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LaserTag for STEM Engagement and Education

ROBERT ROSS, (Member, IEEE), JAMES WHITTINGTON, (Member, IEEE), AND PHAT HUYNH, (Member, IEEE)
Department of Engineering, La Trobe University, Melbourne VIC 3086, Australia
Corresponding author: Robert Ross (r.ross@latrobe.edu.au)

ABSTRACT In a century where technology is rapidly shaping the way we communicate, travel, work, and live, the numbers of students studying the natural sciences (which are often perceived as more difficult) in both the high school and the university is on the decline. Many universities and schools have been addressing this lack of interest using a wide variety of engagement programs to encourage and retain students in science, technology, engineering and mathematics (STEM) disciplines. This paper describes a hands-on activity, *LaserTag*, that has been developed by the Department of Engineering at La Trobe University and has had thousands of high school participants over the last few years. During the activity, students solder together (and keep) electronic LaserTag devices, which they can use to shoot infrared light packets at each other to have their own skirmish activities. The effectiveness of the activity was measured based on anonymous student surveys evaluating students prior and post interest in engineering and the STEM disciplines. The survey results were very positive indicating 97% of the participants found the activity 'highly enjoyable' or 'enjoyable' and that 55% of students who were previously unsure about engineering as a career 'strongly agreed' or 'agreed' they were more interested in studying engineering as a result.

INDEX TERMS Engineering engagement, STEM, education, electronics, photonics, LaserTag.

I. INTRODUCTION

For decades it has been recognised that there is a worldwide shortfall of students graduating from Science, Technology, Engineering and Mathematical (STEM) disciplines [1]. In Australia, despite the recognised need to drive productivity through research and development [1], the numbers of graduates from engineering disciplines has seen little growth over the past decade [2]. Educational providers at all levels recognised this declining trend and have created a vast array of different student engagement programs, both to attract and retain students in STEM disciplines at both secondary and tertiary levels.

In Victoria participation rates in science at an upper Secondary level have been in significant decline over the period 1992 to 2010 with Biology falling from 35.3% to 24%, Physics falling from 20.8% to 14.2% and Chemistry from 22.9% to 17.2% [2]. The same study interviewed 363 non-science year 11 and 12 students to assess their reasons for not studying science. A total of 61% of respondents said they disliked science disciplines or that they were boring, 31% responded saying they felt they were not good at science and 26% responded saying that science didn't align with their career aspirations [2]. Similar perceptions have been reported in other studies [3], [4].

Of the students studying science in year 11 and 12, 30% (the largest percentage) indicated that more interactive laboratory lessons would provide the best improvement in science classes. Of all the students studying year 11 and 12 science subjects, 48% indicated their interest in science stemmed from junior secondary school – triggered by school based lessons or activities, including specific teachers, science enrichment programs and subject information sessions [2].

This paper describes one of the engineering outreach programs developed and run by the Department of Engineering at La Trobe University. The program, *LaserTag*, involves each student constructing an electronic circuit on a Printed Circuit Board (PCB) which they may keep and take home at the end of the session. The activity is low cost and has a typical construction time of 70-90 minutes. Following the activity a seminar is provided which gives an overview of the science and engineering concepts behind the activity (programming, photonics and light modulation and sound).

The LaserTag activity is targeted towards years 7-10 students (ages 12-16) with the purpose of demonstrating that science and engineering can be interesting and exciting, whilst encouraging students to study higher level mathematics and physics disciplines as they complete their secondary school education. This activity fit into a wider suite of programs offered by the Department of Engineering including Year 12 Physics master-classes, robotics seminars, careers seminars, other junior high school programs and the Robotics, Automation and Mechatronics Program (RAMP) that places 3D printers and microcontrollers in selected schools, providing targeted support to systems engineering students. This suite of programs is currently used for student engagement with approximately 5000 secondary school students participating annually.

Traditionally, LaserTag is an electronically simulated battle scenario which involves people moving around and tagging each other by firing packets of infrared light at other players receiver units [5]. When a player has been 'tagged' their tagger is disabled for a certain time interval which disables tagging functionality. LaserTag has wide appeal including use in military war-games, as a high intensity sports workout and most popularly as a game for teenagers [6]–[9].

