Inspiring Australian secondary school students through the Science Bootcamp program

Abstract

For Australia to maintain its flourishing economy and international competitiveness, more of its youth must pursue education and careers in science, technology, engineering, and math (STEM). Our project aimed to increase student interest in STEM by creating two activities for the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Science Bootcamp program. These activities, a build-your-own electrocardiogram (ECG) and a spacecraft prototyping project, will provide students with a four-hour building and testing experience. These activities were informed by our research into science enrichment programs, by our analysis of past Bootcamp assessment data, and by an iterative development process.

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An uncertain future: Australia’s youth are losing interest in STEM fields

Without innovators to generate new ideas, and without Science, Technology, Engineering, & Math (STEM) workers to realize those ideas, a nation is at risk of being left behind in the march of technological progress. Today, Australia and many other developed nations’ youth are not pursuing STEM fields.¹ Many Australian politicians and business leaders worry that a lack of qualified STEM professionals will limit Australia’s research capabilities and seriously hinder economic growth. Australia’s Chief Scientist has voiced concern about this issue after his office reported that “seventy-five per cent of the fastest growing occupations now require STEM skills and knowledge,”³ and yet, some employers have difficulty finding new hires for STEM positions.¹ The Office of the Chief Scientist found that of several hundred employers surveyed, 40% reported difficulty in filling technician roles, and 31% noted difficulty with hiring enough STEM graduates.²

The lack of candidates seeking jobs in STEM may originate from a growing disinterest in science and math among primary and secondary school students, who increasingly choose not to study or pursue careers in STEM fields. While the total number of students in the 12th year of Australian schooling has increased by 12% from 1992 to 2012, the participation rates for most elective math and science courses have fallen, some by as much as 10%.³ Furthermore, according to the Programme for International Student Assessment (PISA) testing from the Organisation for Economic Co-operation and Development (OECD), Australian students’ mathematics literacy rates have declined since 2000. Although Australia still ranks among the top nations (14th overall for mathematics), countries with similar PISA mathematics average scores in 2000, such as Canada and Switzerland, have experienced a rise in scores since then, making Australia’s decline especially troubling. In Figure 1, Australia’s mathematics literacy scores are compared to a top performing country (Hong Kong), other similarly performing nations, and the OECD average score over time. As shown, Australia’s scores are declining faster than the OECD average.

In Australia, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) is attempting to reverse this negative trend in performance and interest in STEM. As a leading scientific research agency, CSIRO is heavily invested in promoting science and industry throughout Australia, offering numerous programs to promote greater student involvement in STEM. These initiatives range from training teachers to implement hands-on learning in classrooms, to producing a television program that shows children how science can be fun and relevant. In an effort to expand their outreach, CSIRO has implemented a Science Bootcamp to encourage more students to enter STEM fields.

Typically held during school holidays in major cities, secondary school students, age 13 to 18, visit CSIRO campuses over a two-day period, touring laboratories, attending presentations, and completing fun science activities. After two years with over 300 student attendees, CSIRO would like to assess which activities, topics, and interactions students most value in these Science Bootcamps. This information can be used to develop effective Bootcamp activities in the future.

The goal of our project was to help CSIRO increase youth interest in STEM through its Science Bootcamps. This goal was achieved through three objectives: (1) reviewing best practices in STEM education, especially the use of hands-on activities to increase student interest; (2) analyzing existing evaluation data on previous Science Bootcamp activities; and (3) using this information to conceptualize, test, and refine a new set of activities for future Science Bootcamps (Figure 2).

Figure 1. Australian math literacy levels

Figure 2. Project goal and supporting objectives
How to motivate students in STEM Fields

Many enrichment programs have been created with the goal of raising and maintaining students’ interest in STEM. Each of these programs utilizes a unique method to motivate students to pursue STEM fields.

Defining student motivation, interest and engagement

Increasing motivation, or the drive someone has to do something, is the end goal of most enrichment programs. When there’s little time to teach a student about a subject, the magnitude of an educator’s impact can be measured not only in facts and figures students have absorbed, but also in the student’s increased motivation to pursue that subject later. Motivation is, in our case, what drives the student to pursue certain academic and professional paths. It is an important construct in psychology, and many experts have outlined effective methods for motivating individuals, especially with the intention of driving long-term impacts. However, motivating students and measuring this impact can often take impractical lengths of time. It can take months or even years to influence a student’s motivation, and just as long to test for changes in motivation.5

Motivation is interrelated with two other constructs of educational psychology, however, that are easier to achieve and measure: engagement and interest. Engagement is how attentive and involved a student is in the moment of a lesson or activity. Because engagement is defined at a given time, rather than over a span of time, a student’s level of engagement can be determined by observing them for a short duration.6 While this is advantageous for short term programs, a student’s level of engagement is often a poor indicator of long-term motivation.6 Interest is a much better indicator. Interest is how much a student cares about the subject. Interest can be sparked by one well-developed class or activity, or it can be instilled over multiple activities on the topic. One researcher, Deci, has shown that interest can be measured with simple short term surveys—an ideal approach for a short-term program, such as the Science Bootcamps.6 Because this construct is developed in a shorter time frame than motivation, but can have more enduring effects than engagement, it is a primary focus of our bootcamp design. These constructs are further compared in Table 1.

