Abstract: - There are many challenges that schools face when implementing technology education in an existing curriculum. For example the interdisciplinary nature of technology education, such as the Picaxe-based mechatronics program that is the focus of this paper, poses questions such as where should the program sit in the curriculum, which teacher(s) should take ownership of it and how should (s)he/they develop sufficient skills and knowledge to implement the program in their classrooms? The aim of this paper is to identify and discuss ways of addressing these challenges. The identification of the challenges is based on a study with five schools implementing a Picaxe-based mechatronics program in their schools for the first time. A conceptual framework for successful implementation of mechatronics programs is presented in the paper.

Key-Words: - mechatronics; Interdisciplinary; implementation; theoretical framework; secondary schools; professional development; technological pedagogical content knowledge; teacher attitudes; intrinsic and extrinsic factors.

1 Introduction

One definition of technology education is that it is a highly structured approach to using data, information, knowledge and technology to solve problems for society [1]. It is an interdisciplinary subject [2] that integrates science, mathematics, technological and environmental knowledge as well as social science content, for example history, economics, sociology and political science. In schools, students engaged in technology education, such as in mechatronics programs, work in ways parallel to engineers and artists to create devices that they are able to program and control while engaging with fundamental concepts of electronics, physics, logic and material science. One of the goals of technology education is to teach students about the processes and content knowledge pertaining to technology and to equip them with the necessary skills to solve problems through manipulating materials and tools to meet their needs in ways that will be of benefit to society. Järvinen, Karsikas & Hintikka [3] assert that learning how to solve problems in ways afforded by innovative, flexible technology enables students to learn meaningfully in authentic situations and see connections between real-life problems and what they are learning. There are however, many challenges that schools face when introducing technology education into an existing curriculum. The aim of this paper is to present a conceptual framework that identifies and discusses ways of addressing challenges for successful implementation of the interdisciplinary Picaxe-based mechatronics program in secondary schools. The framework will draw on data from a study [4] with five schools implementing this program for the first time.

‘Mechatronics’ in this paper is a concept defined as the use of a combination of mechanics and electronics to construct products that are chosen by the students because they are considered worthwhile. The two main components of the Picaxe-based mechatronics program are the construction of the universal project board

Fig. 1. UniBoard circuit
(UniBoard, see Figure 1), where conceptual and technical electronics skills are necessary and programming the microcontroller where IT skills are required. In undertaking their project, students immerse themselves in soldering the electronic components for the UniBoard while increasing their knowledge and developing their skills in programming the Picaxe microcontroller (chip) to create simple electronic devices, including robotic devices. Hence, technology education related to this Picaxe-based mechatronics program includes materials technology (e.g. woodwork, metalwork etc), design and systems technology as well as information communications technology (ICT). Other learning areas that are integrated into this type of program include physics, mathematics, electronics and programming. This wider focus means that the challenges for this kind of program cannot be restricted just to technological issues. Indeed, sorting out choices that teachers have to make will depend on the deeper level of understanding that they have of values that inform the overall program and shape the relationships between students, teachers and resources.

Fig. 2. Example of finished product: musical device

2 Problems with Implementing Technology Education

Issues that teachers face when integrating technology education into their lessons include lack of resources; lack of time to learn and plan activities; classroom management issues; inadequate skills and knowledge as well as lack of financial support [5]. Finger and Houguet [6] have categorised the challenges faced by teachers as either intrinsic or extrinsic. Intrinsic challenges include attitudes, perceptions of the value of programs, content knowledge as well as confidence in teaching and approaches to teaching. Extrinsic challenges include the availability of time, practicality of implementation, student assessment and professional development and support. A further issue identified by teachers in Jones, Harlow and Cowie’s [7] study is being able to fit technology education into an already crowded curriculum. Most of the literature identifies issues in the area of ICT as challenges for technology education when the use of computers is integrated into the teaching. The conceptual framework for this paper is, however, wider since it focusses on a cross-disciplinary mechatronics program where secondary students use the Picaxe microcontroller (chip) to create simple electronic devices, including robotic devices. Hence, technology education related to this Picaxe-based mechatronics program includes materials technology (e.g. woodwork, metalwork etc), design and systems technology as well as information communications technology (ICT). Other learning areas that are integrated into this type of program include physics, mathematics, electronics and programming. This wider focus means that the challenges for this kind of program cannot be restricted just to technological issues. Indeed, sorting out choices that teachers have to make will depend on the deeper level of understanding that they have of values that inform the overall program and shape the relationships between students, teachers and resources.

