ENGAGING SCHOOL STUDENTS AND EDUCATORS WITH THE PRACTICE OF STATISTICS

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ABSTRACT

This paper describes a national statistics-oriented project-based learning activity, which has been delivered annually for five years in Australia and the outcomes of a particular collaboration of this initiative with the discipline of environmental sustainability. The national initiative engages primary- and secondary-school students from varied backgrounds and education levels in quantitative-based investigations. It develops key future workplace skills aligned with national school-curriculum outcomes and motivates students by enabling them to take the lead, determine the context, collaborate, investigate, and create. An underlying delivery model connects primary- and secondary-school students with tertiary educators, industry, and the practice of statistics. A pre-post cross-sectional study revealed significant improvements in students' and teachers' confidence with, and awareness of, the field of statistics. Australian school teachers are saying, "21st Century learning at its best" and "motivates and engages students." Industry mentors are saying, "provides students a unique opportunity." Students are saying, "engaging, educational and enjoyable." The activity has engaged some eighty schools, and annually several hundred students participate.

Keywords: Statistics education; National statistics program; STEM education

1. BACKGROUND AND CONTEXT

1.1 INTRODUCTION

Some three to four decades ago, one in three Australian jobs was in manufacturing, mining or agriculture. This number has reduced to one in ten, and predictions identify some 75% of the fastest growing occupations require significant science and mathematics training (Becker & Park, 2011) and more broadly STEM (Science, Technology, Engineering and Mathematics) skills (PwC, 2015). Further, internationally, reports identify the need for practical statistical expertise and the relative shortfall of adequately skilled individuals for the Big Data age (Manyika et al., 2011; Puang-Ngern, Bilgin, Kyng, 2017; Kyng, Bilgin, & Puang-Ngern, 2016). Such figures require an increasing number of students to engage with and become interested in the analytical, statistical and machine learning aspects needed to fill the growing need for such Big Data skills.

Research has revealed secondary school mathematics and science courses taken, the level of those courses, and interest or confidence in STEM at primary and secondary school predict

postsecondary (higher education) STEM success for students, and that students are forming career interests at an early stage of their schooling – as early as Grade 7 and 5 (Gore et al., 2017; Hinojosa et al., 2016); for the latter, students are 9-10 years of age. Further, immersion in activities alone is inadequate; the quality of the engagement and surrounding support is critical (Reynolds, Howley, Southgate, & Brown, 2016).

Early appreciation of, and engagement with, statistics is currently less than desired. The perceptions and general appeal of statistics, particularly for less quantitatively-minded students, requires educational techniques to enthuse students, maintain their interest and overcome initial hurdles to gain their interest or engagement (Howley, 2008). Statistical anxiety is a recognised impediment, deterring young people to access and succeed in university degrees (Onwuegbuzie & Wilson, 2003; Williams, 2010) and one that seems to particularly affect females and students from diverse backgrounds (Bui & Alfaro, 2011; Onwuegbuzie & Wilson, 2003). Early intervention for improving aspirations and pathways towards STEM and statistics disciplines and success within university for these cohorts is crucial, particularly for students with low socio-economic status (SES) backgrounds (Tai, Qi, Maltese, & Fan 2006; Barnett, 2011; Maltese & Tai, 2010). Mathematical and statistical unpreparedness is a major factor affecting entry to and persistence in the STEM disciplines for students from low SES regions and culturally diverse backgrounds (Bonous-Hammarth, 2000; Clewell, Anderson, & Thorpe, 1992; May & Chubin, 2003). However, despite this research, and the proliferation of resources to teach *mathematics* available through digital media and the internet, data worldwide shows that *statistics* is still considered a significant roadblock for many students (Bell, 2003; Petocz et al., 2007).

Australia's former Chief Scientist commented that "when they do study them (the sciences) at school … the best way to teach inspirationally is to teach it the way it's practised." (Chubb, 2015). However, school teachers have rarely if ever experienced statistics in practice. Nor do they understand the diverse nature and wide reach of statistical thinking, techniques and applications. Teachers' knowledge about the practicing statistician is at best limited, their focus has been on the many other topics and aspects of teaching. The teaching of statistics in secondary school focusses on the theory or mechanics, rather than its practical applications, with statistics topics taught in a manner not clearly part of a coherent whole. The relevance of the discipline of statistics to areas of interest is lost, or at best unclear, for students; yet relevance is such a powerful motivator (Kember, Ho, & Hong, 2008; Howley, 2008).

