SMART GIRLS KNOW HOW TO USE A SCREWDRIVER

Kate F. Wilson[a] and David J. Low[b]

Presenting Author: Kate Wilson (k.wilson@adfa.edu.au)
[a]School of Engineering and Information Technology, UNSW Canberra, Canberra ACT 2600, Australia
[b]School of Physical, Environmental and Mathematical Sciences, UNSW Canberra, Canberra ACT 2600, Australia

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ABSTRACT

The gender gap in the physical sciences is well known, with consistent gaps in performance on many assessment types, including standard tests. Many possible reasons for the gap have been proposed, including innate differences in males and females, and differences in experiences. In this paper we examine in detail the gender gap on one particular multiple choice question from the 2013 Australian Science Olympiads Examination for Physics, which asks how a tight screw can most effectively be loosened. The question is easily answered if one has experience of using a screwdriver; otherwise, an exceptional understanding of torque and friction is required to correctly answer the question.

We find that there are different choices of distractors by males and females and that while males perform better on this question than females overall, the gender gap reverses for high achieving students. This may indicate that very high-achieving girls are more likely than very high-achieving boys to have experience using a screwdriver. We conclude that providing experience using hand tools would be of benefit to all students, male and female.

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INTRODUCTION

A great deal of research has been done on gender differences in performance in science, in particular in the physical sciences, as described in the comprehensive review by Halpern, Benbow, Geary, Gur, Shibley Hyde & Gernsbacher (2007). Whether the observed gaps are due to innate differences in males and females, or to learned differences, is still an open question. Evidence from neuroscience points to physical differences in the brains of males and females. Girls tend to use more cortical areas for verbal functions, while boys use the cortical area more for physical-spatial functions (Gurian & Stevens, 2004). McBride (2009) notes that boys are more focused on spatial aspects of a situation such as movement; and Maitland, Intrieri, Schaue & Willis (2000) note that, while differences decrease with age, males outperform females on spatial manipulations across all age groups. The general consensus seems to be that boys are more comfortable moving things through space, and better suited to using diagrams and pictures, while girls are better at multi-tasking, concentrating, and reading. However neuroscience also tells us that the brain is plastic, particularly during childhood and into adolescence. New connections between neurons form and are strengthened as a result of experiences. As noted by Halpern et al. (2007; p.1):

> Experience alters brain structures and functioning, so causal statements about brain differences and success in math and science are circular.

There have been many studies of gender-based differences in physics, with most concentrating on the relative performance of males and females in standardised tests such as the Force Concept Inventory (FCI; Hestenes, Wells & Swackhamer, 1992; Halloun, Hake, Mosca & Hestenes, 1995). A detailed review of this literature is presented by Madsen, McKagan & Sayre (2013), who conclude that observed gaps are likely to be a combination of many small factors, and suggest that isolated explanations need to be treated with caution due to a lack of repeatability.

Attempts have been made to reduce the gender gap on tests such as the FCI through modifying the tests themselves (see e.g. McCullough, 2004; Hazel, Logan & Gallagher, 1997; Lorenzo, Crouch & Mazur, 2006; Osborn Popp, Meltzer & Megowan-Romanowicz, 2011; and Walet and Birch, 2014), or by using more interactive and collaborative forms of instruction (see e.g. Madsen et al., 2013; Docktor and Heller, 2008; and Kost-Smith, Pollock & Finkelstein, 2009). In this paper, rather than addressing how the gender gap might be closed or reduced, we instead look at what the gender gap can tell us about our students.

Previous analysis of data from the Australian Science Olympiads Examination (ASOE) Physics papers from 2007 to 2014 showed gender gaps, with males performing better on both multiple choice questions (MCQs) and written answer questions. Patterns were identified in the MCQ section, and some aspects of questions such as their presentation and particular content areas that correlated with large gaps were identified (Wilson, Low, Verdon & Verdon, 2015).

In this paper, we consider one particular question from the 2013 ASOE for Physics which showed a large gender gap and explore the differences in patterns of answers by male and female students. The question is interesting because it is atypical of physics examination questions, and shows an unusual pattern in how the gender gap varies with overall achievement level in the examination. The question is atypical of physics MCQs because, as described below, it does not require any mathematics or calculation, nor does it require the application of a single physics principle. Rather, it can be answered with either an unusually sophisticated understanding of the relevant physics, or simple hands-on experience. It was thus hands-on experience that the question was aimed to find. This question had not been used previously, nor has anything strongly analogous.