Fig. 3. Framework for successful implementation of mechatronics in secondary schools.

The framework that is identified in Figure 3 locates the specific issues that are seen as challenges in implementing a technology education program. However, since these challenges overlap, the resolution of the competing demands actually depends on a series of values that is ‘invisible’ in the perception of the challenges.

3 Conceptual Framework for the Successful Implementation of Mechatronics in Secondary Schools

The conceptual framework in Figure 3 shows the elements that need to be considered for successful implementation of mechatronics programs in schools, but does not make explicit the values that shape how these challenges are overcome. The main
players in the framework are the teachers (T), students (S) and resources (R). The intersections between these players, student-teacher (S-T), teacher-resources (T-R) and student-resources (S-R) are also important areas to consider for successful implementation. The different components of the framework will be discussed to show how they overlap with each other.

3.1 Where does mechatronics sit in the school curriculum?
This is the first important question to ask before designing the mechatronics program for implementation in schools. As shown in Table 1, the data from the five schools in the research study [4] showed that the program can be adopted at any year level from 7-10, either as a core or an elective subject. It can also be focussed within a single curriculum area or be designed to integrate diverse areas. For two of the schools (B and C), the targeted students were high achievers and the focus was on the cross-disciplinary nature of the program. The other three schools had more emphasis on teaching the mechatronics unit as a technology subject where students focussed on electronics and robotics. The teachers involved in the implementation of the program across these five schools were science teachers, materials technology and information technology teachers. Most of the teachers taught alone while one of the schools (School C) distributed the program across two teachers and curriculum areas where the science teacher taught the electronics and UniBoard construction while the IT teacher taught the programming part. The study showed that the curriculum focus, the type of students, the students’ year levels and the background of the teachers were not perceived as the crucial elements in successfully implementing the mechatronics program. The attitudes of the teacher(s) involved and the availability of sufficient resources were seen as the most important elements in making the program a success.

3.2 Teachers

3.2.1 Identifying appropriate teacher(s)
As indicated in Table 1, the seat of expertise was either singly owned, for example science (School B), technology (School D), IT (School E) or mixed – science and technology (Schools A & C). The mix of science and technology expertise was also different in that it lay in an individual teacher’s workload in school A while it was split between the science expert and IT expert in School C. School C had conceived of the building of the UniBoard as something to be done in the science area and then handing the programming over to the IT teacher. Others had a cradle-to-grave approach with one teacher owning the total program outcome. While expertise was an important factor in determining success, the study showed that teacher attitude and being able to value teaching the program were the most important intrinsic factors influencing the program’s success. A key component in assisting teachers to develop appropriate attitudes was working with them to make explicit the underlying pedagogical principles/values that the initiative was designed to address. In this particular case, the values did not appear to be directly derived from the content either of the technology or of the science components of the curriculum, but instead were derived from a more abstract set of principles that we labelled ‘persistence, patience and precision’. These values gave teachers frameworks for choosing between different kinds of activities and different aspects of the subject matter available for inclusion in the technology education work.

3.2.2 Teacher attitudes
Figure 4 illustrates the varying levels of success in implementing the mechatronics program and the level of enthusiasm and interest shown by the teachers. The level of success (vertical axis) represents the relevant school’s capabilities in terms of applied skill and knowledge and organization, application to the task in enabling students to successfully construct devices. The horizontal axis represents the relevant school’s level of enthusiasm as perceived by the researchers.

Table 1. Implementation of mechatronics in schools.