As Tukey famously observed, statisticians "get to play in everyone's backyard". It is this diversity and boundless potential to contribute and collaborate in and across all fields, coupled with the associated creativity and empowerment the profession engenders, which provides many a statistician a sense of infinite opportunity and fulfilment. One of the more striking aspects however, is the gap between this reality and the perception of statistics held by school students who are exposed to the more descriptive nature, and mathematical undertones, of statistics. The more broadly appealing creative, investigative and collaborative aspects of statistics are often lost.

1.2 THE NATIONAL POSTER COMPETITION (NSPC): 'X+STATS'

The National Schools' Poster Competition (NSPC), delivered annually in Australia, involves teams of 2 to 5 school students undertaking a small-scale real-world investigation and ultimately presenting their investigation in a poster format, akin to conference poster presentations known to academics and researchers. The initiative engages students from all disciplines and taps into their interests, allowing students to 'take the lead' and determine the topic and investigation, from *any field* (the *X* in *'X + STATS'*), demonstrating the interdisciplinary nature of investigations as Tukey noted. The activity utilises the collection, presentation and interpretation of data and maps to National and State Boards of Studies curriculum outcomes including but not limited to 'Data Collection and Representation', 'Single Variable Data Analysis' and 'Bivariate Data Analysis'. Significantly, the model, structure,

resources and content for the national schools poster competition provides teachers the instruction, connection and support to enable achievement of each and all of the national curriculum's general capabilities, whilst enriching the teaching of the key topics in statistics through the practical and holistic focus.

In 2014, the competition was piloted in the Hunter Region, an area within the State of New South Wales (NSW), Australia, where The University of Newcastle is located. Several secondary schools participated, of which 86 students from across 5 schools completed the activity by the due date and submitted some 32 poster submissions. In 2015 the competition expanded to connect a national audience, engaging some 19 schools across six of the eight Australian States and Territories, with 224 students participating. Following requests from primary schools to be able to participate, the NSPC expanded again in 2016 to accommodate this audience, resulting in 28 schools and 828 students participating. Annually, there are five divisions representing school Stages 2 to 6 (corresponding with Grades 3-4 to 11-12, students aged 8 to 18), with small cash prizes ($50 to $200) awarded to winning teams and schools. Example submissions are available at www.ssaipostercomp.info/winners.html.

Winners from the Stages 5 and 6 Divisions may be forwarded to the biennial International Statistical Literacy Project competition, with which the NSPC is aligned albeit with some key distinctions. One of the unique aspects of the Australian national competition is the strategy of building a network of mentors to attend or otherwise interact with schools to facilitate the activity's delivery and engage students with discussions of the practical importance of statistics. With an increased number of out-of-field teachers in secondary schools, and the ever-increasing demands upon teachers, providing mentors and support mechanisms contributes to the competition's success.

Mentors are trained and supported nationally, guided by the national coordinator and the resources he has produced surrounding how to engage teachers and students and facilitate the activity. Mentors include undergraduates with experience in statistics, pre-service mathematics teachers, current and retired industry practitioners, academics, and practicing professionals.

Additional resources were created to support the delivery of the activity. These include:

i. A platform with resources such as short animated videos introducing introductory statistics topics along with online tests and additional links (Stats Tune Up, n.d.);
ii. several short videos of experts from across aviation, logistics, health, and other fields identifying the practical importance of statistics in their fields; and
iii. short videos of how to deliver the activity, the rationale, and testimonials of participants.

The above combined resulted in the NSPC winning the International Statistical Institute's 2017 Best Cooperative Project Award.

2. METHODS

2.1 SUSTAINABILITY MEETS STATISTICS

An initiative which combined the NSPC with the field of environmental sustainability and STEM more broadly was conducted in 2017, supported by the Commonwealth Government's Higher Education Participation and Partnerships Programme. It aimed to engage students and teachers with innovative and industry-oriented practice, and assist those from remote, rural and regional areas to connect with, and aspire to higher education based on a trajectory of increased STEM-oriented interests, particularly interests in, and awareness and appreciation of, statistics. The initiative sought to support Stage 2 to 6 teachers in remote, rural and regional NSW locations to actively engage students with authentic learning opportunities integrating sustainability, statistics and STEM concepts via fun, educational and interactive project-based learning workshops drawing upon the successes of experienced tertiary educators and practitioners.