THE ASOE FOR PHYSICS

Each September, nearly 1000 Australian high school students, mainly from Year 11, sit the ASOE for Physics. On the basis of performance in the ASOE, approximately twenty-four students are chosen to attend a summer school in January of the following year. The top eight students from the summer school make up the Australian team for the Asian Physics Olympiad (APhO) in April or May of that year; and five of these students go on to attend the International Physics Olympiad (IPhO) in July. There is an additional week or so of team training before each competition. The ASOE is the thus the first hurdle in an intensive selection and training process.

Typically, only a few students from a given class are nominated by their teacher to attempt the ASOE as it aimed at only the most able physics students. The ASOE targets students in Year 11, as they will be in the final year of high school in the following year (students may not compete in the International Physics Olympiad competitions once they have begun a university degree). Teachers are asked to nominate Year 11 students, or, in exceptional circumstances, Year 9 or 10 students. Hence the bulk of the cohort that we are considering here are high-ability (as judged by their teachers) Year 11 students. Approximately 3% of Year 11 physics students across Australia sit the ASOE, and typically between a quarter and a third of these students are female, which is approximately the same fraction as the total Year 11 physics cohort in Australia. In 2013, 842 students sat the ASOE, of whom 618 were male and 224 were female. The answers submitted by these students make up our data set.

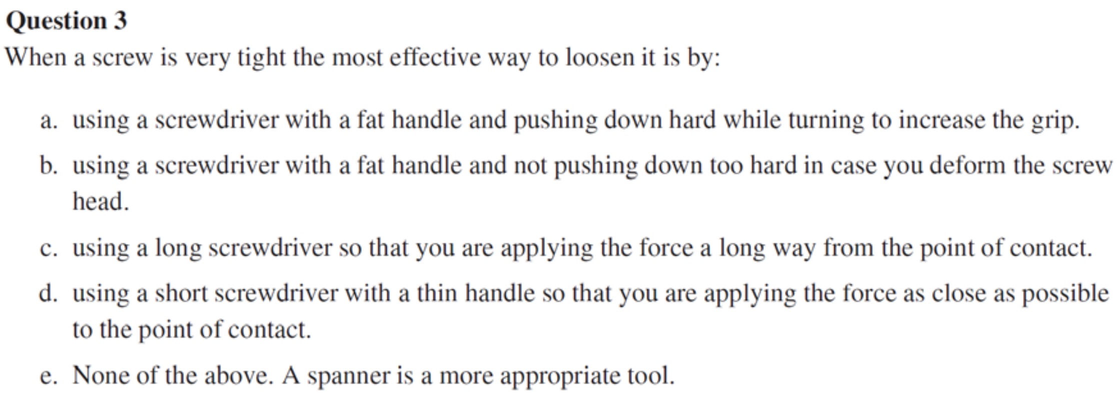
The ASOE for Physics consists of two parts: ten MCQs, each worth 1 mark; and a written answer section. The ASOE MCQs typically include a variety of question types including conceptual questions similar to those on the FCI, scientific reasoning questions, and ‘process questions’ (such as the calculation and expression of uncertainties). The written section includes questions requiring algebraic manipulations and calculations, the graphing and interpretation of data, written explanations of physical phenomena, and experimental design. The ASOE questions are intended to be challenging, and to select for students who have the potential to do well at the APhO and IPhO competitions. To do well at these competitions, students need to not only possess a strong knowledge base in physics, but also excellent problem solving skills, both theoretical and experimental, as they are generally faced with at least some unfamiliar content. In 2013, the written section (four unequally-weighted questions, worth 55 marks in total) included an experimental problem on friction, for which the only permitted equipment was paper, pencil and a ruler. Past ASOE papers, including the 2013 paper, are available at https://www.asi.edu.au/site/past_exams.php. As past papers and their solutions are available online, it is possible for students to study them, and hence the recycling of questions from year to year is minimised.

QUESTION OF INTEREST: HOW TO USE A SCREWDRIVER

The question we are considering in this paper is Question 3 from the 2013 ASOE for Physics, which is shown in Figure 1. In this section, we consider how a student may arrive at the correct answer (answer A), or at each of the distractors. This question is of interest not only because of the large gender gap in the fraction of correct answers, but because of what the different answers given by male and female students can tell us about how each gender is approaching the problem (as discussed in the next section).

