviews gained further insight into the student experience and associated perception changes. Statistical analysis of the survey responses included both hypothesis and nonparametric testing. Interviews were analysed using a thematic qualitative approach. Our analysis showed that a greater understanding of mathematical modelling was achieved, with many students unfamiliar with the concept prior to the teaching unit. It was also found that through the real-world context of the mathematical modelling unit, students had a new-found interest in mathematics.

1. Introduction and literature review

There is increasing evidence to support that mathematical modelling as a pedagogy can enhance student interest in STEM and increase mathematics proficiency and self-efficacy (Dunn & Marshman, 2019; Czocher *et al*., 2020; Czocher *et al*., 2021). Dunn & Marshman (2019) commented on the importance of having a teaching framework that connects mathematics to the real world through the use of real

data and real context, showing students the applicability of mathematics in describing the real world and encouraging good mathematical modelling skills. Klymchuk & Spooner (2020) observed the use of context as significant in allowing mathematics to become connected to the real world and no longer an isolated, abstract activity. Wake (2016) reports on how the instructor emphasizes connections between mathematics and reality can influence how much focus students place on this and contributes to students starting to appreciate and see the relevance and importance of mathematical modelling. Smith & Morgan (2016) described engagement with the real world as a motivation for students to learn mathematics and mentioned the benefits of real-world context for understanding basic mathematics, saying this was more impactful towards younger students as opposed to older students or for advanced mathematics. While Alsina (2007) recommends using contexts that have real meaning for students, rather than unrelated contexts or abstract settings. Carducci (1996) found that when students are given modelling assignments where they can relate to the context, the assignments went a lot smoother for students.

Mathematical practices in real life and the workplace are context specific and applied to real situations (Robitaille & Dirks, 1982; Julie, 2002). If one of our curriculum objectives is to build competent mathematical citizens, including introducing students to the 'mathematics of practice', then the inclusion of mathematical modelling as a topic strand is an essential component of any curriculum (Treilibs *et al*., 1980; Maaß, 2005; Kaiser *et al*., 2006). A range of mathematical modelling skills is beneficial if students are to be competent problem solvers in life (Robitaille & Dirks, 1982; Lingefjärd, 2006). A study carried out by Quiroz *et al*. (2015) found that when students participated in modelling, they were able 'to see themselves as citizens that can read, think, reflect and propose solutions in their own context' (Quiroz *et al*., 2015, p. 239). Burkhardt (2006) believes that 'two kinds of student learning is essential for mathematics to be functional in everyday life', that of 'learning illustrative applications' of 'standard models' and that of active modelling, where 'students use mathematics to tackle problems that are unfamiliar to them' (Burkhardt, 2006, pp 178).

Mathematics is a way of knowing about the world in which we live (Stillman, 2010). It is important that students start to develop this awareness and way of looking at the world early in life. Stillman (2010) and Maaß (2005) believe this awareness of mathematics and the development of equivalent mathematical beliefs should start early in one's education. Stillman (2010) believes exposure to modelling should start as early as childhood with exposure at primary and secondary school and thus sees modelling as an essential component of the school curriculum (Maaß, 2005; Lingefjärd, 2006; Stillman, 2010). Modelling 'is a way of equipping students with the power to exercise a fundamental duty as a citizen to appreciate, critique and use the models and modelling that permeate and format our modern world' (Stillman, 2010, pp. 301). Developing the eyes of mathematics through modelling is believed to be an essential component of the curriculum for the survival of commerce, industry, and science (Lingefjärd, 2006).

Up until 2007, the New Zealand mathematics curriculum mentioned modelling and modelling processes as a mathematical process, specifically promoting the use of mathematical models as a problem-solving strategy (Ministry of Education, 1992). In the current 2007 New Zealand Curriculum it states students will model situations using mathematical knowledge for each level of the curriculum but does not give any specific examples or guidance as to how (Ministry of Education, 2007). In 2022, Applied Mathematics, including mathematical modelling, is being considered as a subject, alongside traditional mathematics and statistics for year 13 students (Ministry of Education, 2022). Aside from New Zealand having strong curriculum statements for modelling, modelling in classrooms appears to be fragmented. See Spooner (2017) for further detail and potential reasons why. Spooner (2017) also presents an example of what could be possible for a New Zealand secondary school modelling experience.