<table>
<thead>
<tr>
<th>School</th>
<th>Year level</th>
<th>Core or Elective</th>
<th>Curriculum focus</th>
<th>Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sch A</td>
<td>Year 7</td>
<td>Core</td>
<td>Electronics and robotics</td>
<td>Technology &amp; science teacher; previous experience</td>
</tr>
<tr>
<td>Sch B</td>
<td>Year 9</td>
<td>Elective</td>
<td>Integrated curriculum; High achievers</td>
<td>Science teacher novice</td>
</tr>
<tr>
<td>Sch C</td>
<td>Year 8</td>
<td>Core</td>
<td>Integrated curriculum; High achievers</td>
<td>Science teacher &amp; IT teacher novices</td>
</tr>
<tr>
<td>Sch D</td>
<td>Year 9</td>
<td>Elective</td>
<td>Electronics and robotics</td>
<td>2 Technology teachers; novices</td>
</tr>
<tr>
<td>Sch E</td>
<td>Year 9/10</td>
<td>Elective</td>
<td>Electronics and robotics</td>
<td>IT teacher; Lego robotics experiences</td>
</tr>
</tbody>
</table>
The chart shows that Schools A and B with teachers who had positive and committed attitudes achieved higher levels of success in curriculum implementation. School A’s teacher’s more extensive prior experience seems to have enabled him to be placed further along the success axis. Even though School B’s teacher was only in his third year of teaching and had a Biology (rather than, e.g. a physics) background, he worked hard in learning about electronics, soldering and programming and sought help when needed. Observations conducted by the researchers indicated that his students were generally motivated to work and supported each other in getting their constructions working. While teachers from Schools C and D were generally enthusiastic and similar in terms of expertise, School D’s teachers were less organised, due in part to the school’s infrastructure and resources disadvantaging their progress. As a result of these considerations, School D was placed further down at the level of capability. School E’s teacher, while knowledgeable with robotics programs, was disorganized and showed less interest in and accountability toward the program.

Most of the teachers saw the value in engaging their students in the mechatronics program. An example of what one teacher (School C) said is given below:

Just seeing the Year 8’s getting into a complex project which presented challenges such as logic, clear thinking and problem solving. Many rose to the challenge. To see them getting all the components together and working was such a fantastic effort. Being able to achieve difficult areas of the project like thinking ‘upside down’ with some of the components and seeing the teamwork helping to spread the skills amongst the group were all highlights.

### 3.2.3 Professional development

Many teachers come into mechatronics programs as novices and this is the case with many of the teachers from the 5 schools in the study, since only one of them had had any previous experiences with teaching mechatronics. It is necessary for teachers who are implementing a new technology program to be empowered with theoretical knowledge and practical skills in both electronics and programming. However, they must also have a framework that makes wider pedagogical goals explicit. If this has been done, then teachers will have been professionally developed in technological pedagogical content knowledge (TPCK), where they are able to integrate technology, content and pedagogy rather than treating each of these entities as separate domains in their teaching [8].

The professional development program for teachers should be premised on principles of effective professional development, for example Lewis [9] and Webster-Wright [10] have identified the following elements of professional development as (i) content knowledge (ii) collegiality and networking between teachers within and between schools (iii) sufficient time for professional learning and practice that extends over a period of time (iv) being actively involved in the learning e.g. constructing one or two devices to completion (v) curriculum coherence where relevance is made explicit in the interdisciplinary nature of the program and (vi) ownership, where teachers are provided with opportunities to develop the curriculum around a mechatronics program that fits into their particular school’s ethos and charter (curriculum) priority. It is areas (v) and (vi) where clarity about the underlying values of the program is crucial for success.

Professional development is the first step in developing teachers’ expertise in mechatronics. They will need to invest time after that to practise what they have learned, for example, constructing a few more simple devices and having opportunities to plan and design their lessons in a coherent manner.

### 3.3 Students

Students are the central focus in any mechatronics program and designing the curriculum around them requires that teachers consider how students learn. The most influential learning theories for mechatronics programs are constructivism [11][12][13] and constructionism [14]. Both theories
are learner centred and as a result build on the student’s prior knowledge and past experiences. The two aspects of constructivist learning are (i) cognitive [11][12], where students are involved in the active mental construction of knowledge through their interactions with the materials being learned, for example understanding the circuit layout of the UniBoard, soldering the electronic components and fault finding and (ii) social [13], where students support each other through conversations and actions to create completed mechatronics products. Constructionist learning theory [14] asserts that students learn better when constructing a product, such as a mini robot, egg timer, musical device or a poster that shows how the completed product works, that can be displayed to their peers or others.

