Using Automata to Teach Science Concepts in Technology Education

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Abstract: There is evidence that design challenges in construction in schools can improve students' later engagement with science and technology. The purpose of the study was to investigate the use of automata (mechanical toys) as part of the New Zealand technology education curriculum, with Year 7 and 8 students (11-12 year-olds). The project presented the students with a context through which to learn and apply the scientific principles of movement. Two major research questions drove the study: (a) would the design and construction of an automaton help students remember how the mechanism worked at a later date and (b) were there any gender differences in students' response to this project? The study involved 74 pupils, and data were collected through observations of the pupils during their five technology periods and from a questionnaire administered after the project had been marked, six months later. Findings indicated that students responded favorably to automata, could understand and describe movements, and were able to recall information and draw mechanisms at a later date. Gender was not a significant factor in the response of the students to the project, their ability to complete the project or the grade obtained.

Keywords: Automata, School Students, Technology Education, Science, Gender

Introduction

There is increasing awareness of the need for countries to meet the challenges and demands of the 21st century, through building capacity, capability and strength in science, technology and innovation (Tytler, Osborne, Williams, Tytler, & Cripps Clark, 2008). A decline in the number of students studying science, technology, engineering and mathematics (STEM) at high school and university, and the increasing number of vacancies within the sector (Autio, 2013), has led to the promotion of STEM in schools (Silver & Rushton, 2008b). At the same time, links have been established between science and engineering. Researchers found students undertaking engineering design challenges, acquired new scientific knowledge through experimentation and research, in order to complete the task, and such challenges provided opportunities for students to understand and use mathematics concepts in finding solutions (Schunn, 2009). Simple projects in design and construction at an early age have therefore been shown to provide a means to encourage more students into careers in science and engineering.

In the United States of America, Schunn (2009) noted that students who pursued engineering degrees did not reflect the diversity of the student body (Schunn, 2009). Weber (2005) and Autio (2013) noted a lack of female students in the physical sciences and engineering (Autio, 2013; Weber & Custer, 2005). Research showed males were more visible and received more support from parents, teachers and peers; whilst females were unwilling to challenge the stereotypes of non-traditional careers, the lack of equality being seen as a wider societal issue (Autio, 2013). In Australia, 54% of all student enrolments were female, but in science, technology, engineering and mathematics, they accounted for less than a third of the students (Tytler et al., 2008). Data on the Ministry of Business, Innovation & Employment (Hikina Whakatutuki) website (Ministry of Business, 2013) indicate that in New Zealand, the majority of the students enrolled in engineering-related courses at tertiary level are European males. At a Bachelor's degree level and above (Level 7 and above), female students account for only 17.9% of the class. Information from the 2006 New Zealand Census showed 86.8% of architects, engineers, and related professionals and 83.9% of physical science and engineering technicians were male (Ministry of Business, 2013).

With the aim of engaging younger students with the Technology curriculum, we asked 11-12 year-old students to design and build an automaton (moving model) of an animal. Two major

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research questions drove the study: (a) would the design and construction of an automaton help students remember how the mechanism worked at a later date? and (b) were there any gender differences in students' response to this project?

Literature Review

Historically, there has been a relationship between science and technology, though they have followed separate pathways; science valued knowing, whereas technology valued doing. The development of engineering science, incorporating technical knowledge, allowed for the transition of the abstract (knowing) into the applied (doing) (Sidawi, 2009).

As a result of growing dissatisfaction with the New Zealand education curriculum, assessment processes, and qualifications in the 1970s and 1980s, major reforms were introduced in the early 1990s, when the National Party of New Zealand introduced "the Achievement Initiative", a policy designed to include identifiable and measureable learning objectives in education and to raise the skill levels in English, mathematics, science and technology (Ferguson, 2009; Jones, 2003; Moreland, Jones, & Northover, 2001). The government's intention was to prepare students for a future where technology would lead development and the country could be more competitive internationally. Rather than divide learning into subject areas as previously, seven areas were designed to provide New Zealand students with a well-rounded education and a framework with eight levels was designed to seamlessly progress the student's learning from Year 1 through to Year 13. Under the New Zealand Curriculum Framework (Ministry of Education, 1995) learning outcomes were to be clearly identified, against which the assessment of students' achievements could be determined (Moreland et al., 2001).

At the same time, developments were also occurring in other countries including Australia, Canada, Hong Kong, the United Kingdom and the United States of America (Jones, 2007). Rasinen (2003) analysed the technology education curriculum of six countries, where developments in technological education programmes had occurred during the previous 10 years, and "profound research experimental programs, and the development of learning materials have been undertaken" (Rasinen p. 31), searching for a theoretical model for technology education in Finland. He found that among the countries studied, technological literacy was a universal goal and technology education was most developed at middle school/junior high (lower secondary) level (Rasinen, 2003). However, it was the reforms in the UK, which were to have the greatest influence on the New Zealand curriculum (Jones, 2003, 2007).