A study by Linnenbrink-Garcia et al. recognized two major categories of student interest: individual and situational interest. They define individual interest as how much one inherently cares about a subject and situational interest as how much an individual cares about a subject at a particular time. If an instructor maintains a student’s situational interest, it can evolve into individual interest.5 One subcategory of situational interest is value-based interest, which occurs when the student thinks the subject relates to their life and is important to know. For example, if an instructor teaches students about structural systems using a spaghetti bridge, they may show how that knowledge applies to real life, such as in the construction of real bridges, as illustrated in Figure 3. A visual representation of how these various types of interest interrelate is shown in Figure 4.

Figure 3. Successful activities demonstrate relevance to real world applications, such as how spaghetti bridge principles mirror real civil engineering principles.

Table 1. Comparison of motivation, engagement, and interest

<table>
<thead>
<tr>
<th></th>
<th>Implementation</th>
<th>Time Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Definition</td>
<td>Methods</td>
</tr>
<tr>
<td>Motivation</td>
<td>The desire or willingness of someone to do something.</td>
<td>Generated when a student is interested in a subject for a long period of time, and becomes invested enough to take action.</td>
</tr>
<tr>
<td>Engagement</td>
<td>How attentive and involved a student is in the moment.</td>
<td>Make a subject seem fun or cool.</td>
</tr>
<tr>
<td>Interest</td>
<td>How much a student cares about a subject.</td>
<td>Make a subject seem fun (short-term) and valuable (intermediate or long-term)</td>
</tr>
</tbody>
</table>
self-confidence and interest in science. This study found 66% of students had high self confidence in Year 4, but only 49% of the same students have high self confidence when tested in Year 8. This trend was also present in the students’ interest in science. 87% of these students were interested in science in Year 4, but only 67% were interested in science in Year 8. Tytler attributes the drop in interest to lower confidence levels with the material and argues for the need for activities to help increase student confidence.8

Ideally, an effective program will create value-based interest and confidence through tangible tasks that students can successfully complete. These tools have already been developed, and are in use today by many successful enrichment programs.

**Pedagogical strategies used to build interest**

There are many pedagogical strategies used to create relevance and increase confidence. Whether implemented in the classroom or as an extracurricular activity, making a program hands-on, inquiry based, cooperative, or competitive can better interest students in STEM fields, and help them understand the importance of STEM in their lives. These attributes are shown in Table 2.

Educators often employ hands-on activities to interest students. To do this, an instructor guides students through an activity that creates personal experiences with real materials to help students gain an understanding of a topic, as opposed to being lectured to about theory.9 Students are often given a better understanding of their potential impact when they are engaged. In particular, “Hands-on learning has been implicated as one of the key factors that can improve a girl’s confidence in the STEM areas.”10 In order for a student to develop interest in subject matter, a student must be confident in their ability to utilize it. One of the most popular hands-on STEM programs in the United States is the FIRST Robotics Competition (FRC). In this program teams of secondary school students design and build their own robots to compete
against each other in various games. Because of the complex nature of a robotics team, FRC produces a culture of cooperation between students interested in business, community outreach, and engineering, allowing the program to demonstrate the relevance and practical side of STEM to a large variety of participants. The impact of FRC has been shown in a study completed by A.G. Welch, who found improved student attitudes towards math and science after participation in FRC. Welch attributes much of this change to the real-world application of science, as well as interaction with FRC mentors.

Inquiry based activities allow students to follow the scientific method to solve open-ended problems, and conduct scientific investigations on their own. Students learn not only the information needed to solve the problem, but they gain a greater appreciation for the value of the process used to obtain scientific findings. Edelson, Douglass, and Roy found that, in order to assess the value of scientific findings, students should inquire for themselves, and produce scientific results. An example of this inquiry-based approach to a STEM enrichment program is the CSIRO CREativity in Science and Technology (CREST) Program, where students pursue their own open-ended scientific investigation. Because “CREST is not a competition but a program which focuses on the individual and encourages success and the development of skills,” a higher emphasis is placed on the scientific process as opposed to end results.

Another proven enrichment strategy to interest students is cooperative learning, which is where students work as a team to accomplish a task or to explore a question. When students are working in a collaborative group, they can each feel the group's appreciation for their contributions, making them feel valued. For example, FRC demonstrates cooperative learning because of the teamwork required to build a robot. Each student contributes to one part of the robot, and they are all reliant on each other to get it done. Each student contributes to the overall success of the project, and as a result the team is able to accomplish lofty objectives in a short amount of time.

Competitive learning is carried out when students compete against one another to best achieve a common goal. While effective, this style must be employed carefully. When used appropriately these activities generate interest and reduce disruptive behavior among students, especially in regards to topics that would otherwise be considered boring. Competitive learning is prominent in successful enrichment programs discussed previously, as well as Worldskills. This organization partners with industry specialists, and provides students an opportunity to train in various technical fields ranging from graphic design to welding. In Worldskills Australia, students compete against each other in various technical fields at state, national, and international competitions, motivating them to master their trades to become the best in the world. Worldskills participants surveys in Australia revealed that involvement in the competitions and hands-on training were viewed by 77% of students as either significantly or critically beneficial to their careers. Because of the competitive nature of this program, it has a lasting impact on students’ interest in a subject.