Research has suggested that 'simulated shooting' activities like LaserTag produce a significantly more positive emotional 'well-being' state when contrasted with video gaming, possibly in part due to the physical activity and teamwork involved [10]. Some 'non-combat' games have also been developed using the fundamental technologies behind LaserTag to emphasis the sporting and teamwork exercises which make LaserTag a very good fitness activity [11].

This paper is structured as follows: firstly, Section II provides a survey of some of the prominent engineering engagement and outreach programs and discusses the effectiveness of these programs. Section III then goes on to provide a description of how the LaserTag activity actually works, including an explanation of some of the specific learning outcomes and costs. Section IV then discusses how the effectiveness of the program was evaluated using the results from student surveys, before the concluding remarks in Section V.

II. SURVEY OF STEM ENGAGEMENT ACTIVITIES

The last decade has shown significant growth and investment into STEM engagement activities, primarily aimed to encourage students into science disciplines and retain students in these disciplines. The scope of these activities is significant and varied so this section describes activities that have synergy with electronics as these most strongly relate to the context of this paper.

Across these activities, student feedback indicated that the 'hands-on' practical activities approach is most engaging for high school students and that activities, ideally, should have a 'doing' or 'hands-on' component, and that merely hearing from practicing engineers or scientists isn't enough [12], [13]. Seminars from STEM practitioners have shown merit and promise when educating students about specific careers, however feedback from these senior school students indicated they desired a 'hands-on' component as part of the seminar. This hands-on component is often difficult for industry STEM practitioners to offer [14].

Many engineering engagement activities include an aspect of competition, where students are competing against their peers, to provide challenge and excitement. One national program which has been very popular is the University of Newcastle's science and engineering challenge where students participate in a wide variety of challenges from load-balancing an electricity supply and optimising hovercraft through to bridge design and trebuchet creation [15]. Another national competition of note is the UAV (Unmanned Aerial Vehicle) outback challenge which involves an autonomous search and rescue exercise for university students and a payload targeting exercise with model aircraft for high school students [16], [17].

At a K-12 school level, (and even in some undergraduate courses), the use of Lego Mindstorms has blossomed as a mechatronics engagement and teaching program [18], [19]. Mindstorms provides students with a very simple to use mechanical framework and an intuitive, block-diagram based programming architecture which facilitates students just not assembling designs but actually performing design work. A large number of programs have been developed revolving around experimental problem solving and design exercises to engage primary school students–with the aim to keep them engaged for high school STEM disciplines [13], [20].

One domain of interest which has proved very popular with high school students in project based learning in robotics and mechatronics [21]. These programs draw together diverse skills from mathematics, electronics, mechanics and general sciences and provide a general platform for STEM careers education alongside specific team based projects. Projects vary from more simple LEGO MindStorms based challenges to interdisciplinary mobile robot competitions [21]–[23].

Specialist science/engineering camps have long been seen as an effective and extended opportunity to engage students in STEM disciplines [24], [25]. Many of these camps involve a whole series of science experiments and engineering challenges (similar to the activity that is being presented in this paper). Often these camps will capture a much smaller group of students (a few hundred for very large camps) and are relatively self-selecting – if students already have a keen interest in STEM disciplines they are much more likely to attend. Thus, these activities tend to be good at maintaining interest in STEM, but not as effective in encouraging new students to develop and interest in STEM.

The ultimate measure of effectiveness for engineering engagement relates to actual changes in students numbers directly as a result of the program, with many of these hands-on partnership programs showing significant results. In Texas an initiative titled Project Lead The Way (PLTW) enables students to get college credits in high school whilst doing hands-on engineering tasks including CAD design, rapid prototyping, testing and training supported by guest speakers [26]. Statistically students enrolled in this program are four times more likely to enrol in engineering, to be retained in engineering and typically graduate with a higher GPA than other high school graduates [27]. An outreach program from the University of Oklahoma involving innovative demonstrations, hands-on activities and advanced engineering technologies saw a annual 5-year decline of 9% per year transformed to a 9% gain per year in engineering intake since the summer camp program was introduced [26].