In anticipation of New Zealand high school students being exposed to more mathematical modelling, there exists a gap in the literature revealing their perceptions towards mathematical modelling, how it

impacts their views on relevance towards mathematics as a school subject and how it influences their view on the world. A study in the UK (Hernandez-Martinez & Vos, 2018) commented on how students exposed to modelling activities had imagined themselves working in professional practices for which mathematics is relevant. Hernandez-Martinez & Vos (2018) also found that for some students, mathematics was seen as relevant only to obtain grades and entering professions after leaving school for which mathematics might not be needed. A study in Indonesia (Hendriana *et al*., 2014) reported junior high school students showed a correlation between mathematics and self-confidence through contextual teaching and learning of mathematics. Applying mathematics to context results in students exhibiting positive perceptions towards mathematics. In contrast, another study (Jankvist & Niss, 2020) found a significant number of high school students expressing negative perceptions towards mathematical modelling as a result of having difficulty in accepting or understanding the modelling tasks given. As mentioned in the study, students struggled in translating the problem into mathematics or 'were unable to successfully pre-mathematise situations in a way that is conducive to sensible mathematisation' (Jankvist & Niss, 2020), causing a challenging stumbling block for students. While there are international studies on mathematical modelling and students perceptions, there are very few studies detailing evidence of New Zealand high school students' perceptions when exposed to mathematical modelling (Christozov *et al*., 2007; Spooner, 2017). In response, this paper explores what impact mathematical modelling has on student perceptions from the context of a high school classroom environment. Using quantitative and qualitative studies, this paper investigates whether exposure to mathematical modelling can further enhance students' perceptions towards mathematics. This will provide insight into how modelling can contribute to students becoming more receptive, thus developing their abilities to contribute as mathematical citizens.

2. Background of study

This study is the first part of a larger continuing study looking into student and practitioner experiences of a holistic mathematical modelling teaching unit. This study reports on the experience of a group of students within the larger study. Spooner (2017) carried out a study looking into if it is possible for secondary school students to have an authentic experience of mathematical modelling. This study expands on Spooner (2017) by using the different stages of authentic mathematical modelling identified in the study. To enable students to have a holistic experience of mathematical modelling, a teaching unit was planned and delivered for 3 hours every week, over a period of ten weeks. The purpose of the modelling unit was for students to develop a model to provide insight into creating future affordable housing for their local area. For example, 'how much affordable housing will be required in Manurewa, South Auckland by 2030? The task for the teaching unit was 'using mathematical modelling, explore future affordable housing options for Manurewa'. The task was chosen as housing in Manurewa and the wider Auckland area is perceived as unaffordable for the average New Zealander. The task was purposefully open-ended and ill-defined to allow students to use the mathematical modelling process to explore issues and factors important to them in regard to their future housing requirements. Through the development of the model, it was envisioned students would start to understand the issues around the current and future housing situation and start thinking about solutions relevant for their own future housing requirements.

To prepare and provide direction to the students the teaching unit was heavily facilitated involving lessons on the modelling process and modelling behaviors. The teaching unit included lessons on: what is mathematical modelling; background skills for modelling, including how to work effectively within a group and how to conduct research; guidance for each stage of the modelling process; presenting model development and findings to an audience. For example, the lesson on 'what is mathematical modelling'

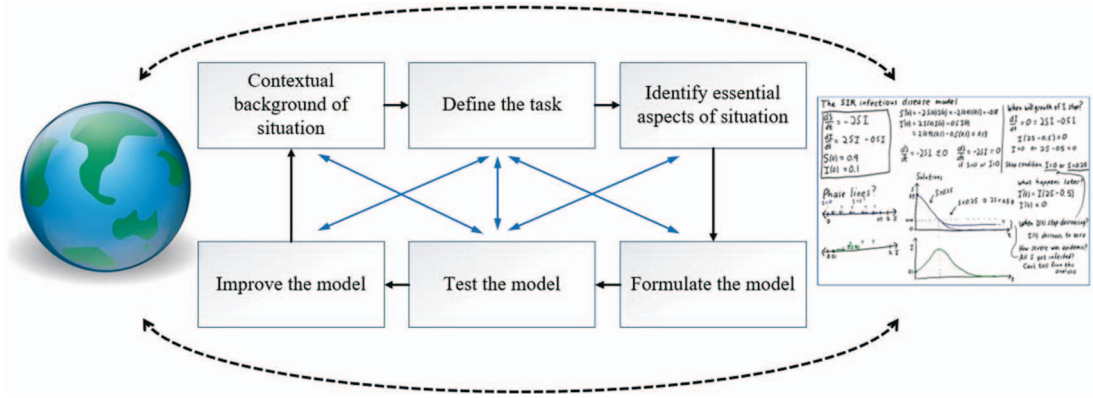

FIG. 1. Mathematics modelling framework.