The project included the combined services and involvement of academics across three principal fields of focus (statistics, environmental sustainability, indigenous peoples) as well as a project officer and assistant. The authors, project officer and assistant (the team) travelled by road to four remote and rural areas of the NSW across a fortnight, visiting schools and delivering hands-on interactive teacher professional development workshops and student workshops as part of the equity-oriented project. At each of four towns the team attended a secondary school (audiences of Grade 7-10 students) and a primary school (audiences of Grades 3-6 students) for an hour each, along with hosting an evening 2-hour teacher professional development workshop (accredited with the NSW Educational Standards Authority so attending teachers would receive formal recognition of participating in professional development activities; an annual requirement of their service). Teacher workshops were hosted at RSL clubs or other halls, each accommodating up to 25 teachers coming from as far as 2 hours away to attend.

At each workshop, the team provided a brief background of their practical work in environmental science and sustainability and the world of the practicing statistician. Presentations began by challenging the audience to describe the working life of a statistician and then provided examples that demonstrated the practical importance of statistics and related existing content taught within schools to practice. Examples of the latter included modelling human features (length of body parts) in forensic anthropology to predict people's sex and heights (Howley, Howley, & Oxenham, 2018), and thus using statistical techniques akin to the line of best fit taught in schools. Further examples of such real-world investigations included the designing, conducting and analysis of clinical trials for new medicines, highlighting the decision-making therein regarding the number of people to test and the interdisciplinary and collaborative nature of the working life of statisticians.

Statistics was further connected with environmental science and renewable energies via discussions around i. electric vehicles, and building mini electric vehicles by choosing the optimal set of wheels (size and number), appropriate numbers and angles of solar panels, and so forth, from a kit (See Figure 1) for greatest speed and endurance; ii. mushroom kits and plant growth, considering the effects of varying sunlight and water, and thus connecting aspects of "the 3Rs" (Howley, 2003) of statistical experimental design; and iii. predictive modelling surrounding whale and other animal life populations, tapping into the altruistic nature of many students.

These, along with reflections about pizza (why is it that we can buy the same type of pizza from the same location on multiple occasions yet like it less on some occasions than on other occasions?) ultimately connecting with statistical process and quality control and six-sigma concepts, were some of the core activities and discussions within this cross-disciplinary workshop on environmental sustainability, statistics and STEM.

Figure 1. Items within the mini electric-vehicle (EV) kit and an example mini EV

This was complemented by a discussion more generally around industry and broader real-world investigations and ultimately the NSPC as an opportunity to engage students with statistics and develop core skills needed in higher education and the workplace. The associated support resources were also discussed. Teachers and schools were provided mini EV kits as inspiration for possible investigations within the NSPC, and teachers created and tested their own mini EV from the kit within 30 minutes during the teacher workshop as further impetus.

2.2 RESEARCH GOALS

The initiative was designed to support Stages 2 to 6 teachers (Grades 3 to 12) in remote, rural and regional areas to actively engage students with authentic learning opportunities integrating sustainability, statistics & STEM concepts. In particular, to introduce such concepts to school teachers and young audiences from low SES culturally diverse and remotely-located schools in a fun, educational and interactive manner via a project-based learning activity. It aimed to encourage and inspire:

- young minds towards increased: interest in investigations surrounding environmental sustainability or any field of interest incorporating statistical and quantitative aspects; confidence in being able to contribute to the development of scientifically-rigorous pursuits (student voice); appeal of such scientific activity and the surrounding disciplines of statistics, sustainability and the sciences; feelings of such being accessible as a pursuit;
- teachers towards an increased: understanding of the role of statistics and STEM in practice, and how to incorporate statistics within teaching the syllabus; feeling of support from and connection with higher education institutions.

2.3 SURVEY INSTRUMENT

Online anonymous surveys of students and teachers (UON ethics approval: H-2017-0090) were conducted prior to our visit and again several months after our visit, to assess the effect of the initiative. The surveys consisted of a series of statements surrounding attitudes, interests and perceptions of statistics, to which students or teachers indicated their level of agreement on a seven-point Likert scale (1 very strongly disagree, 2 strongly disagree, 3 disagree, 4 neutral, 5 agree, 6 strongly agree, 7 very strongly agree).

3. RESULTS

The project involved 85 teachers and principals from 26 schools across four remote NSW locations (Broken Hill, Dubbo, Griffith, Orange) and surrounding areas, having a combined total of 10,702 students (423 indigenous), of which 435 interacted directly with the project team members during school visits. From the cross-sectional study we had 71 students respond to the pre-workshop (pre-intervention) survey and 84 the post-intervention survey, whilst 34 teachers responded to the pre- and 29 the post-intervention surveys. Tables 1 and 2 list key items and the mean (and standard error) responses for the teachers and students respectively.

Across all dimensions tested, both students and teachers responded more positively after the project than before. Prior to the workshops, mean scores were neutral at best across both the teacher and student cohorts. Teachers demonstrated particularly low mean scores pre-activity surrounding feelings of being supported by tertiary (higher education or post-secondary) institutions, student enthusiasm and confidence in connecting students with valuable practice. Students similarly indicated disagreement on average regarding awareness of statistics in practice and desires to be involved in statistical projects, and strong disagreement on average surrounding interest and enjoyment in Statistics.

Table 1. Teacher mean responses pre- and post-intervention

ITEM	Mean_Pre	SE	Mean_Post	SE	DIFF %
I feel well-supported by Universities for developing Statistics activities	3.06	0.29	5.18	0.22	69.1
I feel well-supported by Universities for developing STEM activities	3.13	0.29	5.14	0.22	64.6
I feel able to connect with Universities to pursue innovative collaborations	3.25	0.32	5.21	0.24	60.2
I feel confident in connecting students with valuable and practical examples of careers in Statistics	3.39	0.58	5.14	0.23	51.4
I can see how I can combine Statistics with Environmental Sustainability projects	3.72	0.64	5.59	0.17	50.2
Students are enthusiastic about Statistics	3.09	0.53	4.59	0.25	48.4
I can see how Statistics and Environmental Sciences are valuable to one another	4.56	0.78	5.93	0.17	30.0
I feel confident in connecting students with valuable, practical examples of Statistics	4.09	0.70	5.24	0.20	28.0
Statistics is an important part of Scientific Investigations	5.09	0.87	6.10	0.21	19.8

Table 2. Student mean responses pre- and post-intervention

ITEM	Mean_Pre	SE	Mean_Post	SE	DIFF %
I am involved, or have recently been involved, in projects focussed on Statistics	2.50	0.19	4.96	0.24	99
I enjoy learning about Statistics	2.57	0.20	5.00	0.22	94
I am aware of careers (or jobs) in Statistics	2.30	0.18	4.40	0.22	91
I find Statistics interesting	2.87	0.22	5.16	0.21	80
I am aware of how Statistics is used in the workplace to support investigations	2.91	0.23	4.95	0.21	70
I can see how I can combine Statistics with Environmental Sustainability projects	3.00	0.21	4.79	0.19	60
Statistics is very useful	3.68	0.24	5.70	0.17	55
I would like to be involved in projects focussed on Statistics in future	3.30	0.20	4.78	0.22	45
I would enjoy, or have enjoyed being involved in a project where I choose the topic and collect data to answer my questions	4.24	0.23	5.54	0.19	30
I feel that people outside my school are interested in my ideas	3.34	0.21	4.31	0.20	29
I would like to learn more about Statistics	4.38	0.23	5.29	0.21	21

Following the workshops, for both the students and teacher cohorts, the changes in attitudes were not simply lesser levels of disagreement or negativity. Rather mean responses changed to being above neutral and agreeing with the statements surrounding feelings of support, awareness of the practice of statistics, and interest and confidence in engaging with statistics.

Teachers reported significantly (both practically and statistically) more positive feelings of connection with and support from Universities with pre-intervention mean responses below neutral and near disagreement (3.1) increasing post-intervention in the order of 60-70% to agreement (5.2). Teacher recognition of the value of statistics, and importantly their confidence in feeling able to connect students with valuable practice both increased; the latter by some 50%, from mean scores below neutral and near disagreement (3.4) to positive agreement (5.1). Teachers also reported an equally valuable increase in the enthusiasm of students towards statistics.