With these changes in policy, technology education moved from a vocational and skills-based subject to be sociocultural and constructivist-based, taking the subject out of the narrow confines of the school, and placing it within a context where the school was part of the wider community (Compton, 2009; Snape & Fox-Turnbull, 2011). The development of technology education within the context of the New Zealand Curriculum (2007) provided an exemplar for other areas of the curriculum (Snape & Fox-Turnbull, 2011). Internationally, the focus of technology education was also on developing technical literacy that supported an informed and critical citizenship for the foreseeable future (Dakers, 2006).

Faced with the challenges of an integrated curriculum across both technical and learning areas, and the expectation of developing school based schemes; many New Zealand teachers undertook professional development to gain the necessary tools to assess, guide and support students through the technological units. From the start of the changes in the early 1990s, the process, was informed by academic scholarship, supported with technical knowledge from New Zealand practitioners, and feedback from teachers and teacher educators (Ferguson, 2009).

In the 1980's, research on contextual learning focused on the environment of learning. Numerous studies recorded how people learned to solve problems in their day-to-day lives, and led to new models of cognition (Sidawi, 2009). However, Hennessy and McCormick (1994), found there was scant empirical evidence to suggest that a general problem-solving process could be applied across contexts and curriculum areas (Hennessy & McCormick, 1994). Rather, "research shows that what problem-solvers of all ages in everyday and workplace situations actually do and know depends on the context in which they are asked to work" (Hennessy and McCormick, 1994, 99).

Project-based learning provided a link between knowing and doing. It offered the student a context where the knowledge they learnt could be applied. The application of scientific knowledge to design problems provided an opportunity for students to display scientific knowledge in a useful practical form applied to real life problems (Sidawi, 2009). Andrade (2011) gave students a kit comprising rubber foam and balsa wood parts from which to construct an analogical clock, with the aim of teaching the concept of transmission coefficient. The project demonstrated the relationship between mathematical knowledge and mechanical parts in technological devices (Andrade, 2011).

Learning in technology education classrooms therefore focused on creativity, problem solving and decision-making. Students developed skills in use of tools and addressed problems as they arose, during the design process (Sidawi, 2009). "The classroom forms a community of learners that collectively builds knowledge" (Sidawi, 2009, 278).

Problem-based Technology Projects

Although technology education in schools began as vocational and craft-based programs, cross-curriculum links exist with science, technology, engineering and mathematics (STEM). A number of studies have explored these links and addressed gender issues with students from the early childhood sector to students in tertiary education.

Mawson (2011) wrote that if the early primary sector was more aware of the level of technological practice and knowledge children brought to school, teachers could use these interests and skills to create more relevant and authentic programs in the first year of formal schooling, with the flow on effects impacting on the technology education program in the school (Mawson, 2011).

CLOHE, "Toys in the Classroom" was an arts-based education project funded by the European Union based on automata. It was designed to develop creativity across the primary school curriculum, and exposed students to basic engineering concepts, fosters problem-solving skills and improved their ability to work in three dimensions (Bargelli & Bartoletti, 2012).

Silver and Rushton (2008) researched an initiative in Horsham, England known as the Horsham Greenpower Goblin Challenge, a hands-on science, technology and engineering project involving primary-aged students in Years 5 and 6 (aged 9-11 years) constructing a single seat electric car. The vehicle was assembled from a kit, with students designing and constructing a body, and when complete the vehicle was raced for an hour, against 18 other schools (Silver & Rushton, 2008b).

In Western Canada, Roth (2001), using the principles of technology design, initiated a simple machine unit in science with Year 6 and 7 students (aged 10-12). When he tested the students at the end of the module, his results did not show any differences between genders or age groups (Roth, 2001). More recently in 2009 and with older students, Dakers and colleagues (2009) undertook a pilot study in a Scottish secondary school with seventeen Year 1 pupils (aged 12-13 years). The project asked the students to design, manufacture and package a fragrance for a person of the opposite sex. The high levels of enjoyment and satisfaction observed, demonstrated the success of the project, and gender differences were not evident in either the answers to the questionnaire or the observations (Dakers, Dow, & McNamee, 2009).

Weber and Custer (2005) found that in the middle school, technical education activities appealed to both genders, but the selection and development of gender-balanced activities was important. Female students favored projects with an emphasis on design and collaboration, that were socially relevant, involved the environment/people and how knowledge could be applied, whereas male students were more interested in how things worked. The researchers were surprised to find that female students supported the concept of competitions, which contradicted previous research.

Chatoney and Andreucci (2009) undertook research in France involving a group of 13 and 14-year-old students who were given a list of 14 objects used by technology teachers, and asked for their opinion on whether they were masculine, feminine or neutral. Objects associated with play and sporting activities were reported as masculine, a penholder, office set and humidity detector were feminine and a clock, workbook and key chain were neutral. When the students were presented with design projects of gendered objects, e.g. jewelry box and a mini football goal, the gender of the object had little impact on the male students, who just completed the tasks, whereas for the female students, the "gender" of the project contributed significantly to how they developed solutions and completed the project. The researchers concluded that female students' interest in technology might be retained by using projects which appealed to them (Chatoney & Andreucci, 2009).

Methodology

The research was undertaken in an intermediate/middle school in the South Island of New Zealand with a decile rank of 3[1], although this does not reflect on the quality of education the school delivers (Ministry of Education, 2010). All 98 students in Years 7 and 8 (11-12 year-olds) studied technology education, and of these, 74 students agreed to participate. The school population consisted of 63% New Zealand European, 27% Māori, 5% Pacifica and 5% other ethnicities. Students were organized into one of five groups for all their subjects, except for the afternoon programme where they choose from a range of options including science. All groups included both Years 7 and 8, the rationale being that the older, more experienced students would help those who were younger and less experienced. One of the five study groups was established for students who demonstrated a strong interest or ability in art. Students spent five morning sessions once a fortnight on the project.

Table 1: Gender and Age of the Students in the Project, and on the School Role

	Research Group			*School Role*		
	Female	*Male*	*Total*	*Female*	*Male*	*Total*
Year 7	15	16	31	23	29	52
Year 8	18	25	43	19	27	46
Total	33	41	74	40	58	98

The University of Otago Human Ethics Committee approved the project (Consent 11/050). An information sheet and consent form were provided for each student, as well as for their parents/caregivers, stating that the project was part of the technology education curriculum, that students might be interviewed, and a questionnaire would be administered.

The project involved written and design work, which formed part of brief development in the technology design process (Ministry of Education, 2009), also demonstration of the skills required to construct artefacts. Students were asked to make either a cardboard dog or a cat, and build an automaton from wood, using the facilities in the wood workshop. The process of constructing an automaton is described in Table 2.

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[1] School deciles range from one to ten; with decile one schools drawing their students from low socio-economic communities and decile ten schools drawing their students from high socio-economic communities. The level of funding given to New Zealand state schools is determined by its decile rank, thus low decile schools receive greater funding.

Table 2: A Sequential Breakdown of Declarative and Procedural Knowledge Involved in Making an Automaton
Based on the Work of Hong and Colleagues, 2012

Steps	*Activities*	*Declarative knowledge*	*Procedural knowledge*
1	Mechanism design 1	Cams, followers and washers	Cut out and sand the parts
2	Mechanism design 2	Axle, shafts and handle	Cut out and assemble the parts
3	Base design 1	Measure the pieces	Cut out, saw and sand all parts
4	Base design 2	Placement of holes	Drill the holes
5	Base design 3	Spatial/structural knowledge	Assemble the base, axle mechanism and followers
6	Base design 4	Properties of adhesive	Glue the base
7	Function testing	Transmitting the power from the handle to the cams and followers	Test and modify action, glue mechanism when testing complete
8	Designing the figure	Art concept	Cutting, sanding, assembling and colouring
9	Function test with the figure	Gravity and balance	Test, adjust as required, apply glue

Simple automata have two parts: a base, with all the mechanical parts, and a stage, where the actor (or actors) reveals the story or action. In the example given to the students, a handle turned the axle, on which were situated two cams (Figure 1). The eccentric cam under the head produced an up and down movement to open and close the mouth and a cam at the rear rotated the tail. Colour was applied when the assembly was completed.

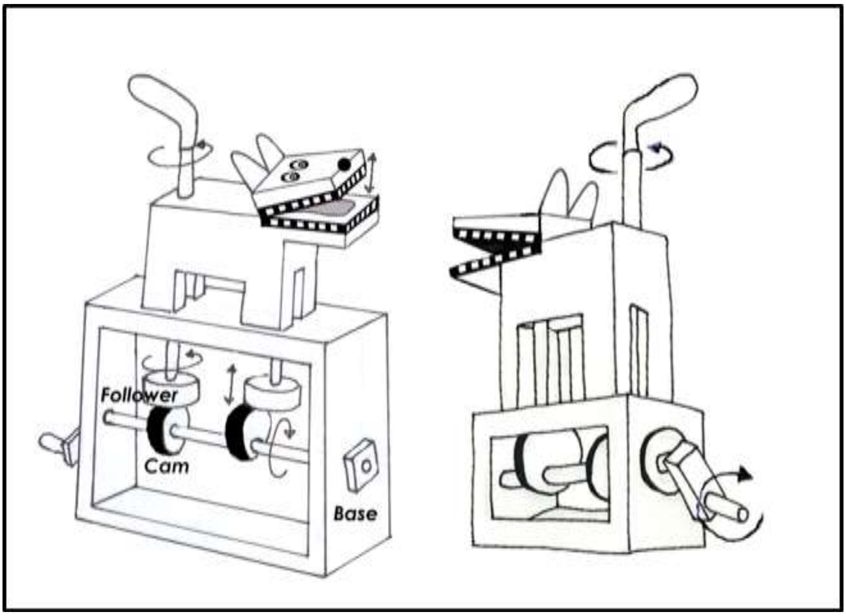

Figure 1: Illustrations of a Cardboard Mechanical Dog with Labels Indicating Movement
Based on an Idea by Peter Markey

Making the Cardboard Automaton

The cardboard model introduced the students to the principles of mechanical movement, which they would incorporate into their design, and provided a guide to the size of the wooden automaton. Whilst constructing a cardboard automaton (Figure 2) was a new experience for all of the students, the least able students had a teacher-aide, and the teacher and one researcher (SEO) were available to assist other students with specific difficulties.

Making the Wooden Automaton

Constructing an automaton from wood gave students opportunities to gain skills using hand and electrical tools in the workshop. It required them to demonstrate accuracy in measuring, sawing and assembly. The task provided an opportunity for the students to understand the process from the design stage to the finished product.

The Questionnaire

The design of the questionnaire was informed by the research of Alice Bell, *Designing and testing questionnaires for children.* She wrote students should be able to answer the question with valid and reliable information, and if presented with the same questionnaire at a future date give similar responses. Furthermore, few questions should remain unanswered (Bell, 2007). The questions were sequential and followed the structure of the project. Students were told the reasons for the information being sought, and reminded their details would be kept confidential. Questions requiring written responses were interspersed with ones requiring a circled response. Written responses allowed students the opportunity to expand on answers and provide additional information. Consideration was given to the appropriateness of the language in terms of age and allowing for the same questionnaire to be given to all the students in the school. It asked a series of questions about the student's attitudes to undertaking the project, as well as their response to constructing both types of model. A final question asked them to draw one of the movements they had seen or used.

A Likert-type scale was chosen, with descriptors rather than numeric markers (Bell, 2007; Clason & Dormody, 1994). Bell (2007), found students of intermediate school age were able to understand and answer a question that had up to four options. The chosen descriptors avoided the need to explain the nuances, where one is required to say how strongly one agreed or disagreed with a statement, or to choose a number to represent a level of satisfaction experienced with aspects of the project (Table 3).

Table 3: Matrix for Responses to the Questionnaire

Question number	*Choices available*			
1, 2	a bit	was ok	better than ok	lots
5, 6	easy	ok	hard	too hard
11	easy	hard	too hard	
7, 9, 10, 12	yes	no		

Questions 1 and 2 sought information about students' response to the project; questions 5, 6 and 11 covered specific skills; questions 7, 9, 10 and 12 addressed their understanding of the project and experience of the workshop; whilst question 13 asked the student to draw one of the movements they had seen. A further drawing space was provided as an option for students who found writing difficult or chose to add a drawing. Questions 3, 4, 8, and 14 required a written answer, whereas the others required the answer to be circled. Question 15 asked the students if they would like to make more automata. The technology teacher administered the questionnaire six months after the project ended.

Coding and Analysis

Where the students were required to reply to a question by writing the answer, similar answers were grouped together and numerically coded (Table 4). The student responses were entered numerically into a spreadsheet and converted to percentages in each category. Information was analyzed under five headings (all students, female, male, Year 7 and Year 8); and 100% stacked bar charts were created to provide an initial analysis of the data. Differences between years or gender were subsequently analyzed by Student's t-test.

Table 4: Matrix for Codes and Categories

Q.3 What did you enjoy most?					
Coded 1 Automata	Coded 2 Skills	Coded 3 Workshop Wood skills	Coded 4 All equal Not sure		
Q.4 What did you enjoy least?					
Coded 1 Automata	Coded 2 Skills	Coded 3 Workshop Wood skills	Coded 4 All equal Not sure		
Q.8 What would you change?					
Coded 1 Automata	Coded 2 Skills	Coded 3 No responses	Coded 4 Nothing Don't know	Coded 5 Time issues	Coded 6 Choices
Q.14 What would make the project better?					
Coded 1 Automata	Coded 2 Skills	Coded 3 Workshop Wood skills	Coded 4 No responses	Coded 5 Time issues	Coded 6 Choices

Results

Outcomes for Cardboard Automata

Of the 74 students, fewer than half completed the written report. However, all students successfully completed the labeled drawing of their automaton. The original design of the cardboard automaton tested the limited manual skills of some students, as the cardboard was easily bent and twisted, making the cams and followers less rigid. These parts were then made from corrugated card, which ensured all students successfully completed and decorated their cardboard automaton (Figure 2).