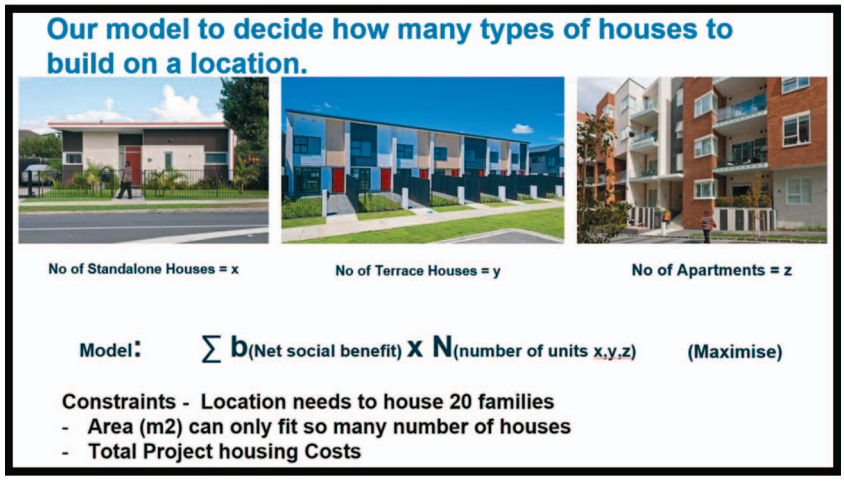

FIG. 2. Example of a base model students used.

included the following: what is a model; unpacking a model; the process of mathematical modelling. The framework used for mathematical modelling, as shown in Fig. 1 compromises of iterative steps of looking at: contextual background of the situation; define the task; identify essential aspects of situation; formulate the model; test the model; improve the model. Figure 1 illustrates to students that modelling is an iterative process and involves moving between the real world and the mathematical world. The infectious disease model (SIR model) in Fig. 1 is used to represent the mathematical world and is an example of a mathematical model that has been produced using this process. Figure 1 is based on modelling work undertaken by Spooner with the Centre for Mathis in Industry, Massey University and draws on Dym (2004), Svobodny (1998) and Treilibs *et al*. (1980). Figure 2 is an example of a student base model for the affordable housing situation. Students were given the opportunity to present their key issues on affordable housing identified through their modelling experience to the local council in charge of decisions for local housing development.

The modelling unit was offered as a self-selecting extracurricular course taking place within school time. The study involved teacher researcher practitioners, one teacher, and a class of 23 students. The 23 students compromised of New Zealand year 12 and 13 students. All students had completed compulsory mathematics up to year 11 and were currently studying a mathematics course. No students had previous experience with holistic mathematical modelling.

This study focused on how participating in the mathematical modelling unit has affected student perceptions on mathematics and on mathematical modelling. This study addresses the research question 'how does exposure to mathematical modelling influence students' perceptions and understandings of mathematical modelling?'

3. Methodology

The purpose of data collection was to inform teaching practices, by providing the students' perspective. Data were collected through pre- and post-project student surveys and student interviews following the teaching unit. The surveys were used to establish any changes in students' appreciation of mathematics for real world problems and their understanding of mathematical modelling. A five-point Likert scale ranging from strongly disagree to strongly agree was used in the surveys. This study uses results from four questions from the pre- and post-surveys. The questions were: Maths is important in my daily life; I understand what mathematical modelling is; Maths is an important subject for people to study at school; Mathematical modelling is helpful in understanding problems relevant to my future. The question statements were chosen from an already established survey prior to the unit delivery to evaluate students' perception of mathematics and mathematical modelling in terms of a subject including its relevance and importance towards their daily lives and future use as a problem-solving tool. Other questions in the wider survey were not related to student perceptions of science and STEM. These were not included in the paper due to being outside the scope of the study. There were 23 pre-surveys and eight post-surveys completed. The decrease in number of post-surveys was due to these taking place on the last day of the teaching unit, which coincided with the last day of term. The last day of term is traditionally not well attended. Despite the low sample size, Morgan (2017) and Jaiswal *et al*. (2021) provide confidence that it is still possible to detect large effects through testing, e.g., Mann–Whitney or Kruskal-Wallis with sample size $n < 10$ Morgan (2017). Consequently non-parametric and hypothesis testing using SPSS software was used to analyse and compare the pre- and post-survey.