Similarly, student interest and enjoyment in learning about statistics increased by as much as 94%, on average, with mean scores of disagreement and strong disagreement (2.9) significantly improving to positive agreement (5.2). Interestingly, students reflected positive changes, of some 30%, in aspects surrounding student voice and leadership, key points of focus on the initiative. Self-perceived awareness of the value of Statistics rose from a mean below neutral (3.7) to near strong agreement (5.7).

Some of the relative changes, for both teachers and students, weren't as large since the 'pre-intervention' mean scores were already quite high and thus the relative percentage improvement was smaller in magnitude. Importantly even those with higher pre-intervention means increased post intervention.

4. DISCUSSION

The project involved 85 teachers and principals from 26 schools across four distantly located NSW locations, each some 5 to 8 hours of driving away from one another. Teacher and student reflections upon the NSPC were very supportive of its approach, and identified how this competition and the broader initiative importantly fill a void. In 2017, a record 356 poster submissions were received, from some 955 participants, with even more engaging in the activity but not completing in time to submit a poster; the due date is 10 November annually. Since, the annual number of participants have remained strong with 82 different schools competing across the past five years, with about 25 schools and several hundred students in any given year.

The symbiotic aspects of STEM were reflected in an increased appreciation for statistics (usually considered within the M of STEM) and its support of, and combining with, the environmental sciences and electric vehicles (which lies within and across the S, T and E of STEM). This outcome supported one of the key aims, namely, increasing the appeal and accessibility of statistics through increased understanding of its collaborative and pervasive nature and thus demonstrating Tukey's observation regarding statisticians. The integrated nature of STEM is an important aspect, one that needs to be exemplified, and experienced by teachers, since teachers have understandably focussed in the past more so on their respective disciplines. The interdisciplinary and collaborative workplace practice that industry and business personnel experience daily is not one teachers have necessarily experienced, or not to a great level. Nor do teachers necessarily have strong connections with tertiary institutions which may be limited to those academics in the Education Departments within which they have been trained. Thus having practitioners and academics from multidisciplinary fields interacting with, and bringing authentic learning experiences to, teachers and students is invaluable to help bridge this divide.

Such engagement initiatives are important for the discipline of statistics and the predicted future STEM workforce and the associated needed skillset. Connecting students with engaging and inspiring activities, and demonstrating the cross-disciplinary nature of statistics, and its accessibility, is invaluable for increasing interest in our discipline and supporting the growth of

individuals and society as a whole. Doing so early in a person's schooling life is critically important.

This competition, delivered annually in Australia since 2014, is a fun, educational and engaging project-based learning activity that develops students' critical thinking, investigation, collaboration, communication, reporting and creative skills, and their awareness of how statistics, quantitative and scientific skills can help us better understand the world, no matter the field of interest. The activity also demonstrates the importance of having good classroom mentors and support resources.

Relatively speaking, research surrounding STEM engagement activity is an emerging area, and one that is complex given the many factors that may influence, both positively and negatively, students and teachers. The value of this particular project was the relatively focussed pre- and post-intervention survey approach, reducing the chance of other influential factors. Of course, the durability of these positive outcomes and consideration of underlying student and teacher factors are a matter for further research.

Ideally larger numbers of respondents, a more longitudinal paired testing and use of control groups would be preferable to the cross-sectional study. Whilst attempts to do so were employed, including the self-creation of unique anonymous codes by respondents in both pre- and post-intervention surveys via the combination of answers to questions including 'numerical day of month born', 'first two letters of your street address' and 'first two letters of school where you commenced Grade 1', unfortunately too few identifiable repeat respondents occurred. Further the respondents were only those who participated, despite requesting teachers provide the surveys to both those who did and those who did not participate in the workshops and associated competition.

Interacting with teachers, understanding their needs and supporting them is a valuable pursuit for the education system and for the discipline of statistics which rarely is taught in an inspirational manner. An arm's length approach of expecting primary and secondary teachers to upskill alone to the point of piquing students' interests in statistics and driving students to further studies in the discipline is fraught. Activities such as the NSPC are designed to foster collaboration, critical thinking, and creativity and overcome misperceptions surrounding the field of statistics. The challenge is to ensure that it is not left to the few to continue this charge, rather that all recognise the supply chain is only as strong as its weakest link and thus unite in this charge towards addressing the needs of the STEM workforce in the Data Age.

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