Having established the need and background to engineering engagement activities, the following section details the technology involved in the LaserTag activity.

III. LaserTag SYSTEM OVERVIEW

The term LaserTag is somewhat misleading, as although the commercial versions of the taggers have LASERs, the LASERs are only used for aiming—not for actually transmitting 'tags'. The LaserTaggers constructed in this activity don't include a LASER at all which helps to keep them inexpensive and safe for students to assemble and use. Students perform all assembly (soldering with though-hole components) under the direction of some laboratory demonstrators (typically with a 10-to-1 student-to-demonstrator ratio).

The taggers essentially consist of an infrared (IR) Light Emitting Diode (LED) and infrared receiver pair as shown in Figure 2. This IR LED allows packets to be transmitted using Amplitude Shift Keying (ASK) modulation. This modulation is typically performed at a frequency of 38kHz, (similar to TV Remote controls) to mitigate against spurious InfraRed (IR) sources of interference.

The IR packet protocol was implemented to be compatible with the Open Source MilesTag protocol [28], allowing keen students access to an open source community which can provide inexpensive hardware and a wealth of knowledge as they further investigate electronics. The protocol, as shown in Figure 1), uses ASK modulation, and includes a 2.4ms header followed by a series of logical '1' (1200us pulse) and logical '0' (600us pulse) pulses. An inexpensive IR Receiver/Demodulator is used as the receiver to demodulate the IR signals before being sampled by the microcontroller.

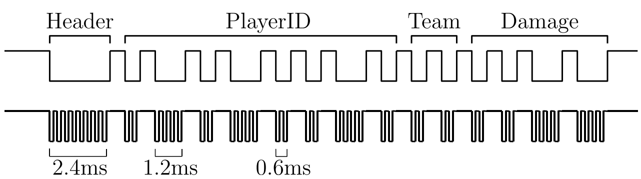

FIGURE 1. IR Packet protocol with demodulated signal (above) and modulated signal (below with modulation not to scale).

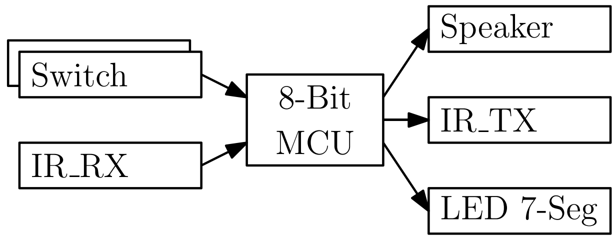

FIGURE 2. Block diagram for the LaserTag unit.

TABLE 1. Parts list.

Component	Qty
Custom PCB	1
AT-Tiny24A Microcontroller	1
DIP 14Pin Socket	1
Resistors (10R, 39R, 39R)	3
Speaker	1
NPN Transitor 2N3904	1
7-Segment LED Display	1
2xAAA Battery Holder	1
IR LED 940nm	1
RED LED	1
IR Demodulator TSOP4838	1
Toggle Switch	1
Momentary Switch	2

FIGURE 3. Image of fully assembled LaserTag unit.

Figure 3 shows a block diagram of the LaserTag system. At the centre of the system is a low cost Atmel AT-Tiny24A 8-Bit microcontroller – chosen to provide a uniform platform across many of the different outreach programs. Feedback to the user is provided using a 7-Segment LED display and a speaker which generates mono-phonic tones (different 8-bit tones for power-up, power-down, shooting and reloading).

The 940nm IR LED is driven by a transistor to increase the drive current and has been tested to have an effective range of 20m indoors without any lenses. Many commercial models advertise up to 100m ranges with lenses which could be an extension project for the students as they study photonics and optics.

The software is programmed to give 9 lives (a player can be tagged 9 times before they are completely out). Each time a player is tagged they are deactivated for 5 seconds. A player gets 12 shots before reloading is required which takes 3 seconds. Insertion of the microcontroller (into the socket) is performed by a laboratory demonstrator after a brief inspection of the soldering quality.