In addition to the surveys, student interviews were conducted after the teaching unit had been completed. The purpose of the interviews was to gain individual perspectives on the student experience of the teaching unit as a whole, and an understanding of outcomes for students in terms of students' perceptions of what mathematical modelling is and its usefulness. Four student interviews were conducted, with students volunteering to participate. These interviews were examined for insights into gained student understanding of what mathematical modelling is, and the development of students' beliefs regarding how mathematics can be used in real world situations. The findings from the student interviews were then examined in conjunction with the survey findings. Analysis involved identifying themes within the data in accordance with general qualitative approaches (Gibson & Brown, 2009).

4. Findings

Figure 3 displays the percentage of each type of response (strongly agree, moderately agree, neither agree nor disagree, moderately disagree, strongly disagree) for the pre-project (top) and post-project (bottom)

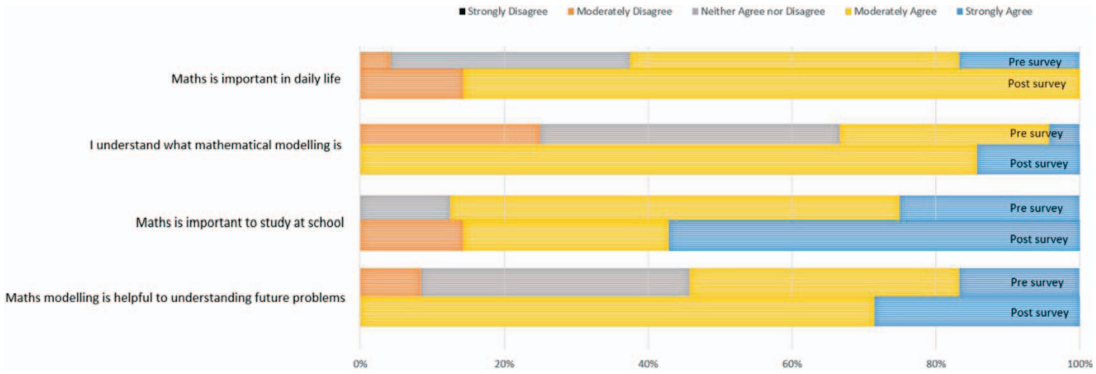

FIG. 3. Students project survey question statement responses for pre-project survey and post-project survey.

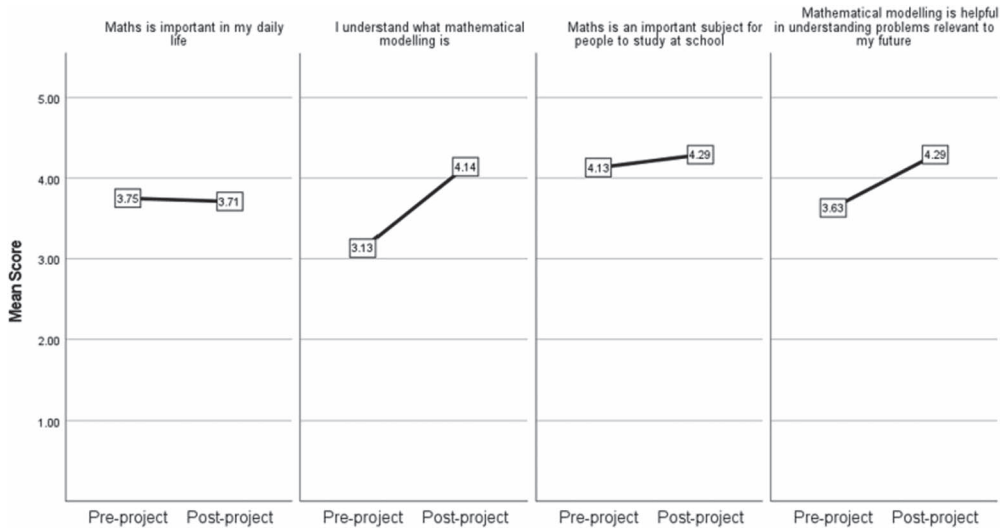

FIG. 4. Simple means plot for pre-project and post-project question statement scores.

survey responses. Interesting to note, after completing the teaching unit, there were no undecided student responses for the reported items in the post-survey i.e. no 'neither agree nor disagree' responses. The increase in percentages in the post-survey responses could be from the smaller post-survey sample size; therefore, as mentioned in the methodology, further investigation was undertaken.

Figure 4 displays the mean score differences from pre- to post-project survey responses. A mean score of 5.00 equates to strongly agree down to 1.00 strongly disagree. As can be seen, there is again in students understanding of mathematical modelling.

Comparing the pre- and post-project survey scores of questions pertaining to students' thoughts of mathematics and mathematical modelling revealed that there was a significant difference for the question statement 'I understand what mathematical modelling is'. Least squared difference comparisons show that students understanding had a significantly higher mean scoring for the post-project ($M = 4.14$) compared to the pre-project ($M = 3.13$) surveys, $F(1,29) = 9.314$, $p = 0.005$. Perhaps

worth noting, 'Mathematical modelling is helpful in understanding problems relevant to my future' showed an improvement between the pre- and post-surveys, although this result was not enough to claim significance. All nonparametric tests used indicated the post-project survey means for 'I understand what mathematical modelling is' was significantly higher than the pre-project survey scores. The independent samples median test showed $p = 0.007$, Mann–Whitney test showed $p = 0.005$, and Kruskal–Wallis test showed $p = 0.005$.

Despite having a small sample size (pre-project $n = 24$, post-project $n = 8$), these effects were able to be detected via both hypothesis and nonparametric testing across all tests which indicated the effect was very strong. The student interviews were used in conjunction with this testing to give further insight.

4.1 Students understanding mathematical modelling concept

The pre-project survey data shown in Fig. 2 revealed a substantial number of students did not understand what mathematical modelling was prior to participating in the modelling unit, having answered combined responses of 'neither agree nor disagree' to 'strongly disagree'. When students were interviewed and asked 'what they thought mathematical modelling was?' example responses were:

Student A '*I really didn't have a clue what mathematical modelling was. I kind of thought, you know, the word "modelling". I thought we, you have to make stuff and I didn't understand you know, that it was like related to actual maths and like, you know, describing how the real-world works.'*

Student B *"I honestly, I'd never heard of it before. Like in any context anywhere. But I read like the description of it, and it was like part math, part literacy and I was like 'Oh yeah, that could be something that's interesting'.*"

Students A's comment showed they had an idea about mathematical modelling, though they were not confident about their viewpoint, while Student B had never heard of mathematical modelling before. Both responses suggest the term mathematical modelling without prior knowledge can be confusing to students as the term not associated with everyday language and students identifying modelling as something physical to build. However, both Student A and Student B's comments show students can now identify mathematical modelling being associated with mathematics and literacy and describing how the real world works.

Further interviews highlighted students obtained a better grasping of mathematical modelling when they were first introduced through the written description of the course. When modelling is introduced with context and purpose in the form of a description like in this case, it raises student interest and awareness. This is illustrated in a response from Student C below.

Student C '*I'm looking at the description that our school gave us about mathematical modelling, I find it so interesting. I was like, wait, we could use modelling in order to find answers? Cause like beforehand I used to think that only like science experiments can find answers to like, like find solutions to problems.'*

In contrast to the pre-project survey, post-project survey data showed all students agreed they knew what mathematical modelling was having completed the modelling unit, having answered 'moderately agree' or 'strongly agree' to the question statement 'I understand what mathematical modelling is'. Student C's interview responses illustrate this:

Student C *'I got it, like a new perspective towards our mathematical modelling and even like I'm like finding out that not only scientists answers to everything, but like maths, could also have answers.'*

It is evident from post-survey data and interview responses; students gained a good understanding and a new perspective on mathematical modelling having completed the modelling unit.

Alongside gaining understanding of the concept of mathematical modelling, students engaged with the stages of modelling. Initially students were overwhelmed with the process. Comments from Student A and Student C show that while students were initially overwhelmed with the process, at some point, things started to make sense.