Imagine a student who has never used a screwdriver attempting to answer this question. At Year 11, many students have met the idea of torque or leverage, and will recognise that the longer the lever arm used, the greater the mechanical advantage. If the student further recognises that the lever arm in this case is related to the width (and not the length) of the screwdriver handle, this allows them to restrict the possible correct answers to A (the correct answer) and B. The second parts of answers A and B are both plausible, and difficult to distinguish between on the basis of the knowledge held by a Year 11 student. While Year 11 students are likely to have met the idea of friction, applying it in the context of a screw, with multiple forces acting in different directions on the surface of the screw (which is itself not a simple shape) is likely to be well beyond the applications they have met and are able to deal with. Hence a student with a good knowledge of physics, but lack of experience using screwdrivers, is likely to only be able to eliminate all but two possible answers.

Students with some knowledge of torque, but who do not recognise that the lever arm is half the handle width rather than the length of the handle, will most likely choose incorrect answer C (long handle is best).



Question 3

When a screw is very tight the most effective way to loosen it is by:

a. using a screwdriver with a fat handle and pushing down hard while turning to increase the grip.

b. using a screwdriver with a fat handle and not pushing down too hard in case you deform the screw head.

c. using a long screwdriver so that you are applying the force a long way from the point of contact.

d. using a short screwdriver with a thin handle so that you are applying the force as close as possible to the point of contact.

e. None of the above. A spanner is a more appropriate tool.

Figure 1: Question 3 from the 2013 ASOE for Physics.

Now consider a student who does have experience using screwdrivers. It takes very little experience of tightening or loosening screws to come to the conclusion that the most effective way to use a screwdriver is to push firmly in the direction of the screw. Even if such a student has not had extensive experience using screwdrivers with different thicknesses of handle, they will still be able to correctly answer this question on the grounds that only answer A mentions pushing down on the screw.

A student who has neither met the idea of torque, nor used a screwdriver, may select any of the answers, although we would expect the distractor E to still be unpopular because of the cueing in the wording of the question (screw and screwdriver). It is likely that students choosing answer D come from this group. A student who is simply guessing or randomly selecting answers may of course select any of the answers, including E.

Hence this question primarily differentiates between students on the basis of their practical, hands-on skills rather than their physics knowledge. This is important in team selection, as an ability and willingness to use simple tools such as screwdrivers is often required in the practical examination at the APhO and IPhO competitions. Students with exceptional mathematical skills and physics knowledge, but who have very poor hands-on experimental skills, often do poorly in the experimental component of the competition, which comprises almost half the marks available in the competitions.

RESULTS

2013 ASOE PHYSICS EXAMINATION DATA

Over the entire 2013 ASOE Physics examination, the facility (fraction of cohort answering the question correctly) on the individual multiple choice questions varied from 0.340 to 0.796 with an average facility of 0.517. Hence the average mark out of ten on the MCQ section of the paper was 5.17. The gap in facility (defined as [male facility] – [female facility]) amongst the ten MCQs varied from 0.009 to 0.160, with an average gap of 0.094. Hence, on average, males scored almost one mark higher (out of ten) than females on the MCQ section: the male average was 5.4, compared to 4.5 for females. While MCQs have previously been identified as problematic for female students (see e.g. Hazel et al., 1997), similar gaps were noted on the written answer section of the 2013 ASOE for Physics. Hence, the gap is not solely due to the question format. These gaps are typical for the ASOE physics papers (Wilson et al., 2015), and persist in spite of efforts to construct an examination with reduced gender gaps (Wilson, Kueter, Dennis, Nulsen & Verdon, 2007).

QUESTION 3: HOW TO USE A SCREWDRIVER

The complete cohort facility on this question was 0.473. For the females overall the facility was 0.366 and for the males overall it was 0.511, giving a gap of 0.145. This is a large and significant gap, although not the largest on the examination. This gap in facility is not particularly surprising given that, on average, boys are more likely to spend time than girls using tools such as screwdrivers. In this instance, the experience of using the tool is helpful – and perhaps necessary – in answering the question correctly, particularly when it comes to distinguishing between answers A and B.

To explore the responses to this question, we group the cohort into three subsets based on scores in the MCQ section of the 2013 ASOE for Physics: low-scoring (0-3 out of 10, comprising 73 females and 128 males); mid-scoring (4-6 out of 10, comprising 109 females and 279 males); and high-scoring (7-10 out of 10, comprising 42 females and 211 males). Table 1 shows the facilities and gap on Question 3, and the overall MCQ section gap, for the entire cohort and for these three subsets.

Table 1: facilities and gaps from the 2013 ASOE for Physics, for a number of male and female subsets.

Cohort/subset (included scores)	**All 10 MCQs: Average gap in facility**	**Q3 only: Male facility**	**Q3 only: Female facility**	**Q3 only: Gap in facility**
All students (0-10)	0.094	0.511	0.366	0.145
Low (0-3)	−0.002	0.297	0.164	0.132
Mid (4-6)	0.018	0.491	0.367	0.124
High (7-10)	0.051	0.668	0.714	−0.046

The first column of Table 1 shows (as expected) that the gender gap in the MCQ section overall arises from differences in the mid- and high-performing students. There is no measureable gap between low performing male and female students, who (by our definition of the subsets) are getting very few questions correct. As the scores increase through the mid- and high-achievement ranges, we see the overall gap increase. Note that the “all-student/all-questions” gap is not simply the average of the subset gaps, as subset gaps are not simple functions of each other, and the gaps for each of the ten MCQs are independent of each other.

When we consider Question 3, however, we see quite a different pattern. Low- and mid-achieving males are significantly more likely to answer Question 3 correctly than are low- and mid-achieving females. Males scoring 3/10 on the test are twice as likely as females scoring 3/10 to answer this question correctly, and males with scores of 5 have a 50% chance of selecting the correct answer, compared to only 35% for girls. Hence this gap persists from low- to mid-achieving students, although it does not increase as we might expect from the increased facilities.

Of particular interest, however, is the high-achieving group, comprised of those who scored 7/10 or above in the MCQ section. The gender gap is reversed for this group, and high-achieving females are more likely to answer this question correctly than high-achieving males. This is in contrast to most other questions in the MCQ section, and the MCQ section overall, where the gender gap is larger for the high-achieving students. Hence there is a difference in the high-achieving male and female students that is not apparent in the overall scores or on other questions. We remind the reader at this point that all students undertaking the ASOE Physics paper are selected by their teachers as being of high ability in physics. The labels ‘low’, ‘mid’ and ‘high’ achieving used here are all relative, and are solely based on the distribution of results in the MCQ section of the 2013 ASOE for Physics.

To further explore the reasons for the large gap in performance, and its reversal for high scoring students, it is useful to plot an item response curve (Morris, Harshman, Branum-Martin, Mazur, Mzoughi & Baker, 2012). An item response curve, as shown in Figure 2, displays the fraction of students selecting each answer as a function of their overall score on the MCQ test. The graph on the left shows the item response curves for the 224 female students, and the graph on the right shows the item response curves for the 618 male students. Note that in 2013 no females scored 10/10 on the MCQ section, and so the curves in the left hand graph all end at a score of 9. Note also that the number of students scoring 0 or 1 is also very low, comprising only 14 females and 23 males in total.

Examining Figure 2, we can see that the crossover point for the correct answer A (the point at which it becomes the most commonly selected answer) occurs at a score of approximately 4/10 for females and 2/10 for males. This indicates that low achieving males (as measured on this test) are more likely to answer this question correctly than low achieving females. The curve for the correct answer is also higher in the middle part of the male cohort than the female cohort, indicating that this trend continues to students scoring in the mid-range (scores of 4 to 6 out of ten). Figure 2 also shows a very steep rise in the number of females correctly answering this question for scores greater than 6/10.