In the Student-Teacher (S-T) intersection in Figure 2, interactions between teachers and students are crucial to enable students to value the knowledge gained in mechatronics classes and to develop positive attitudes towards their learning. Teachers need to motivate and challenge students to be active and creative learners, communicate with them regularly and encourage collegiality between students so that they can learn from each other. The best way to achieve this is for the teachers to role model enthusiasm and to demonstrate expertise where they possess it and to show a willingness to learn from those students who may be technically better with electronics and/or programming. Interviews with students in the research study revealed that many of the students had difficulty articulating what they had learned. At the practical level, the study also found that different students found difficulty with different parts of the practical side of the mechatronics program. Some found soldering the most difficult aspect of the program while others found identification of faulty soldering joints or programming more difficult. Encouraging students to work in teams and across teams to share knowledge and skills would be a solid basis for building success in producing complete and working products. Establishing a safe and friendly working environment that is built on trust is important for practical programs such as this to succeed. Negotiating expectations and accountability, for example whether students work individually or in groups for larger projects allows for some ownership by the students of their learning. Assessment in mechatronics classes needs to be appropriate and criterion-based and have a balance between testing students’ understandings of the theories that they have learned and assessing the final product. As part of the assessment, it is important to encourage students to communicate their final products in front of an audience, for example with a PowerPoint presentation or poster, in order for them to make explicit their understanding of the product that they have created and the principles that the product or their own learning reflect.

3.4 Resources

In the Teacher-Resources (T-R) and Student Resources (S-R) intersections in Figure 2, School B had the ideal infrastructure set-up for teaching mechatronics programs. Attached to the science laboratory, where the soldering and physical constructions of the mechatronics devices took place was a computer-pod, a small room with about 10 computers. This catered well for students with different abilities working at different paces on their devices as they could test their constructions with programming whenever they needed to. In comparison to students in other schools, students in School B were observed to be more focused and ‘on task’ as there was continuity in the work that they were doing. Nevertheless, across the schools, it was a common observation that there was extensive peer-support happening in problem-solving design, manufacture and programming issues as students gathered around computers or devices to discuss faulty programming or technical constructions that were causing difficulties.

Apart from ready access to computers, timetabling and provision of sufficient equipment/materials are areas that need to be addressed adequately for successful learning to take place. The nature of constructions, programming and testing at various stages of mechatronics programs require that classes are timetabled in longer classes so that learning is not disrupted when students encounter difficulties and have to attempt to resolve them. Ensuring that there is sufficient equipment and that enough materials are available such as electronic parts and soldering irons is also essential for successful learning to take place. In this regard, the support of the principal in making available sufficient funds to purchase parts to enable more complex application products to be constructed is needed as indicated by the teacher in School A:

…(funds to cover) the cost of getting some of the more complex application products like the six-legged bug which costs $200. The kids are limited by the number and type of supporting hardware items we can get hold of.

This teacher’s comment is not just about money, but is indicative of an orientation to support of
innovations that needs to be demonstrated by central authorities in the school (and ideally in wider educational systems). The money is an index of support for integrated approaches to innovation rather than an ambit claim for larger budgets.

4 Conclusion

This paper has provided a framework for successful implementation of mechatronics programs in secondary schools. The framework involves consideration of the distinctive and intersecting needs in the areas of teachers, students and resources, underpinned by a wider set of curriculum principles that need to be articulated separately for each program. Mechatronics programs are complex in their cross-disciplinary nature and determining where they sit in the school’s existing curriculum and how they act to shape that curriculum is the first step in their implementation since this determines the choice of teacher(s), year level and type of students to be taught as well as the fundamental educational orientation that the program will have. The type of environment needed for successful implementation demands teaching skills that include flexibility, a practical outcome orientation, problem solving skills at both the component and system level and a willingness to supervise a dozen or more mini-projects at various states of work-in-progress and technical complexity. A positive, enthusiastic and committed attitude from the teacher is a necessary, but not necessarily a sufficient condition for a high level of success.

In concluding, the value of mechatronics programs for school students is captured by the following comment provided by the teacher from School B:

Seeing students sharing different components to get their products working was good too. It helps them to plan, design, build, test and modify electronic products and models. They learn workplace skills. Many here won’t go to uni so more useful and practical learning took place. I got lots more out of this than I expected. Rapid progress was made in some cases, which was not expected. Some students took home their projects to get them finished or working in their own time (School B Teacher)

References: