TEACHABILITY: IT'S HARDER TO TEACH A YOUNG DOG NEW TRICKS

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ABSTRACT
Previous studies have found that taking a 'gap year' has a positive effect on students' achievement at university. The positive effects of the gap year have been ascribed to improved life skills and higher motivation. However the effects of taking longer between leaving high school and beginning tertiary studies are unclear. In contrast, we find that students straight out of senior secondary studies of physics, and those who have taken only a single gap year away, have no significant difference in gain in conceptual understanding of Newtonian physics, measured using the normalised learning gain on the Force Concept Inventory. However, we find that those who have been away from study for two or more years, and those who have never studied physics before, have a 50% higher normalised learning gain than those fresh from school or with a one year gap. This may be because students without a significant gap period are less receptive to having their ideas challenged, and experience lower motivation towards learning things that they think they already know.

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INTRODUCTION
MOTIVATION
There is a developing body of literature that suggests it is advantageous for students to delay the start of their tertiary studies after completing secondary school. Cohorts of students who engage in such a 'gap year' have been found to display improvements in objective metrics such as performance, along with retention and completion rates, coupled with more subjective measures such as attitude and engagement. Explanations for these observations generally centre on how students who have taken time away from academic study develop increased maturity compared to their direct-progression peers. This maturity can express itself as the ability to employ time-management skills learned from the world outside academia, that are more important in the arguably more self-directed learning environment of tertiary education compared to the structured environment of high school. It is also worth noting that the results are far less clear cut for 'mature age' students (defined in Australia as those over 21 years of age when beginning their university study), who have taken more than one year away from study.

For science subjects, however, and particularly those at the more 'technical' end such as physics, taking time away from study might be seen as detrimental, due to the loss of 'academic momentum'. For example, students may become 'rusty' in their ability to manipulate and solve problems; they may forget key physical and mathematical concepts; or they may revert back to the misconceptions that they held prior to the suppression (if not complete extinction) of these 'alternative models' during senior secondary instruction. These effects are less likely to be a factor in the narrative and discursive disciplines, where one might well expect that the greater life experience developed in the gap year outside of academia would provide students with advantages (upon their return to study) that immediately outweigh any loss of familiarity with the nature and rigours of academic study.

Our question: is it possible to quantify how the various advantages and disadvantages from taking time away from study combine to affect students in a technical course such as first-year physics?

BACKGROUND
The proportion of students – in Australia, and overseas – who elect to take time away from study between secondary and tertiary level education is increasing. Birch and Miller (2007) quote rates of approximately 4% in 1974 increasing to 11% in 2004, while Martin (2010) reports figures of between 15%-20% in more recent times. In the United States of America (USA), where deferral rates have been estimated to be as high as one-in-three, highly regarded institutions such as Harvard positively

encourage prospective students to consider taking a gap year, noting that students are occasionally admitted because of their accomplishments during a gap year, and that ‘time away almost never makes one a less desirable candidate or less well prepared for college’ (Fitzsimmons, McGrath & Ducey, 2011). In a world that appears to increasingly value life experience, abilities and adaptability, over the skills and knowledge that may soon become outdated in a rapidly evolving workplace, the value placed on a gap year may be expected to increase as well.

Birch and Miller (2007) developed a model to estimate the determinants of academic success from a sample of nearly 7000 student records, and found that gap year students had marks 2.3% greater than direct progression students. Martin (2010) found that taking a gap year was positively correlated with academic motivation upon return to study, and that gap year students demonstrated significantly higher adaptive (and significantly lower maladaptive) behaviour. Engler (2010), reporting on the academic performance of over 30,000 students in New Zealand between 2006-2008, found that taking a gap year was particularly beneficial for students within the cohort that displayed lower levels of secondary school achievement. In the context of the system in the USA, Connelly, Harrill, Clagett, Bull and Knight (2013) have shown that gap-year students outperform their non-gap year classmates, even after controlling for levels of secondary achievement: that is, students who took a gap year achieved better results across all four years of the college program than would have been predicted for them, based on the results of non-gap year students with otherwise similar backgrounds.

A clear picture thus emerges from the recent literature regarding improved academic outcomes for students who return to university after a gap year. However, in terms of determining the effect that taking a gap year has on student performance, one must be very careful about selection influences. For example, students who return to academic study after taking a year off may be expected to be more motivated regarding study: many students who do not continue straight to university after high school, never go to university. It is reasonable to expect that the motivation levels of mature age students are higher than students who have taken a gap year, as the decision to return to study after a significant absence brings with it often greater sacrifice in terms of employment opportunities, or time spent with family. Hence to ascribe any change in performance to the taking of a gap year, rather than to the nature of the students who take a gap year or longer break in study, is dangerous.

A longitudinal study of over 900 students across the arts, social sciences, and sciences, demonstrated that deferring the start of tertiary study by one or two years positively predicted university results throughout the entire degree (Martin, Wilson, Liem & Ginns, 2013). Interestingly, this same study noted that students classified as “mature age” within this cohort performed as per the larger grouping, with neither positive nor detrimental effects ascribed to their longer deferral, suggesting that the loss of academic momentum after two years absence is sufficient to outweigh the positive effects of a greater capacity for self-regulated and self-directed learning behaviour.

Other studies are inconsistent in their findings on age as a predictor of academic success, with positive (Sheard, 2009), negative (de Koning, Loyens, Smeets, Rikers & van der Molen, 2012) and no significant effects (McKenzie and Schweitzer, 2001) all found in different studies.

Apart from the commonality of the results regarding gap years noted above, there is one other important observation to make: they are based on students who, generally speaking, are taking liberal arts style programs. The exception is the work by Martin et al. (2013); but even in that work, no evidence was presented for differences in performance between mature age students studying the different degree programs. At the risk of falling into the trap outlined by Lazarsfeld (1949) regarding the drawing of ‘obvious conclusions’, one might be tempted to suggest that the liberal arts are the very programs where a year off study would be more likely to help a student put the world in perspective, as well as giving them the real-life skills that can be transferred to the tertiary learning environment. In what follows, we look exclusively at students of physics, who are taking the course as part of either a Science or Engineering degree, in an attempt to see if the story from the literature is transferrable to the physical sciences.

OUR STUDENTS AND THEIR ENVIRONMENT

The Australian Defence Force Academy (ADFA) is located in Canberra, and recruits students from across all states and territories in Australia. Approximately 90% of the annual intake of approximately 300 students is made up of officer cadets and midshipmen, who undertake military training and education during their time at the Academy, with an aim to become an officer in the Australian Army, Navy or Air Force. The remainder of the cohort comprises serving officers in the Australian Defence Force (ADF), or civilians on scholarships from Defence-related organisations (such as the Defence Materiel Organisation). During their time at ADFA, all students study for an undergraduate degree with the University of New South Wales (UNSW). The degree program is full time, and delivered on-site by the Canberra campus of UNSW (UNSW Canberra), which is co-located with ADFA. Undergraduate bachelor degree programs are offered in Science, Engineering, Technology, Arts, and Business. Available majors in the Science program include Physics, Mathematics, Oceanography and Chemistry (amongst others); there are a similar number of options available in each of the other programs. In total, there are about twenty distinct academic pathways for students to choose from.

Almost all officer cadets and midshipmen live on-campus, in communal accommodation blocks. Divisional Officers often assign students to rooms on the basis of their degree stream, in an effort to foster academic collaboration between like-minded students. Between their living arrangements, military training and academic commitments, students spend a great deal of their time together. The students are accustomed to collaborating, and are encouraged to do so in many of their courses.

In this paper, we consider the 153 students (22 female, 131 male) from the first-year cohort of 2013 who enrolled in the course ZPEM1501 Physics 1A in semester one of 2013, and continued on to enrol in the semester two course ZPEM1502 Physics 1B. Ten students (7% of the cohort) had not studied Year 12 Physics at all. Of the remainder, 84 (55%) took Year 12 physics the preceding year (2012), 30 (20%) in 2011, 11 (7%) in 2010, and 17 (11%) in 2009 or earlier (between 1996 and 2008). The one student not accounted for in that breakdown studied Year 12 Physics over a two-year period (2011-12). Students came from all States and Territories of Australia, with most taking their Year 12 physics in Queensland (44) and New South Wales (35), with lower numbers originating from Victoria (18), South Australia (12), the Australian Capital Territory (11), Western Australia (6), Tasmania (5) and the Northern Territory (5). Six students completed their secondary physics overseas, and one student did not identify their Year 12 background.

WHAT WE DID

The Force Concept Inventory (FCI) (Hestenes, Wells & Swackhamer 1992) is a well-established tool that can be used to gauge students' conceptual understanding of Newtonian mechanics. By comparing student results across two (or more) attempts at the FCI, spaced in time, the impact of instruction on that understanding can be measured. In the work presented herein, we applied a revised version of the FCI (Halloun, Hake, Mosca & Hestenes, 1995), which tidies up some points of potential confusion, and is regarded as the standard instrument in this type of study.

ZPEM1501 Physics 1A is a calculus-based first-year physics course, which covers the traditional topics of mechanics, fluids, waves and thermodynamics in a 13 week semester. Instruction is via lectures (three 50 minute periods each week), tutorials (one 50 minute period each week) and laboratory classes (five 3-hour periods, held approximately fortnightly). The course is taught by three lecturers, and one of the authors (DJL) was responsible for delivering the first block of lectures, which included the material on Newtonian mechanics.

We applied the FCI in the first lecture of ZPEM1501, before any instruction began; this is our 'pre-test'. It was then applied again in the first lecture of ZPEM1502 in semester two, nearly five months later, and approximately five weeks after the end of semester one. This 'post-test' is therefore a reasonable indication of student learning (as opposed to short-term retention), in a situation where the students are also likely to be distant from cognitive interference (Sayre, Franklin, Dymek, Clark & Sun, 2012). As noted earlier, a total of 153 students sat both the pre-test and the post-test, and their results comprise our sample.

The metric we use to gauge learning is the Normalised Learning Gain (NLG), which was brought to the widespread attention of the physics education research community by Hake (1998), who demonstrated that, over a large number of disparate courses, there was no significant correlation between pre-instruction scores and NLG; and that learning gains were independent of the instructor (although not of the instruction method). These results have been reproduced by other investigators (see e.g. Redish & Steinberg 1999; Hake 2002a), and the NLG is now widely regarded as a robust measure of learning. The NLG for a cohort is usually expressed as:

$$\boxed{\mathrm{NLG} = \frac{\langle \text{post-test score} \rangle - \langle \text{pre-test score} \rangle}{\text{MaxPossibleScore} - \langle \text{pre-test score} \rangle}} \qquad \text{[Equation 1]}$$

where the angled brackets indicate a cohort average. The NLG thus shows how much a cohort of students improved, as a fraction of how much they could potentially have improved.

The difference between using cohort averages to determine the NLG via Equation 1, as opposed to averaging the NLG of individual students within a cohort, has been discussed in detail by Bao (2006), and is ascribed to the dynamics of shifting distributions. However, Equation 1 does not readily allow the estimation of uncertainties, which is important for the meaningful comparison of NLGs between cohorts within a sample. Furthermore, the use of Equation 1 to determine individual student NLGs (which could then be analysed as a distribution) suffers from a negative bias, which is seen when students who scored highly in the pre-test have a decline in their post-test score. Hence, in addition to calculating the NLG of cohorts within our sample via Equation 1, we also calculate individual student NLGs via the modification suggested by Marx and Cummings (2007) and Bao (2006), where negative learning gains are instead normalised by the pre-test score (i.e. by the most a student could have declined). From the distribution of individual student NLGs within a cohort, we then calculate the standard error in the mean (SEM), and use that as an estimate of the uncertainty for the purposes of comparing the NLG of cohorts within the sample.

For the remainder of this paper, we use ‘cohort NLG’ to refer to a quantity calculated via Equation 1, and ‘average NLG’ to refer to a quantity calculated by averaging individual student NLGs across a cohort. For our sample, and the cohorts we identify within our sample, the absolute differences between these two methods are relatively small, and are always smaller than the SEMs.

WHAT WE SAW

Our results are displayed in Table 1, where the cohorts within the sample were determined on the basis of the year in which the students undertook their Year 12 physics. While some of the cohorts are small in number, the SEMs can be used as an indication of uncertainty.

Table 1: Analysis of normalised learning gains by cohorts within the total sample. For each cohort within the sample, the rows give the number of students (*N*), the normalised learning gain of the cohort as calculated via Equation 1, the average normalised learning gain of the students within the cohort, and the standard error in the mean (*SEM*) of the average NLG.

Cohort Description	***N***	***Cohort NLG***	***Average NLG***	***SEM***
All (entire sample)	153	0.28	0.27	0.02
Year 12 in 2012 (no gap)	84	0.25	0.25	0.03
Year 12 in 2011 (gap year)	30	0.24	0.22	0.05
Year 12 in 2010 (gap two years)	11	0.31	0.29	0.08
Year 12 before 2010 (mature)	17	0.37	0.39	0.05
No Year 12 Physics	10	0.36	0.37	0.06
Year 12 in 2011 or 2012	114	0.24	0.24	0.03
Year 12 before 2011	28	0.35	0.35	0.04
Year 12 pre-2011, or No Year 12 Physics	38	0.36	0.35	0.04

The cohorts who studied Year 12 physics in 2012 or 2011 (i.e. one or two years before starting university physics in 2013) show similar NLGs, whether they are treated as distinct cohorts or grouped together. These students, who entered ADFA either direct from high school or after taking a year’s gap, had a normalised learning gain of ($0.24 \pm 0.03_{\mathrm{SEM}}$).

In comparison, student cohorts who studied Year 12 Physics earlier than 2011 – or who had never studied Year 12 physics – displayed markedly higher NLGs, but all broadly similar to each other. When grouped together, this combined cohort had a normalised learning gain of ($0.36 \pm 0.04_{\mathrm{SEM}}$).