Figure 2: Examples of the Completed Cardboard Automata

Outcomes for the Wooden Automata

Many of the initial student ideas were far too complex to be completed in the time available, and their designs had to be simplified. When asked to describe the movement and the action they wanted to achieve, the students' answers showed they had understood how the mechanism worked. Constructing an automaton from wood gave students opportunities to gain skills using hand and electrical tools in the workshop. It required them to demonstrate accuracy in measuring, sawing and assembly. The task provided an opportunity for the students to understand the process from the design stage to the finished product. All of the students produced an artefact (Figure 3).

Figure 3: An Example of a Completed Wooden Automaton

The Questionnaire

Overall, more than 80% of the students found the automata project interesting and enjoyed constructing the automata, with 11% enjoying it a great deal. Eighty percent of the students liked being able to choose either a cat or dog.

A group of four questions, (Table 4), attempted to gauge the students' ideas about the project, and provided the opportunity for both positive and negative feedback. The students were encouraged to provide a written answer to each question. In the skills category, students found cutting out the cardboard automaton, using the glue, scoring the cardboard, and assembling the wooden base unenjoyable. Coloring both the cardboard and wooden models scored highly, but students stated they needed more time to complete tasks, especially in the wood workshop. When asked what they would like to change, the most common response was "nothing", followed closely by having more time. The majority of students (74%) found the instructions clear and understood what they had to do.

Most students (87%) indicated they knew how their automata worked. However assembling both the cardboard model and the wooden base challenged all the students. Whereas 40% of the students found assembling the cardboard automaton a difficult task, 96% of all students selected "hard" or "too hard" when responding to a question about making the wooden base. An unpaired t-test comparing the responses between the female and male students was applied to all questions. No significant gender differences were observed when students were asked if they enjoyed being in the workshop. A breakdown of the answers showed 70% of all female students and 83% of all male students responded positively, with 84% of Year 7 students and 72% of Year 8 students recording a positive experience.

A significant statistical difference in response between females and males was observed in question 5 (How did you find cutting out the cardboard model? t-test, two-tailed, t=2.0020, p=0.0491), when data from both years were combined (Figure 4). Female students found the task of cutting out the model easier than males. When female and male students in each of the two years were compared, the result was only significant for the students in Year 8 (t-test, two-tailed, t=2.6095, p=0.0128).

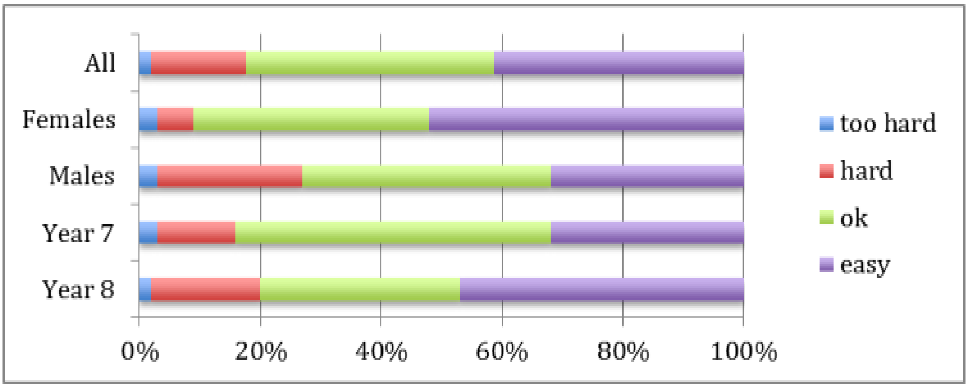

Figure 4: Student Responses to Cutting out the Automaton

Student Recall of Mechanisms

Students were asked to recall the automata mechanisms, six months after completing their automata. The majority (85%) attempted to draw a mechanism, and 71% were able to reproduce at least one movement (i.e. achieved a score of 2 or above). Eight of these drawings are shown in Figure 5. In (a), the drawing of an axle with a cam with no further information, rated "poor", whereas (b) contained more information, depicting a follower above a cam, and with arrows to indicate the direction in which these parts turned, was marked as "fair". The remaining six illustrations contained at least three out of the four marking criteria, and were placed in the top category, "good" (Table 5). The students' ability to draw a mechanism is summarized in Figure 6.

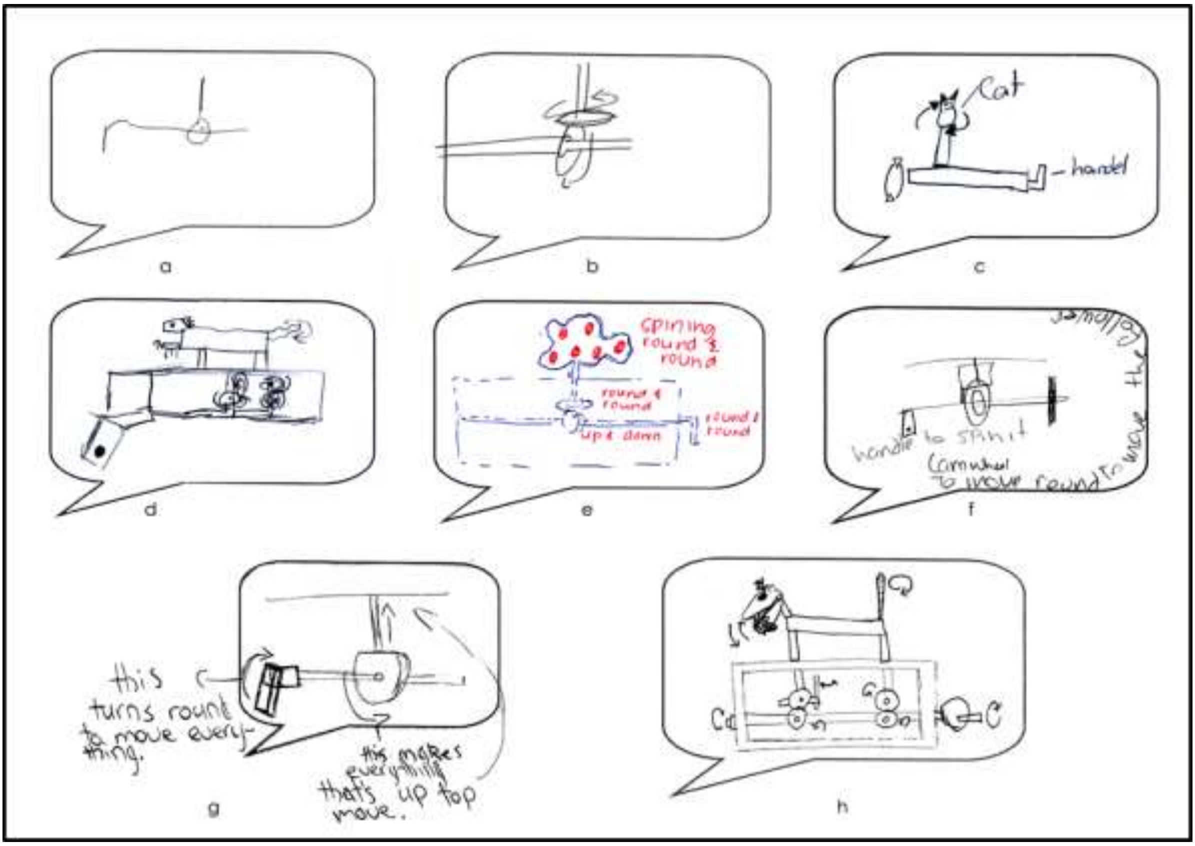

Figure 5: Drawings of Automata Movements, Showing the Range of Ability to Describe the Mechanism

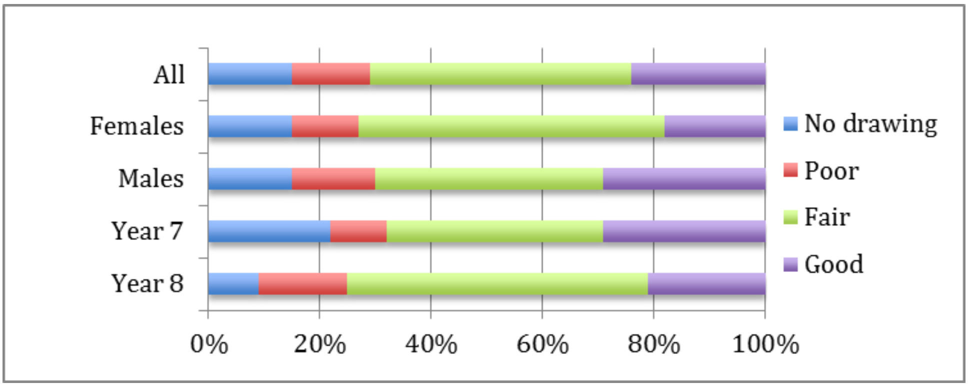

Figure 6: Students' Ability to Draw an Automaton Mechanism, by Year and Gender. No Significant Differences were observed in Mechanism Recall between Males and Females or between Years 7 and 8

Table 5: The Marking Scheme for the Drawings

			Drawing	*Direction*	*Labels/text*	*Extra effort*
Grade	*Description*	*Number of criteria covered*				
0	No drawing					
1	Poor	1	x			
2	Fair	2 out of 4	x	x	x	x
3	Good	3 out of 4	x	x	x	x
Drawing						
Figure 10(a)	Yr 8 male		x			
Figure 10(b)	Yr 8 female		x	x		
Figure 10(c)	Yr 7 male		x	x	x	
Figure 10(d)	Yr 7 male		x	x	x	
Figure 10(e)	Yr 8 male		x		x	x
Figure 10(f)	Yr 7 female		x	x	x	x
Figure 10(g)	Yr 7 female		x	x	x	x
Figure 10(h)	Yr 8 female		x	x		x

A final question asked the students if they would like to make more automata (Figure 7). Their responses were usually one-word answers: yes, maybe (occasionally qualified) and no. A comparison of the data shows a non-significant trend for more female than male students, and more Year 7 than Year 8 students to choose to make further automata.

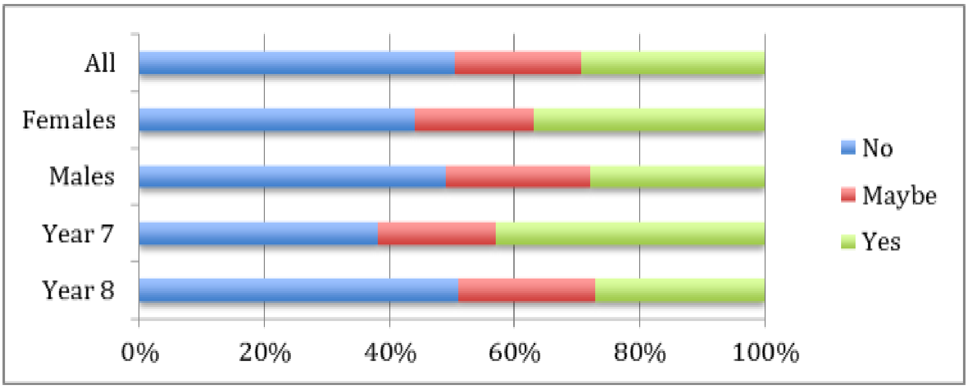

Figure 7: Student Responses to Making More Automata

Assessment

The project was assessed based on the models the students constructed. Consideration was paid to how well the movement worked, whether the automaton was finished, the detail of the decoration and how robust the finished models were. The grades attained were within the range of 2 – 5. One male student in Year 8 achieved a grade 5 for his work and a male student in Year 7 received a grade 2. Overall, 58% of the students attained a grade 4, with 68% of Year 7 students, achieving grade 4. There were no significant differences in the marks received by Year or gender (Figure 8).

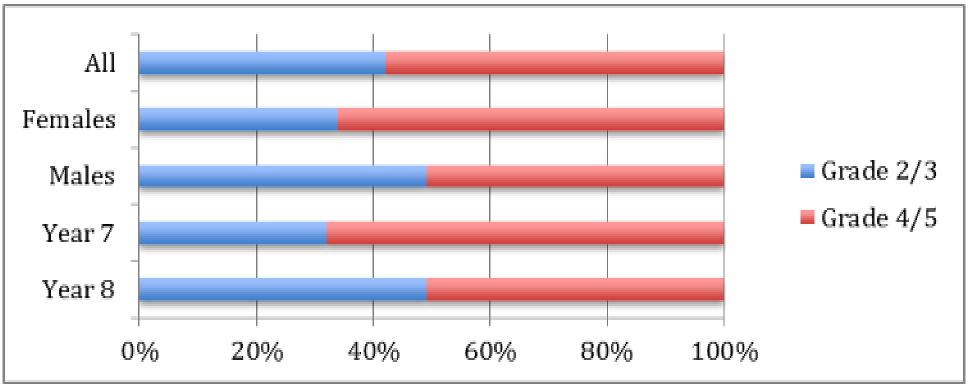

Figure 8: Final Student Grades for the Project

Discussion

Our findings provide an insight into the pupils' perspective of an automaton module in technology education and their reactions to the experience. The study showed the automaton project was well received by the students, and apart from one minor instance where females found the task easier than males; there were no significant gender or age differences in the results. Students were able to describe an automaton movement either by drawing and/or attaching labels. As a way of introducing science into technology, the project was successful. Future work in this area might consider the effects of socio-economic background on the students' ability to construct their automaton or work in the technology workshop. Correlation of students' ability in science or art classes with their grades for this exercise was not possible in this study, but would extend understanding in this area.

The students learned all movements were governed by mechanical principles and could explain how basic mechanisms worked, and then apply their knowledge to designing and constructing an automaton (Figure 5). They discovered if their rotating shaft, with other mechanisms attached to it, did not turn smoothly, the rest of the machine would also have problems. Their cardboard automaton had two cams, a concentric cam that produced a smooth circular movement, and an eccentric one that turned a rotary motion into an upward and downward movement. These cam profiles were tracked by cam followers, which reproduced the same movement for each revolution of the cam. The students transferred this knowledge about predictive movement to their automaton.

This project did uncover a lack of technical skills in New Zealand 11-12 year-olds. Collier-Reed (2009) also found older engineering students had little experience or exposure to classical technical stimuli, for example Meccano, constructing model aircraft and boats, maintaining a car, building tree houses or taking objects apart and subsequent reconstructing them. Weber and Custer (2005) reported middle school students found technical education activities more interesting than high school students, and posited the development of appropriate curriculum materials made the subject attractive to the age range. Their research showed education technology appealed to both genders, but the selection and development of gender-balanced activities was important. Female students favoured projects with an emphasis on design and collaboration, that were socially relevant, involved the environment/people and how knowledge could be applied, whereas male students were more interested in how things worked (Roth, 2001; Sherman, Sanders, Kwon, & Pembridge, 2009; Weber & Custer, 2005).

Hong et al. (2012) looked at gender differences in a technology design project with 66 seventh-grade students (aged 12 years) at a junior high school in Taiwan. The students were organised in single sex pairs. Hand and power tools were used to construct a robot called the King of Beasts. When observing the operation of power tools, the researchers wrote the females *'tended to be frightened and intimidated by machinery',* and males *'more likely to take to the challenge with curiosity and ambition'* (Hong, Hwang, Wong, Lin, & Yau, 2012). These results were not replicated in our New Zealand research, where we observed no significant differences in female and male attitudes and approaches to using machinery.

Silver and Rushton were aware of research which identified student attitudes towards science being formed between the ages of 8 and 14 years (Ormerod & Duckworth, 1975; Osborne, Simon, & Collins, 2003; Smail & Kelly, 1984), and wanted to examine the attitudes of Year 5 students towards STE(M). When questioned, the students described science as investigating, engineering as repairing and technology as designing and making. They enjoyed constructing and driving the car, but did not want to be either scientists or engineers, which the researchers found was based on students' stereotypical images, rather than disliking the subject (Silver & Rushton, 2008a).

Conclusions

We conclude from this study that the design and construction of automata in the classroom appeals to a wide range of students and contributes significantly to students' understanding of mechanisms and their engagement with technology. Learning in technology is further enhanced when it is integrated into the other curriculum areas. Students learning about mechanisms in science while making an automaton in the workshop would learn to understand each subject more deeply, and not experience technology as an isolated subject.

Increasing the amount of choice of subject and time for completion would increase student engagement and satisfaction with this project. Although students were scheduled for five sessions of technology, other factors impacted on the timetable and reduced the available time to only four sessions for most. The lack of time available for them to satisfactorily complete the project was reflected in their answers to the questionnaire.

The data suggest several future research possibilities. Are students more engaged if they are allowed to design their own characters/assemblage on a given mechanism? Does this engagement extend into the design process for the wooden automaton? Do the designs require adaptation? Future research could also include following up students as they transition through secondary school, to determine if the automata project had any influences on subject choices.

Research suggests primary age students should be exposed to positive experiences in technology if they are to be attracted to STEM subjects. The European Union CLOHE project, completed in 2013, provides a useful resource for research in using automata with primary aged students. This project could therefore be usefully repeated with primary age students and their subsequent subject choices monitored.

The context in which technology education is taught may have an impact on what and how children learn. An increasing emphasis on design activities in technology education courses may provide some balance between designing and constructing to make technical education activities more appealing to both sexes. Our results showed no gender differences in students' interest in or ability to complete the automaton project. Females and males interacted and engaged throughout the project, and collaborated and helped one another. The project challenged all of the students to seek answers when their automaton did not function as expected, and to make changes to improve its performance.

It was clear from our results female students wanted access to the workshop, wanted to use the tools and machinery, and would choose to make more automata. In response to the question, what aspect of the project they found most enjoyable, one female student wrote: “I enjoyed completing the automaton, and taking home something I made.”

Acknowledgements

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