Student A *'Once we decided on the base model to use and explored different real-life factors and how they related to that model, that's when it started making sense.'*

Student A went on to further say that it was '*when we had to prepare the presentation for Auckland Council. I think that kind of really at the time solidified it. You know how to those factors inputted into a mathematical model.'*

While **Student C** commented "*I think the struggle was necessary 'cause like so like what you did was actually put us into the problem and you guys allowed us to actually like find solutions by ourselves. Obviously like when we asked for help you guys were there to help us but like I think that was very necessary*." Student C comments suggest that supported struggle was productive in students transitioning from feeling overwhelmed to finding direction with their model.

4.2 Student perceptions towards mathematics

The survey data revealed a change in how students viewed maths as an important part of their daily lives having completed the modelling unit. Pre- and post-project surveys tracked a positive shift towards the proportion of agreed responses to the question statement 'Maths is an important part of my daily life'. Student C commented in an interview question:

Student C *'I think mathematical modelling is actually like a useful understanding to have in life. It actually like helps you to solve real life problems which are actually applicable to our own lives. It actually like helps to make changes in our society and allows us to live in a better society.'*

Student C illustrates how being exposed to mathematical modelling can enable students to see the importance of modelling and its application in real-world contexts. This is also illustrated in another comment form the same student below and a comment from Student D.

Student C *'I think like teachers never took that time to explain problems and how it could relate to the real world. And I think that really like allowed me to develop this perspective that maths couldn't actually be used to solve problems. But that actually changed when I came into and I was doing mathematical modelling.'*

Student D *'For me, science makes so much sense because I know I can do this reaction and then I like find things out. But like that was the thing that I did not see maths to do. But then mathematical modelling actually changed my perspective.'*

What is viewed in comments above is, exposure to mathematical modelling not only provides students context to applications of maths in the real-world but can also create new-found interest in mathematics altering their perspective on the subject.

The survey data also highlighted a strong change in student's opinion towards viewing maths as an important subject to study at school. Survey data found over double the number of 'strongly agree' student responses between the pre- and post-survey to the question 'maths is an important subject for people to study at school'. This preludes to the notion, exposing students to mathematical modelling through the context of tackling real-world problem that students can identify with, highlights the importance of mathematics in application and as a subject in school. This is also illustrated in Student C and D interview comments below.

Student C *'I never like knew that maths could, could like actually be applied into the real world, in to like find solutions in that maths like in that perspective I used to like question, okay so how am I going to use algebra when I go outside high school but like now I know how I'm gonna use it.'*

Student D *'It's something that should be taught more in school because after this, I felt like I understand more about what's happening.'*

The interview responses make it clear that students not only support maths as a subject in schools, but also the application of real-world maths is essential for understanding concepts and its relevance beyond schooling. An important note is that the students are signifying that they don't believe real-world applications to maths are currently being expressed in the curriculum and perhaps a mathematical modelling unit such as this can offer the grounding needed.

4.3 Mathematics viewed as a helpful part of my future

There was a change found in students' perceptions on mathematical modelling as being helpful in understanding problems relevant to their future after having participated in the modelling unit. The post-survey saw all students answered either 'moderately agree' or 'strongly agree' to the question statement 'mathematical modelling is helpful in understanding problems relevant to my future', showing an increase from just over half of students answering the same responses in pre-survey prior to the modelling unit. Interview responses also provided insight behind students' perception shift here. This is best highlighted in the comment below.

Student A *'I think it was different because you guys like actually used a real-life problem like housing and you guys like showed us some problems that we are personally facing in our society. And like what really made me connect was the fact that OK ten years down the line, I probably won't be able to buy a house because of like increasing prices and like the housing conditions not being good and that really connected me to the whole like problem.'*

While Student B verbalised that context needed to be relevant to her or she would not have engaged fully with the problem, as seen from the students' comment below.

Student B *'I only care about like problems that really like help me to connect to it and like allowed me to find like a solution for my generation.'*

Both of these students reflect the importance of the real-world context of affordable housing had for them to grasp the relevance of mathematical modelling and how it can be used to find solutions to relevant real-world problems.

Students felt a sense of empowerment from being able to present their findings identified through the process of mathematical modelling to the local council. Student A and C comments below reflect this:

Student C *'It was really cool that we could actually go somewhere and show that we knew what we were talking about. To have people listen to our ideas was cool.'*

Student A *'Mathematical modelling is something we can definitely use to make changes in our society, like with housing'.*

Being able to present to the local council enabled students to feel their ideas were valued. For students to have their ideas heard and considered in future planning positively affected the belief in their ability to have an impact on their future.

5. Discussion

The survey data showed student's perceptions had a positive shift towards mathematical modelling, what modelling is, and how it can be useful after having completed the modelling unit. Students who did not

really know what mathematical modelling was at the beginning of the unit now had understandings of what mathematical modelling is. As a collective, students now saw mathematics as being useful. The active experience with mathematical modelling gave students an appreciation of how mathematical modelling could have an impact on their future.

Through the use of using a real-world problem relevant to the students, students developed an understanding of what mathematical modelling was and that it was used to solve, and/or gain insight into, real-world problems. The future affordable housing problem was relatable and applicable to students, giving them a context to anchor their experience of the modelling process and begin to develop mathematical modelling skills. This is in alignment with what both Dunn & Marshman (2019) and Smith & Morgan (2016) say, that using real-world contexts encourages the development of modelling skills (Dunn & Marshman, 2019) and that context can act as a motivator for students' mathematical activity (Smith & Morgan, 2016). Problems being relatable to the student are important for students' development of mathematical modelling (Carducci, 1996; Alsina, 2007). What was different here from past research was how relatable the problem was to the students. Housing in their local area was perceived as unaffordable for the average New Zealander, which has a direct impact on these students' future lives. As students had self-selected to be involved with the problem, this provided ample motivation to engage with the problem and mathematical modelling process.

Being involved with the project had a big impact on developing students' understanding of mathematical modelling from not being confident with what modelling was and how to carry out modelling, to having developed a solid conceptual understanding of what modelling is and its uses. The experience allowed students to see the importance of modelling through its application to a real-world context (Czocher *et al*., 2021). Although it may not be surprising that students gained understanding of mathematical modelling after participating in a mathematical teaching unit, it was the use of a real-world problem that was personally relevant to the students in conjunction with providing students an opportunity to use the findings to have a direct impact on their future that made this experience different.

Stillman (2010) and Maaß (2005) recommended an awareness of how mathematics and the real world can be related should start as early as possible in a students' mathematics education. Due to the total immersion modelling experience, it was difficult to determine if the previous lack of exposure to modelling affected the students. It appears that students' limited understanding of mathematical modelling did not end up being a barrier for students, as students got the opportunity to develop their own understanding through personal experience. In addition, some students in this study developed better understanding of what modelling was from just reading the written description in the project's advertisement. This illustrates how providing pre-reading material on modelling can have a positive impact on students' development.

Based on the discussion presented above and data collected in this study, the students' experience of the mathematical modelling unit produced positive perception outcomes. However, a main limitation of the study was the small sample size. The timing of the post-survey was an additional limitation. In order to verify the results, the study should be repeated with a larger sample size. Before repeating the study, further development of the survey could be carried out drawing on already developed attitude surveys for mathematical modelling. The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available.

6. Conclusion

The use of relatable real-world contexts enabled high school students to engage in, and develop a greater understanding of, mathematical modelling. Students developed an understanding of what mathematical

modelling is and gained an appreciation for mathematics and mathematical modelling in relation to their own lives. After completing the teaching unit which included presenting their findings to the local council, students could now see the potential for mathematics, and more specifically mathematical modelling, as a tool for real world problem solving which was previously only thought as applicable to science subjects. This realisation allowed for a positive perception change towards mathematics. The future affordable housing problem provided a relatable context for students to develop mathematical modelling skills, something that was absent from their traditional mathematics lessons. The future affordable housing context and the opportunity for students' findings to be implemented as part of the solution to the problem was the driving force of the experience. The opportunity to have a direct impact on their future contributed to students' engagement and hence understanding and experience of mathematical modelling. This implies that if we are to give students problems that have a direct impact on their lives, they are highly likely to be willing to engage with the mathematical modelling process. This allows students to develop skills of seeing the world through mathematics, helping to develop deeper understanding of how mathematics can be used in their own lives (Lingefjärd, 2006). Using modelling in this way helps contribute to developing mathematical citizens ready to contribute mathematically to society. Stillman (2010) and Maaß (2005) believe modelling should start as early as possible. There is an implication that if students are exposed to mathematical modelling or mathematics in a relatable real-world context earlier in their education, an appreciation for mathematics and its applicability may be achieved sooner.

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