What we see here, then, is that students who have not ‘recently’ studied Year 12 physics have a normalised learning gain about 50% higher than those who studied Year 12 physics in the last year or two. The difference between these results is significant at the 5% level, using the Behrens statistic for a two-sample non-Normal different-variance comparison of means. It is important to reiterate that normalised learning gains show how much students improve, relative to how much they could have improved. These results indicate that the cohort of students who have not studied for two or more years are, in some way, more amenable to instruction: that is, they are more ‘teachable’.

WHAT WE THINK IT MEANS

The suggestion that there is no single cause for differences in learning gains between cohorts of a sample population is a common one (Hake, 2002b; Pollock, 2005; Harlow, Harrison & Meyertholen, 2014), and the results often seem sample dependent. It is also important to remember that correlation does not imply causality: the same ‘hidden’ factor(s) might be affecting two observed parameters. For example, since the FCI is an exercise in conceptual physics, one might suppose that a student’s mathematical skill and background is unlikely to be important. However, Meltzer (2002) noted a strong correlation between mathematical ability and NLG on a conceptual physics test.

Perhaps more relevant to our situation, Coletta and Phillips (2005) found that scientific reasoning ability was linked to learning gains for a number of university-level samples, identifying the cognitive development of reasoning ability as a key indicator for higher NLGs.

We contend that students who progress directly from high school to university are less likely to have developed the ability to apply their knowledge to new situations; while those students who have had time away from study are more likely to be accustomed to reasoning their way through problems, and applying new knowledge to unfamiliar situations: something that develops with experience and maturity. Our results give some indication as to how the distance of exposure (or even lack of exposure) to high school physics might be compensated, or even overcome, by expanded life skills. A single gap year does not appear to make a significant difference to students’ ability to learn from instruction in physics. While at first glance the results for our ‘mature’ cohort appear in conflict with the results of Martin et al. (2013), it should be remembered that we are looking at NLGs rather than academic results; that is, at improvement from a personal entry baseline, rather than at absolute performance.

DISCUSSION AND CONCLUSIONS

This study of 153 first-year physics students showed a statistically significant difference in normalised learning gain between the students who undertook their Year 12 physics studies one or two years before entering university, and those who studied Year 12 physics earlier than that (or not at all). The older students demonstrate a NLG about 50% higher than their direct-entry or gap-year classmates. This is in contrast to previous studies, which found that a single gap year might be advantageous (e.g. Birch & Miller 2007; Sheard 2009; Engler 2010; Connelly et al. 2013; Martin et al. 2013), but that any longer absence from study was not (e.g. de Koning 2012; Martin et al. 2013).

This difference may simply be due to the better-developed life skills and practical reasoning ability of the more mature cohort, particularly as most (over 60%) of the members of this group are ADF officers; who are, due to their training and careers, experienced problem solvers. They are also likely to be more motivated than their younger classmates, as they have chosen to begin study when already an officer: the selection process for officers to come to ADFA emphasises the end result of an academic qualification. The (younger) cadets and midshipmen, on the other hand, are undertaking their study at the beginning of their military careers. The (extensive and exhaustive) selection process for these students ensures that their primary motivation in coming to ADFA is to become an officer in the ADF, while gaining a degree in the process. This appears to be reflected in internal UNSW Canberra First Year Experience surveys, where students associate themselves with “ADFA” rather than with “UNSW” (Tranter and Hancock, private communication, 2014).

However, it is also possible that the cohort who progressed directly to tertiary study are less receptive to having their preconceptions from high school physics challenged in the university classroom: note the NLG for the “No Year 12 Physics” cohort in Table 1, compared to that of their peers. We see this in both formal classroom settings and informal conversations with our students, when discussing concepts such as weight and the normal force, or the difference between situations that required either Newton’s Second or Third Law to be applied. Students whose most recent experience of formal physics instruction was high school have a pronounced tendency to preface their responses with phrases such as, ‘But at school, we learned that…’, indicating that they are attempting to fit current material into the framework that is uppermost in their mind. This approach and mindset causes problems when the high school level treatment presents a convenient simplification, which is later expanded upon at the tertiary level: for example, in the definition and use of the normal force.

There is more work to be done here, and this initial study has, perhaps, raised more questions than it has answered. For example, in analysing the data we saw significant differences in normalised learning gains as a function of where (not just when) students undertook their Year 12 physics education. The change in facility on individual questions in the FCI likewise showed patterns of performance which encourage further investigation.

In future years, we intend giving students an entry diagnostic which combines questions from the FCI that are significant contributors to learning gains, together with questions in the Classroom Test of Scientific Reasoning (Lawson, 1978) that have been identified as highly correlated with learning gains in the FCI. In this way, we hope to be able to identify students who are both weak at scientific reasoning, and who have a poor conceptual understanding of Newtonian mechanics, as these students are likely to be at higher risk of failing to improve their understanding. These students can then be offered appropriate additional support, which may include help with study skills and scientific reasoning, as well as additional physics instruction.

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