CSIRO is the leading scientific research organization of Australia and is attempting to integrate these best practices into their Science Bootcamp program.

**CSIRO and the Science Bootcamp**

Originally established by the Federal Government of Australia in 1916, CSIRO has been conducting research in various scientific fields to promote Australian defense, industry, and health (for an extended overview of CSIRO, see Supplemental Materials B). Over the past 30 years, CSIRO has expanded its focus to include the education of future scientists and technical workers through several programs, including the Science Bootcamps. The Science Bootcamp program is targeted for Australian secondary school students ages 13 through 18. The bootcamp is a two day, non-residential program held on CSIRO campuses during school holiday breaks. There are two bootcamps held in each Australian capital city every year. In Science Bootcamps students are introduced to professional scientists, who explain their research and how it impacts the world at large. Students also complete a hands-on activity, where they “undertake various investigations and activities using scientific apparatus and technology.” CSIRO aims to inspire students to pursue STEM by showing them the real working environment of scientists as well as shedding light on the research and problem solving that scientists work on every day.

As a fairly new program—just two years old—the Science Bootcamp currently only employs four activities. These include a gel electrophoresis, a 3D printing activity, an audio amplifier, and a chem-magnetism activity, as described by Carly Siebentritt, the CSIRO National Bootcamp Coordinator. The gel electrophoresis activity allows a student to explore cellular biology, specifically techniques for DNA extraction. The 3D printing activity involves the design and physical testing of more effective 3D printed wind turbine. The other two activities, the phone speaker and ferrofluid, shown in Figure 5, were developed by previous WPI students working with CSIRO. In the activities, students use 3D printing and electrical engineering to build a phone speaker, and magnetic fluids to clean up an oil spill. CSIRO is looking to expand and diversify their program to include more activities, so they can reach more students and foster their interest in STEM.

The literature shows that bolstering interest and building confidence are imperative and may motivate them to pursue STEM in the future. Employing the principles of hands-on work, relevance, inquiry, cooperation, and competition in the design of an activity may help make the activities more interesting to the students completing them. By incorporating these ideas into the design of new Science Bootcamp activities, the team intended to maximize the long-term im-
Students rank the same question on a different numerical scale than other surveys, while others presented the same question in a different way (i.e. a chart to choose topics from instead of an open response question). Overall, all of the surveys had commonly themed questions and asked for the same information, so they could be analyzed together.

The student surveys were distributed and collected at the end of the bootcamp. This section explains analysis and results for 346 student exit surveys from two years of Science Bootcamps.

Student survey research questions

In order to gauge the performance of the main activities and to aid in the improvement of the bootcamp experience, CSIRO intended to use the surveys to answer the following questions:

Questions focused on enjoyment:
- Did students find any of the activities particularly enjoyable or boring?
- Were any of the main activities more or less enjoyable to students than the rest?
- Did enjoyment of the main activities vary by location?
- Did enjoyment of the main activities vary by age?
- Did either gender enjoy any of the main activities more than the other?
- Did gender affect the likelihood of the student returning?

Questions focused on interest:
- Did students report they would like to return?
- Was the type of main activity correlated with students’ reported likelihood of returning to another bootcamp?

Questions useful for future bootcamp design:
- Did the students enjoy the lab tours and presentations?
- What topics did students want to see in future bootcamps?

Student survey items

The surveys asked the age and gender of the student, as well as the location of the bootcamp. CSIRO gauged students’ enjoyment of the activity by including the question in Figure 6(A). They generally rated the main activity of their camp on a scale from Poor (1) to Excellent (6), although some versions used a 1 to 4 numerical scale. The immediate rating of the activity is more likely to represent the short-term engagement than a student’s intention to pursue it further.

Interest was measured by the student’s reported likelihood to return which was on a scale from not likely at all (1) to very likely (7). Wanting to return to the bootcamp implies a desire to pursue these topics further. Examples of the likelihood-to-return question can be seen in Figure 6(B). This data was supplemented by 107 parent surveys. These surveys included a question on the likelihood of the parent to rebook, a measure of the student’s interest as perceived by their parent.

To help see what future content might interest them, students were asked their favorite and least favorite part of the bootcamp (Figures 6C/D). CSIRO also asked for topics that they would like to see in future bootcamps (Figure 6E/F).
### Coding

To analyze the open-ended student responses, the team recorded responses verbatim and then coded them in the manner seen in Figure 7. We developed coding categories based on the actual bootcamp activities (for example “activity”, “lab tour”) and used these to code the responses. We each coded several surveys and refined our approach by comparing results.

Depending on the location and date of the bootcamp, similar closed-ended questions had been recorded on different scales. In order to merge the data, the team linearly scaled the data to make all of the responses on the same scale.

### Findings from student surveys

Our analysis answered eight questions.

#### Were any of the main activities more or less enjoyable than the rest?

CSIRO was interested in determining if students enjoyed the four current activities, and also whether there were any significant differences between the student reported enjoyment of each activity. Overall the ratings for all of the activities were favorable, meaning the students enjoyed them (M=4.94). On the rating scale, 4 was “Good”, 5 was “Very Good”, and 6 was “Excellent.” The 3D printing activities Hochberg adjusted means demonstrated that it was between “Good” and “Very Good” on average, while the phone speaker and magnetic slime activities were between “Very Good” and “Excellent” on average.

A one way ANOVA test (p<0.05) was conducted and revealed that there was a difference in the rating of these activities, F(3,342)=3.06, p=0.03. A post-hoc Hochberg test (p<0.05) showed that magnetic slime (M=5.28) was more enjoyable than gel electrophoresis (M=4.71), but not significantly more enjoyable than the 3D printing activity (M=4.86) or the phone speaker activity (M=5.12). Similarly, the 3D printing activity and the phone speaker activity are not significantly more enjoyable than the gel electrophoresis activity. The Hochberg results are shown in Table 3. The data groupings demonstrate if the means are different or not. If the means are in the same group it shows they are not statistically different. The results show that not all activities are equally enjoyable and that the less enjoyable activities (gel electrophoresis) could be improved.
Table 3. Hochberg distribution for student reported enjoyment of main activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>Mean Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic Slime</td>
<td>5.28</td>
</tr>
<tr>
<td>Phone Speaker</td>
<td>5.12</td>
</tr>
<tr>
<td>3D Printing</td>
<td>4.87</td>
</tr>
<tr>
<td>Gel Electrophoresis</td>
<td>4.71</td>
</tr>
</tbody>
</table>

**Did enjoyment of the main activities vary by location?**

CSIRO was also interested in how the different locations of the bootcamps affected the students’ enjoyment. To determine this, our team used the survey question asking students to rate activities (Figure 6A). The location of each bootcamp was recorded on the surveys and put into our database. We split the dataset in SPSS by the main activity and ran four ANOVA tests of the locations and enjoyment levels (p<0.05). The phone speaker, F(3,69)=0.72, p=0.54, and magnetic slime, F(1,55)=0.002, p=0.96, enjoyment did not vary by location, but we found that the gel electrophoresis (Figure 8), F(4,99)=53, p<0.001, and 3D printing (Figure 9), F(4,107)=17.58, p<0.001, activities both differ. We then ran a post-hoc Hochberg test (p<0.05) which showed that the gel electrophoresis (M=2.54) and 3D printing (M=3.42) activities were significantly less enjoyable at Sydney than they were at other locations, while at Brisbane (M=5.61), the gel electrophoresis activity was as enjoyable as Melbourne (M=5.39) and Canberra (M=5.42), but more enjoyable than at Adelaide (M=4.70) and Sydney. The difference shown between the activities among the locations suggests that either cultural differences among the students in the different cities or the different instructors may play a role in the enjoyment of the activity.

**Did enjoyment of the main activities vary by age?**

To answer this question our group split the data in SPSS by activity, and then ran three ANOVA tests (p<0.05) using the student age as the independent variable and the rating for each activity as the dependent variable. The 3D printing activity had no data for age, so it was excluded from this analysis. While the tests for the gel electrophoresis, F(4,29)=2.24, p=0.09, and magnetic slime, F(5,47)=0.88, p=0.50, had no significant rating differences among different ages, the phone speaker, F(4,68)=2.88, p=0.03, found that students of different ages rated it differently. A post-hoc Hochberg test (p<0.05) showed that 15 year olds (M=5.32) and 14 (M=5.28) years olds, but as much as the 16 (M=4.75) and 12 (M=5.00) year olds as shown in Figure 10.
Does one gender enjoy any of the main activities more than the other?

In order to determine if there was a difference in enjoyment between the genders, the data was split by activity and four T-tests (p<0.05) were conducted. The 3D printing T-test found that there was most likely a difference with, t(57)=-2.15, p=0.004, while the rest of the activities found no difference with the phone speaker, t(34)= -0.96, p=0.95, the gel electrophoresis, t(17)=-0.16, p=0.78, and the magnetic slime, t(8)=0.19, p=0.49. The mean rating for females (M=5.68) for the 3D printing is higher than for the males (M=4.89). This demonstrates that female students generally enjoyed the 3D printing activity more than the male students (Figure 11). There was no significant difference between the genders with regard to their activity rating in the other main activities. The fact 3D printing was enjoyed more by females suggests bootcamp activities that are aimed towards girls should have similar aspects, such as a reliable take home item and strong real world connections to helping people.

Were male students more likely to report being interested in returning than females?

CSIRO was curious as to whether or not the male students were more interested in the subjects taught at the bootcamp than female students. To answer this question, we ran four T-tests (p<0.05), one for each activity. We found that there was no significant differences for any of the activities between gender and the student given likelihood of returning; the phone speaker, t(34)=0.80, p=0.14, the gel electrophoresis, t(17)=-1.16, p=0.22, the 3D printing, t(56)=-1.42, p=0.44, and the magnetic slime, t(8)=-0.24, p=0.37.

Did the activity affect the student’s likelihood of returning?

Overall, the students did state they were fairly likely to return to the bootcamp program, (M=4.97) out of 7. In our analysis, we used an ANOVA test (p>0.05) to determine if there were any significant differences in reported likelihood to return between students who attended bootcamps running different main activities. We found that there was no significant difference, F(3,340)=1.23, p=0.30, between activity and the student given likelihood of returning. This suggests that the interest generated in STEM by the bootcamp is independent of which of the main activities they did.

What did the students think of the lab tours and presentations?

CSIRO was also interested in what segment of the day the students most enjoyed, such as the main activity, lab tours, research presentations by CSIRO researchers, or other minor activities. To answer this, we used the open-ended survey question that explicitly asked the students about their favorite part of the bootcamp. We calculated the frequency with which each of the categories were mentioned. Students most often stated that they most enjoyed the main activity, followed by lab tours, as shown in Figure 12. Out of the 346 students who took the survey, 141 stated they enjoyed the main activity the most, followed by 70 stating they enjoyed the lab tours the most.

CSIRO also inquired about the student’s least favorite part of the day. This was coded in a similar manner as responses to their favorite part of the day. The most common least favorite response was the research presentations with 87 responses, followed by lab tours with 58 (Figure 13).
was to the students:
- Did any of the main activities have a high or lower likelihood of the parent rebooking?
- What did parents most often state as the most worthwhile aspect of the bootcamp?

**Parent survey items**

The parent surveys recorded the location of the child’s bootcamp and information on how worthwhile the parent felt the bootcamp was. CSIRO asked the parents to rate how strongly they agree with the statement that they would book another bootcamp again from strongly disagree (1) to strongly agree (7). How strongly the parents agreed with the bootcamp being worthwhile was also asked with the same scale. The parents were then asked what about the bootcamp they saw as the most worthwhile in the form of an open response question. The parent surveys were coded in the same manner as described earlier in the student surveys section.

**Did activity affect parent likelihood of rebooking?**

Overall the data showed that parents were likely to rebook, averaging 4.4 out of 5 without looking at a specific activity. In order to determine if an activity had an effect on the likelihood of the parent rebooking, we ran an ANOVA test (p<0.05) on the given likelihood of the parent rebooking split by the main activity that their student did. There was no data recorded for the magnetic slime and slick activity so it was excluded from this analysis. We found that there was no difference, F(2,83)=1.01, p=0.37, in likelihood to rebook between the phone speaker, 3D printing, or gel electrophoresis activities.

**Most worthwhile aspect of the program to the parents**

In the parent survey CSIRO wanted to know what they saw as the most worthwhile aspect of the bootcamp. This coding used the same process as presented previously. The complete list of coding categories for this question and previous ones appear in supplemental material C. As seen in Figure 15, most of the parents that responded felt that the exposure to science was the most worthwhile part of the bootcamp, followed by their children being able to socialize with other students that have similar interests.

**Takeaways for the development of activities**

Our analysis also validated our third objective, to make new hands-on bootcamp activities, as we found that they were by far the favorite part of the bootcamp program. Overall, the Science Bootcamps are performing well and are generally well received by
students. Lab tours and researcher presentations were enjoyed by students—one of CSIRO’s most important goals. It revealed the most desired activity topics, which we kept in mind when designing new activities. It also brought to our attention that the hands-on nature of the activities, having a consistently functional take home item, and relating the activity to helping others helps to engage females, as shown specifically in the enjoyment of the 3D printing activity. The information gathered was helpful in guiding the team’s planning of new bootcamp activities. For a full description of the outcomes of the analyses, see Supplemental Material D.

**Design and development of bootcamp activities**

The third objective of this project was to design and develop two new Science Bootcamp activities to pique Australian students’ interest in science and technology, while emphasizing the scientific research of CSIRO. We chose topics for the activities highlighted by students in the post-bootcamp surveys, namely astronomy, chemistry, and biology, and brainstormed possible activities. We analyzed these using a decision matrix, allowing us to rank each activity by seven criteria, as shown in Figure 16. The full matrix is available in Supplemental Materials E.

The team took the six highest ranked activities and discussed their potential with CSIRO educational experts. The pros and cons of each activity are shown in Table 4. This discussion narrowed down the activities to the toothpaste and do-it-yourself electrocardiogram activities. We also introduced a spacecraft design activity, as the experts wanted to publicize CSIRO’s astronomy accomplishments. The team initially developed the make-your-own toothpaste activity, but due to unenthusiastic tester response, decided to leave it for a future group to finish developing.

**Table 4. Reasons for and against each activity concept.**

<table>
<thead>
<tr>
<th>Activity Selection</th>
<th>For</th>
<th>Against</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromatography</td>
<td></td>
<td>• Potentially boring</td>
</tr>
<tr>
<td>Are you a detective?</td>
<td></td>
<td>• Too much waiting</td>
</tr>
<tr>
<td>Make your own toothpaste</td>
<td></td>
<td>• Not enough activity material</td>
</tr>
<tr>
<td>Telescope</td>
<td></td>
<td>• Design based</td>
</tr>
<tr>
<td>Homopolar Motor</td>
<td></td>
<td>• Relatable to Chemistry</td>
</tr>
<tr>
<td>Magnetogravity</td>
<td></td>
<td>• Physics related</td>
</tr>
<tr>
<td>Magnetogravity</td>
<td></td>
<td>• Slingshot related</td>
</tr>
<tr>
<td>Water bottle rocket</td>
<td></td>
<td>• Too similar to younger student's activities</td>
</tr>
<tr>
<td>Do it Yourself</td>
<td></td>
<td>• Electrocardiogram</td>
</tr>
<tr>
<td>Electrocardiogram</td>
<td></td>
<td>• Biology Related</td>
</tr>
</tbody>
</table>

**Design process**

Once the two Science Bootcamp activities were selected, the team iteratively tested and developed them. A visual representation of our methods can be seen in Figure 17. From the start, we built in teamwork and hands-on features, using pedagogical strategies discussed previously. We conducted pretesting ourselves and did additional testing with other students, refining the activity templates and instructions further. Finally, upon speaking with CSIRO educational experts, the team redesigned some activity aspects.

**Preliminary design: Astronomy activity**

The astronomy activity incorporates interest-generating aspects of hands-on activities, such as elements of inquiry-based, competitive, and cooperative learning. In this activity, students design and
build their own spacecraft, then test it to determine if it would survive the tribulations of space travel. This can easily be related to CSIRO’s extensive research in deep space observations and communication assistance during the lunar landings.

The team began by considering different tests the completed spacecraft could undergo, which would provide design criteria. During each of the tests the spacecraft contains an egg, representing the astronaut, and each test represents different challenges in space travel (Table 5).

The team also determined appropriate materials for the construction of the spacecraft. We chose inexpensive household materials such as cardboard, as well as more specialized materials such as gasket tape. A complete list of the spacecraft build materials can be found in Supplemental Materials F.

**Preliminary Design: ECG activity**

The electrocardiogram (ECG) activity provided a topic that many students had expressed interest in (biology), as well as insight into a technology that has relevance in many students’ lives—as most have been in a hospital either for themselves or a relative. The students build an electrocardiogram—a device that monitors electrical signals from the heart—and use it to explore biosignals and cardiovascular health.

The team began by designing a basic and inexpensive electrocardiogram amplifier circuit to amplify the difference in electrical voltage across an individual’s forearm. The design utilizes a headphone jack connection plugged into a computer and analyzes the signal using an audio recording software. The completed initial design can be found in Supplemental Materials G. After some troubleshooting and redesign, the team successfully built the electrocardiogram. An image of testing is shown in Figure 18.

We created student instructions to construct the ECG, making breadboard images—pictures of what the actual circuit should look like (Figure 19). These images were then compiled into a document with assembly instructions. Then, we developed an activity sheet that outlined ways to explore how the body’s actions affected the displayed heartbeat.

**Table 5. Summary of proposed spacecraft student tests**

<table>
<thead>
<tr>
<th>Test</th>
<th>Astronomy Activity Possible Tests</th>
<th>Procedure</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamics</td>
<td>Spacecraft must be aerodynamic to escape the atmosphere efficiently.</td>
<td>Place the spacecraft on a cart in front of a fan. The less it moves, the more aerodynamic it is.</td>
<td>Fan, Cart</td>
</tr>
<tr>
<td>Impact</td>
<td>Spacecraft must be durable in case of a hard landing.</td>
<td>Drop the spacecraft from a high place. If the egg breaks, it is not impact resistant.</td>
<td>Stepladder</td>
</tr>
<tr>
<td>Heat</td>
<td>Spacecraft must be resistant to heat because of the heat caused during reentry into earth’s atmosphere.</td>
<td>Aim a heat gun at the spacecraft. If a thermal sensor on the egg changes color, the heat shielding fails.</td>
<td>Heat gun, thermal sensors</td>
</tr>
<tr>
<td>Air-tight</td>
<td>Spacecraft must be airtight to preserve oxygen in the vacuum of space.</td>
<td>Submerge the spacecraft in water. If a paper towel wrapped around the egg is wet after submersion, the test is failed</td>
<td>Container filled with water</td>
</tr>
<tr>
<td>Dust</td>
<td>Spacecraft must keep out dust because of the abundant dust on other planets.</td>
<td>Weigh the spacecraft. Place the spacecraft in the sand-filled container and shake. Remove the craft and weigh it. If the spacecraft weighs more, the test is failed.</td>
<td>Large plastic container, sand, scale</td>
</tr>
</tbody>
</table>
Preliminary self-testing

Our own pre-test of the ECG and spacecraft activities was completed to ensure the activities could be done in the allotted time with the provided materials. We used a general guideline of two-and-a-half hours to pre-test the building of the prototype spacecraft. Each member sketched a design, built the physical model, and tested their models (Figure 20). The results from the self-test can be seen in Table 6.

Given the successful pre-test, we then created a student worksheet outlining the various tests that the spacecraft would undergo and providing space for the student to sketch a preliminary design. The team decided that the students would be allowed to purchase the materials they desire from a shop. They would receive a fictional budget of $1,000, and the cost of the materials was scaled so that this was the equivalent of 8 AUD.

Self-testing of the ECG activity was completed during the preliminary design period. Portions of the activity were completed individually and team members reviewed them as progress was made. The team focused on the clarity of the instructions, so students could complete the construction in a reasonable amount of time. Results are shown in Table 7.

Table 6. Results and revisions from astronomy activity self-test

<table>
<thead>
<tr>
<th>Testing Success rate</th>
<th>Drop-test</th>
<th>Aerodynamics</th>
<th>Heat Resistance</th>
<th>Air Tight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3/4</td>
<td>4/4</td>
<td>4/4</td>
<td>1/4</td>
</tr>
<tr>
<td>Price</td>
<td>Target: $15.00 per student</td>
<td>Actual: Average $8.00 per student</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confusion</td>
<td>•The amount of materials necessary for building a spacecraft was unknown (i.e. how much should be allowed in later testing).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>•Some participants took too long to build their spacecraft.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revisions</td>
<td>•The team measured materials used for the spacecraft to establish a ballpark estimate of materials students would use. A budget system was established and students are now given a &quot;budget&quot; and have access to a &quot;shop&quot; for materials.</td>
<td>•The order of the tests was changed to make water test last to preserve spacecraft as long as possible.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7. ECG self-testing results

<table>
<thead>
<tr>
<th>Time</th>
<th>Target: 4 hours: 2 building, 2 testing</th>
<th>Several hours (untimed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>Target: $15.00 per student</td>
<td>Actual: $14.90</td>
</tr>
<tr>
<td>Success Rate</td>
<td>2 functional ECGs were created</td>
<td></td>
</tr>
<tr>
<td>Confusion</td>
<td>•Schematic of circuit was too complicated for the age group without a lot of guidance.</td>
<td>•Issues occurred when trying to make it work on different computers.</td>
</tr>
<tr>
<td>Observations</td>
<td>•ECG could be built on the breadboard used for phone speaker, but needed to be planned carefully.</td>
<td>•ECG could also be used as EMG (electromyogram, tracks muscular electrical signals) to diversify inquiry questions.</td>
</tr>
<tr>
<td></td>
<td>•A free audio editing software worked well with the signal.</td>
<td>•Two batteries may be too high a voltage to be safe.</td>
</tr>
<tr>
<td></td>
<td>•Step-by-step instructions were created with visuals to walk the student through the construction.</td>
<td>•Step-by-step instructions were created with visuals to walk the student through the construction.</td>
</tr>
<tr>
<td></td>
<td>•A single battery design was implemented.</td>
<td>•A single battery design was implemented.</td>
</tr>
<tr>
<td></td>
<td>•Diodes were added as a safety feature between outputs.</td>
<td>•Diodes were added as a safety feature between outputs.</td>
</tr>
</tbody>
</table>

Figure 20. Spacecraft prototypes from self-test
This self-testing guided the development of the instructional material and improved how the device would be built. In addition, the observations helped the team to improve the flow of the post-construction activities.

**Peer testing**

In order to gain a better understanding of how the activities would fare in a real Science Bootcamp environment, the activities were tested with our peers from Worcester Polytechnic Institute. The team utilized an observation sheet (Figure 21) to organize notes as the activity progressed. Images of peer testing appear in Supplemental Materials H.

**Spacecraft**

The results from peer testing are summarized in Table 8. The completed spacecraft are shown in Figure 22. The peer testing suggested that the activities were enjoyable and could be completed on time with the appropriate materials, but it also highlighted necessary improvements such as clarifying instructions.

**ECG**

Two WPI peers, and one year 10 Australian student, tested this activity. Each student built a working ECG within the time constraints. The results from the peer testing are in Table 9 and a student completing the project with his ECG output can be seen in Figure 23.

While the team had prepared worksheets for post construction activities, they were not tested because we lacked the materials. However, the students enjoyed building the device and the year 10 student managed to operate his circuit as an EMG, detecting the muscle contractions in his forearm. The team used this feedback to make the instructions clearer.

---

**Table 8. Results and revisions from peer testing the astronomy activity**

<table>
<thead>
<tr>
<th>Time</th>
<th>Target: 3 hours: 2 building, 1 testing</th>
<th>Actual: 3 hours: 2 building, 1 testing (one student finished building early by 1 hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing Success rate</td>
<td>Drop-test</td>
<td>Aerodynamics</td>
</tr>
<tr>
<td>2/3</td>
<td>3/3</td>
<td>3/3</td>
</tr>
</tbody>
</table>

Confusion
- Questions were asked early about design parameters, materials, and testing.
- The instructional materials were not always clear regarding procedures in these areas.
- Tests were not fully defined in the handouts.

Observations
- Activities were completed within the time limits.
- One student failed two of the tests (but rushed through the build stage).
- Two other students failed one test each.

Revisions
- More detail was added to the written instructions, including information on the design parameters, materials, and pre-testing.
- The presentation was edited to better convey the format of the activity.

---

**Figure 21. Observation sheet used for peer testing**

**Figure 22. Prototypes spacecraft from WPI peers**
Specialist review of activities

After revisions were made based on the self and peer testing, completed materials were presented to an educational specialist for review of feasibility and clarity.

Astronomy

When the instructions were reviewed, it was determined that they were too structured for secondary school students. The educational specialist suggested the testing be revised, so the students design the tests themselves in a more inquiry-based style. Long wait times were a concern due to the large class size and were reduced by using multiple testing stations.

ECG

The educational specialist completed the ECG with the step-by-step instructions to identify any issues. Observations, results, and revisions can be seen in Table 10.

<table>
<thead>
<tr>
<th>Time</th>
<th>Target: 3 hours: 2 building, 1 testing</th>
<th>Actual: 2 hours, build only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success Rate</td>
<td>3/3 built a functional ECG</td>
<td></td>
</tr>
</tbody>
</table>
| Confusion | • There were mistakes in the circuit diagram.  
• Circuits did not work immediately.  
• One student could not get her biosignal to show up. |
| Observations | • Students enjoyed creating the ECG.  
• Worked consistently when troubleshooting complete.  
• Signal easily seen without extra filtering in the software. |
| Revisions | • Troubleshooting guide was created for students to walk through issues on their own.  
• Pictures in instructions were edited to fix color errors, and to match the questions more. |

<table>
<thead>
<tr>
<th>Time</th>
<th>Target: 2 hours</th>
<th>Actual: 45 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success rate</td>
<td>1/1 Participant built a working ECG</td>
<td></td>
</tr>
</tbody>
</table>
| Confusion | • Pointed out issues with there being too many instructions per step.  
• Discovered holes in the instructions.  
• Missing Feedback wire instructions.  
• Some pictures were still incorrect.  
• Signal was not detected on educational specialist, but it was on team member. |
| Observations | • Instructor troubleshooting guide needed.  
• Missed some instructions due to paragraph structure.  
• Math took longer than expected.  
• Instructor built it correctly on the first try. |
| Revisions | • Student instructional material updated.  
• An instructors guide was created to help students quickly with common problems.  
• Changed resistor values so that anyone’s heartbeat would appear. |
Final outcomes

The revised astronomy activity focuses on CSIRO’s role in astronomy and space exploration. The four-hour activity begins with a short presentation, followed by a design and build phase, then a testing phase. Students are introduced to requirements for a real spacecraft, and must budget resources to build a spacecraft that meets these criteria. The students create their own tests with given materials and discuss if their tests were representative of what is required of actual spacecraft. Supplemental activities were included for the students to perform during downtime between testing phases.

During the ECG activity, the basic concepts behind the nervous and cardiovascular systems are explained, including how signals are produced and how medical devices can detect these signals, to learn more about health and the body. CSIRO has done research on these biosignals, as seen in the development of techniques for interpreting EEG and ECG signals to replace more invasive procedures. The students build and then test an ECG with questions to familiarize them with the device, later conducting their own experiments.

The activities required specific deliverables, described in Table 11, which include an activity template (Figure 24), presentations (Figure 25 and 26), student handouts, (Figure 27 and 28) and information for CSIRO to reformat into take home notes. The full deliverables can be found in Supplemental Materials sections I through K for the spacecraft activity and L through N for the ECG. These deliverables will enable the activities to be run at the bootcamps with minimal adjustments from the CSIRO educational experts. Like all educational programs, they will likely require revision after the first full-scale implementation.

Figure 24. Outline of Astronomy Science Bootcamp from the activity template

Figure 25. Astronomy presentation slides about CSIRO’s radio telescopes and spacecraft criteria
<table>
<thead>
<tr>
<th>Deliverable</th>
<th>What is in it</th>
<th>Who it is for</th>
<th>Focus For Astronomy Activity</th>
<th>Focus for ECG Activity</th>
</tr>
</thead>
</table>
| Template       | • Activity Overview  
• Activity Timeline  
• Risk Assessment  
• Instructor Notes  
• Material List with suppliers and prices | Instructor             | • Testing logistics  
• Supplemental activities for downtime                           | • Circuit construction procedures  
• Relevant concepts to student                                                          |
| Presentations  | • Background on topic  
• Connections to CSIRO Research  
• Introduction to Activity | Instructor to deliver to student | • Space exploration  
• Radio Telescopes  
• Materials used in spacecraft  
• Spacecraft Conditions                  | • Nervous system and biosignals  
• Medical equipment  
• Electrical components on the ECG                                                  |
| Student Handouts | • Instructions for activity  
• Space to design tests/experiment    | Student                | • Material list for the spacecraft  
• Budget sheet  
• What each test represents for a spacecraft                              | • Instructions for building ECG  
• Troubleshooting guide  
• Experiment sheet                                                               |
| Take Home Notes | • Additional information on topic  
• Additional activities  
• CSIRO Stories (more connections)   | Student                | • How space is explored from Earth  
• More tests for spacecraft  
• DIY telescope activity            | • Research involving CSIRO and Biosignals  
• Additional ECG investigation  
• Heartbeat activity                                    |
CSIRO and Telehealth

Figure 26. ECG Slide about CSIRO’s home care development

Recommendations and Conclusions

To aid in future development of the CSIRO Science bootcamp program, we suggest the following:

- **Assessment**: Standardize surveys to simplify data analysis. Additionally, modify survey questions to focus on changes in student interest, rather than enjoyment (See Supplemental Materials O).

- **Long-term impact**: Provide students with resources on how to get involved with longer-term STEM education programs or organizations like robotics teams, math Olympiads, or other after-school programs to encourage pursuit of future studies and careers.

- **Activity Development**: Test the activities with other WPI students, or Australian secondary school students earlier in the timeline of development to allow for more iterations based on participant feedback.

In the process of researching science instruction methods, analyzing previous bootcamp survey data, and developing new activities, we learned to effectively meet deadlines as a group. Our activities will be implemented and further refined by CSIRO educational experts during their upcoming Science Bootcamp programs. We hope that the interest students develop will encourage them to continue their education in STEM fields.

Acknowledgements

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References