The LaserTag activity is a fun, self-contained engagement activity that also has learning outcomes which can be explored or further integrated into many STEM areas. These include: photonics, optics, electronics, sound modulation, software design, data modulation and communications. These aspects are explained briefly in the 20 minute 'how it works' seminar which follows the construction exercise and is tailored to appropriate age groups. Key components discussed include microcontrollers (along with embedded software), transistors as switching devices and light modulation using IR light. For younger age groups (years 7-8) more complex details around light modulation would be abbreviated.

These seminars also give students a picture of what engineering design looks like, and inform students of the skills required (an engineering degree) to succeed in this area. The total cost of parts (as outlined in Table 1) for this activity (quantities of 1000) is relatively inexpensive (approximately $5AUD per kit) and provides a functional lasting reminder (students keep their kits) of the experience.

IV. EVALUATION

Besides the traditional school excursions that these activities are generally used for the Department of Engineering also runs the LaserTag activity for the annual University Open day—providing a good measure of annual growth for community engagement activities. In 2011, before LaserTag was introduced, a headphone amplifier activity was provided which attracted a couple of dozen interested students who completed the soldering exercise. In 2012, the first year LaserTag was run at Open Day, a total of 180 students completed the exercise with great enthusiasm. For the 2013 Open Day, the activity was expanded across two other La Trobe campuses (where Electronic Engineering is not taught but course information is provided) and saw a total of 400 students completing the LaserTag activity with candid feedback from parents that it was the best Engineering Open day they had attended anywhere.

Since early 2012 a total of 2500 LaserTag kits have been assembled by students, primarily in the year 8-10 age range, but students as young as 8 years old have successfully completed the LaserTag under close supervision.

An anonymous survey recorded student feedback based on year level and gender and asked questions relating to their enjoyment of the activity with space for general comments. A series three questions asked students about their prior interest in studying engineering, prior interest in studying a STEM discipline and their expectation to study at university in the future. Reflecting over the engagement activity the students answer a further three questions: their increased interest in studying engineering, increased interest in studying a STEM discipline and greater interest at studying at a University in the future.

A total of 207 surveys were completed with an age and gender distribution highlighted in Figure 4. The surveyed students came from 63 different schools around Victoria, including state, independent and private schools. The age and gender distribution show the bulk of respondents to be year 9 students (with some all-girls schools at this year level changing the gender balance). Student numbers tend to decrease towards the higher years as it becomes difficult

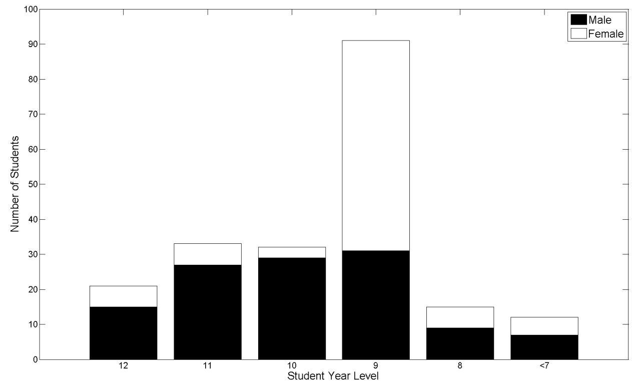

FIGURE 4. Breakdown of age and gender from survey feedback.

to integrate such an activity into an already crowded VCE program.

The results from the prior interest in engineering, STEM and university studies are shown in the first three columns of Figure 5. As expected, Engineering (a subset of the STEM disciplines) exhibited less interest in the 'Agree' and 'Strongly Agree' categories than the general STEM category (as students who ranked high interest in Engineering universally ranked high interest in STEM disciplines).

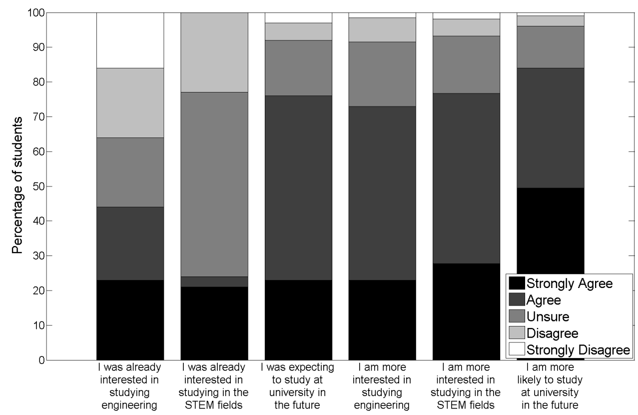

FIGURE 5. Student responses for question related to the students attitudes before and after the activity.

The prior interest results show a great deal of diversity reflecting the distribution of students completing the activity. Some students were selected by teachers as showing an aptitude or interest in engineering, some were self-selecting in attending activities such as Open Day and some attended as part of a general junior/middle science program and hence show the greatest diversity in scientific/engineering interest. Overall, there were a significant number of students interested in both STEM fields and specifically in Engineering (68% and 51% respectively indicating they 'Agree' or 'Strongly Agree' with these questions).

The results also indicate that the vast majority of the students were expecting to complete university study. When the results were further analysed is was found that the majority of students who were not expecting to commence university studies were either from designated low-SES (Socio-Economic Status) schools or from regional schools. Students from these schools have been traditionally under represented as University graduates due to lower educational aspirations, lower education achievement and lower school completion rates [29].

The post activity survey results (shown in the last three columns of Fig. 5) show a marked increase in student interest for both engineering and STEM fields. Additionally there was a small increase in student expectations to attend university (predominately from students who previously indicated they were unsure about university studies).

Reflecting the general student desire to have more activities and practical sessions in science [2] the students uniformly rated their enjoyment of the activity highly as shown in Figure 6. For enjoyment there was little discernible gender bias and only two students saying they 'Disagree' or 'Strongly Disagree' on the activity being enjoyable.

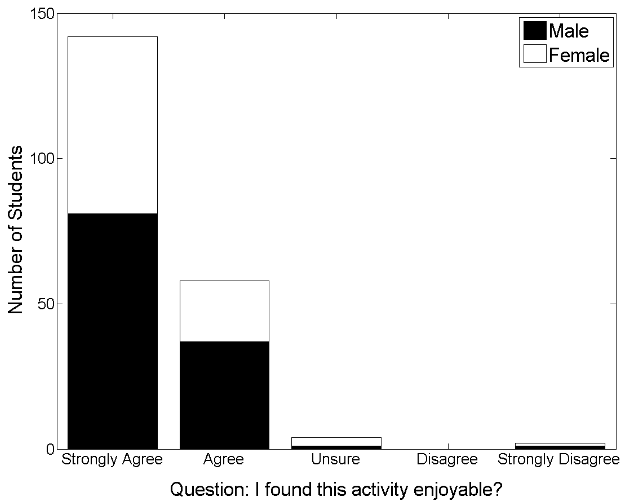

FIGURE 6. Responses based on student enjoyment show uniform high levels of enjoyment with the activity.

Figure 7 shows the post activity results for students previously identifying they were 'Unsure', 'Disagree' or 'Strongly Disagree' they have an interest in studying engineering. These results show a considerable shift towards engineering with 55% of the students indicating they 'Agree' or 'Strongly Agree' with the question they are now more interested in studying engineering as a result of the activity.

Figure 8 performs the same analysis for students indicating they previously were 'Unsure', 'Disagreed' or 'Strongly Disagreed' with the question as to their interest in studying in STEM disciplines. This group of students was 35% smaller than the group who were unsure or disinterested in engineering study (as engineering is a subset of STEM). The improvement for students post activity 'Agreeing' or 'Strongly Agreeing' they are now more interested in studying in STEM fields is also smaller at 45%.

Only 20% of the students wrote a comment in the comments field of the survey. Of these students, over 71% commented that the activity was fun or cool which is a

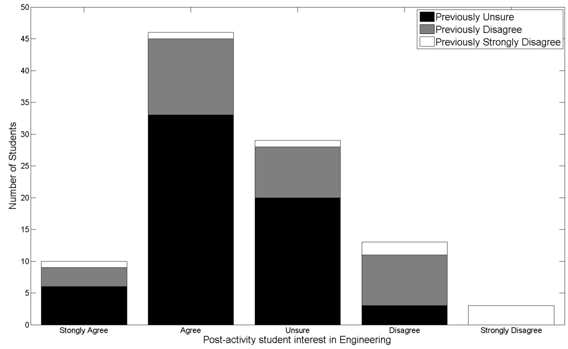

FIGURE 7. Post activity responses for students previously unsure or not interested in engineering.

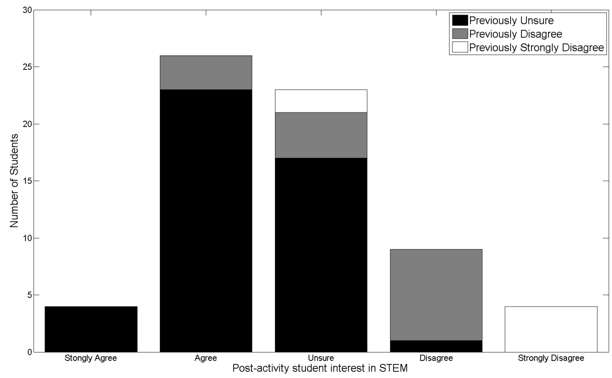

FIGURE 8. Post activity responses for students previously unsure or not interested in STEM discplines.

pleasing result given the aim to engage students in STEM areas. About 10% of the students requested more detail in the notes, although some mentioned that the supervisors were excellent in helping them out. A further 10% of students said the activity should provide more than one LaserTag per student to allow them to play with their siblings rather than just their classmates. We inform all students that they can return to the labs to build additional LaserTaggers on Open Day with their parents which has in part accounted for significantly higher numbers of visitors at recent Open Days.

The overall feedback from these activities has been so positive they have been integrated (in a more academically rigorous form) into our undergraduate program. For one of the laboratory classes in a second year microcontrollers subject students solder together a LaserTag board and write all the code to send and receive data – forming the basis of a rudimentary LaserTag system. This involves a practical application of timers and interrupts as well as extensive use of digital storage oscilloscopes and modulation. This laboratory was received so well that several students, as an extension, implemented different teams (each with different IR codes), different gun types (varying in damage and firing rate) and shields (which can accept more damage from different guns).

The ultimate measure of success of such engagement programs is the increased numbers of engineering and STEM enrolments. Although this and other engagement programs have only been running for a few years, they have seen a 5-year annual enrolment decline of 13% being reversed to a 3-year annual enrolment increase of 30% for the electronic and mechatronic engineering courses at La Trobe University after the introduction of the suite of engagement programs.

V. CONCLUSION

This paper has presented and discussed the LaserTag program which is being used as a highly engaging outreach activity targeted towards middle and junior secondary school students. The activity, which annually is completed by over 700 students, was rated by 97% of participants as highly enjoyable or enjoyable and provides good teaching examples of more traditional physics and IT concepts including: photonics, electronics, programming and communications. Importantly, the survey results indicate a increased level of interest in engineering and STEM fields more generally with 55% and 45% of students respectively indicating an increased interest in studying in these areas. The LaserTag activity is an excellent example of a junior through to middle secondary school engagement program designed to encourage student interest in the STEM fields.

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ROBERT ROSS received bachelor's degrees in electrical engineering and computer science and the Ph.D. degree from La Trobe University, Melbourne, Australia in 2007, 2007, and 2013, respectively. He is currently a Lecturer with the Engineering Department and has been actively involved in research into sensors, robotics, machine vision, and innovative marking systems to facilitate laboratory development and marking.

JAMES WHITTINGTON received B.Sc. (Hons.) and M.Eng. degrees from La Trobe University, Melbourne, Australia. He is currently a Senior Lecturer with the Department of Engineering and has interests in the development of digital systems and techniques for communication, HF radar, automotive safety, and control applications. This particularly includes the real-time hardware implementation of digital signal processing structures in FPGA technologies.

PHAT HUYNH received the bachelor's degree in electrical engineering and the Ph.D. degree from La Trobe University, Melbourne, Australia. He is currently an Associate Lecturer with the Department of Engineering and has interests in robotics, image processing, and machine vision.