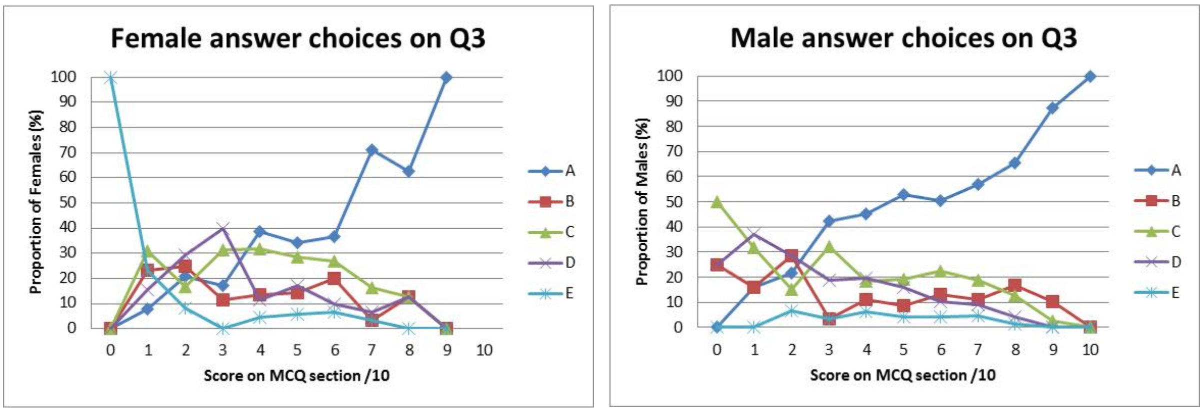


Figure 2: item response curves for females (left) and males (right) on Question 3 of the 2013 ASOE for Physics. The horizontal axis shows the students' scores; the vertical axis is the proportion of students with that score choosing each of the five possible answers, as indicated by the legend.

When we examine the number of students choosing each answer as a function of overall MCQ score we find that females at the low end of the distribution are more likely than males to select answer D, indicating a lack of knowledge/understanding of torque. The spike in answer E (a spanner is a more appropriate tool) at the low end of the Item Response Curves for females is due to only a small number of students and is not statistically significant.

In the middle of the distribution, females are more likely than males to select answer C. The choice of C indicates some theoretical understanding of torque, although it is misapplied. While C is still the most popular distracter for males, many more males are now answering the question correctly, indicating actual experience using a screwdriver rather than relying on a theoretical model.

Males at the high achieving end, when not answering correctly, are more likely than females to select answer B, indicating a good knowledge of torque and an ability to apply the concept, but a lack of experience actually using a screwdriver. Females at the high end, when not answering correctly, are more likely than males to select answer C, indicating some idea of torque but an inability to apply it in this context.

IMPLICATIONS

As described earlier, Question 3 of the 2013 ASOE for Physics selects primarily for students who have had some experience using tools, in particular screwdrivers. While knowledge of torque and friction is also helpful, the experience of using a screwdriver is more useful in this instance. From the data described above, it seems that for the bulk of the cohort who attempt the ASOE, who have been chosen by their teachers as being of 'high physics ability', the boys are much more likely to have had this experience than the girls. Given typical gender stereotyping, the marketing of construction toys more strongly to boys than girls (just as the marketing of tools is primarily aimed at men rather than women), and typical choices of hobbies by boys and girls, this is disappointing but not surprising. Social change is slow, and it is likely to take generations for girls and boys to be given the same encouragement and opportunities to engage in a wider variety of activities. As this happens, we may expect to see decreasing gender gaps on questions of this kind. In the meantime, we can only try to ensure that as teachers (and parents, grandparents, etc.) we encourage the young people that we interact with to explore a wider variety of activities, and not to be bound by current gender stereotypes. We need to ensure that we provide girls with the same opportunities as boys, and send the message that they have the right to undertake those activities and the ability to succeed in them.

What is more interesting in the data is the reversal of the gap at high achievement levels. This indicates that high achieving girls may be (at least slightly) more likely than high achieving boys to have had experience using tools such as screwdrivers. We could speculate that this reversal of the gap to from male- to female-favouring may be because boys who do well on the other questions on this test, which are primarily based on theoretical physics knowledge, together with some mathematical estimates, are not particularly likely to also be engaged in hands-on activities using tools. Alternatively, it may be that girls who engage in hands-on activities such as construction (or deconstruction) are also more likely to be engaged in, and achieve highly in, physics and mathematics. In this case, simply being exposed to possibilities outside stereotypical gender roles may have a positive effect on their achievement. We do not, of course, claim a causal relationship between encouraging girls to use tools and higher female achievement in science and mathematics; but based on this data, there is at least some correlation.

The implication here is that encouraging girls to engage in hands-on activities, to join in with the boys when they go out to the shed to build something or take something apart, may help them later on to succeed in mathematics and science alongside their male colleagues. Whether this occurs because of the skills that they learn from engaging in these activities, or because it enables them to imagine more possibilities for themselves beyond typical gender stereotypes, is a matter of speculation. Recent research on female role models, in particular working mothers (McGinn, 2015), does show that being presented with female role models undertaking roles and activities beyond housekeeping and child-raising has a positive effect on girls. Interestingly, this same research also showed a positive effect on boys, who grew up to have greater involvement in their own families.

In addition, if males who are high achievers in mathematics and science do not have a basic understanding of how to use hand tools, then including more opportunities and encouragement for them to do so may be a valuable way of broadening their life skills. After all, everyone should know how to use a screwdriver.

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