RESEARCH DIRECTIONS

Student Attitudes to Science in an Undergraduate Interdisciplinary Science Programme

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Abstract

We address the extent to which students developed expert attitudes in the individual disciplines of biology, chemistry and physics during their degree programme. By attitudes we mean the way students think about the sciences compared to discipline experts.

We used the standard CLASS survey instrument to compare student attitudes to biology, chemistry and physics with those of experts. The programme featured interdisciplinary modules involving biology, chemistry and physics delivered by a form of problem-based learning across a three-year (BSc) or four-year (MSci) degree. The survey was administered at the start of the programme and at the end of each year of the programme allowing us to execute a longitudinal study of changes over the three- or four-year degree. The survey was run over a total of six years to students on the Interdisciplinary Science degree at the University of Leicester.

We find positive results in the formation of expert-like attitudes in biology and chemistry and for higher performing students in physics. We note that the nature of science, that is the beliefs of experts about science with which our students' responses are compared, are not taught explicitly in this programme, but acquired through experience of the problem-based pedagogy. Our conclusion is that students generally develop more expert-like attitudes in the separate disciplines, and hence a greater understanding of the sciences, over the first years of the degree.

The numbers of students on the degree programme averaged around 20 and the questionnaires were completed by about 60 students in total. This imposes a limitation on the power of the survey. Nevertheless, we find some statistically significant results.

This is the first use of the CLASS tool to investigate the development of attitudes across the disciplines with the same set of students and over an extended period. We believe this is an important contribution to the argument for greater interdisciplinarity at all levels in STEM education.

Background

In this research we investigate the development of attitudes to science of students in an undergraduate interdisciplinary science programme delivered between 2011 and 2016. Our principle research question was whether expert attitudes to the individual sciences could be fostered while studying multiple disciplines in the absence of direct instruction in what an expert attitude comprised. The meaning of "attitudes" will be explored more fully below, but it refers to the way in which students view the discipline content and the nature of the science. To see why this is important, consider the difference between "Physics is a lot of equations that you learn" and "Physics is an approach to understanding through abstraction" and which of the two we might prefer graduates to espouse. One might think that for science majors the inculcation of expert attitudes over a degree programme would be a given. In fact, there have been no longitudinal studies over multiple years of a programme, perhaps because the outcome seems obvious. However, studies of physics majors show that a significant number of students do not develop expert attitudes by the end of the first year of a degree (Slaughter et. al., 2012). At a more practical level, these studies are important because some studies have shown a correlation between attitudes and achievement. For the programme under study here we are interested in whether the parallel teaching of biology, chemistry and physics throughout the degree obscures attitudinal differences between the disciplines. The outcomes are relevant to discussions around interdisciplinarity in science education.

All core modules in the programme under study, comprising about half of the content, were interdisciplinary, involving biology, chemistry and physics delivered by a form of problem-based learning. The question therefore is whether or to what extent students develop attitudes to the individual disciplines which concur with experts in those disciplines. The programme does not involve explicit instruction in the nature or philosophy of science, but the problem-based pedagogy allows students to experience scientific research across all years. The pedagogy should provide some basis for the acquisition of expert-like thinking. Uniquely we follow the extent to which expert-like attitudes are developed over the course of the three or four years of the degree with the same students in each of the disciplines.

For the purpose of the research, we use the CLASS survey pre- and post- instruction. We adopted this as it is the most widely used instrument in such studies at post-secondary level (Lee et al, 2021). Furthermore, it is available and validated in forms adapted to each of the three disciplines (Adams et al., 2006, Adams et al., 2008, Semsar et al., 2011). No changes were made to the survey questions. The early investigations using the CLASS questionnaire were directed at introductory courses in undergraduate physics. These appeared to show decreasing expert-like attitudes post-instruction (Redish et al., 1998, Adams, et al., 2006) even where there were positive learning gains. One response was to include explicit instruction in the nature of science (Lindsey et al., 2012). Subsequent research led to claims that various non-traditional modes of instruction could also reverse these results, including modelling instruction (Brewe et al., 2009), problem-based learning (Sahin, 2000) and inquiry-based learning (Abaniel, 2021), without explicitly teaching the nature of science. This impacted equally on males and females with both showing positive shifts in attitudes and conceptual understanding. Differences were also found depending on the educational background of students (Marina Milner-Bolotin, 2011) and whether they were physics majors (Nissen, 2021). In the latter case the results are confusing with claims that non-majors improve their understanding of the nature of science in contrast to majors, while others find that the more able students develop more expert like attitudes (Reddy, 2019). The limited number of longitudinal studies indicate that attitudes to physics are stable over time (Carolan et al., 2014, Slaughter et al., 2012). Generally, more expert-like attitudes are associated with higher learning gains.

There are far fewer studies of attitudes to biology and chemistry using the CLASS instrument. Unsurprisingly perhaps, biology majors studying physics benefitted from the use of examples from the life sciences in development of attitudes to physics (Geller, 2018). In biology, Hansen and Birol (2014) conducted a longitudinal study over four years demonstrating an overall shift to more expert-like attitudes. On the other hand, Ding and Mollohan (2014) report that biology non-majors grew more expert-like while majors became more novice-like in the course of a semester. For biology there is also evidence of a link between attitudes and content knowledge (Presley, 2021). A comparison of attitudes to chemistry across multiple institutions showed small or negative gains (Duis et al, n.d.) while Reid (2008) found a positive correlation between attitudes to chemistry and learning outcomes. The programme under study here comprised a set of interdisciplinary modules each involving at least two of biology, chemistry, physics and earth sciences. These modules, which ran sequentially each over five weeks, were delivered by a form of problem-based learning (PBL) across all years of the degree programme. This differed from canonical forms of PBL in that learning issues for each twiceweekly facilitated group workshops were specified in the student documentation. We refer to this elsewhere as problem-based tuition (Raine, 2013; Raine, 2020). There were additional laboratory modules and "support" modules in mathematics, computing and professional skills that ran alongside the core discipline-focussed courses. All the modules were developed for the programme and delivered only to students enrolled on the programme, typically around twenty in each year group. Students who entered the programme must have studied at least one of the science disciplines to pre-university level and have a basic level of mathematics. Very few students would have studied all three disciplines beyond age 16. One student on the programme was a mature student, three had joined from other degree programmes and the others were all school leavers,

Our results for biology and chemistry show increasing gains in expert-like attitudes over the course of the programme with somewhat less clear-cut results for physics. Any fears that a broader science curriculum impacts negatively on students' understanding of the nature of science in general and on disciplinary differences in particular would appear to be unfounded.

Methodology

The CLASS survey was originally developed for physics as a way of gauging students' development of mastery of the discipline (Adams et al. 2006). This is achieved through matching the students' answers to a set of questions about attitudes towards physics with those of subject experts. For example, "I think about the physics I experience in everyday life" and "Spending a lot of time understanding where formulas come from is a waste of time".

The instrument has been widely validated and used extensively in North America, mainly in introductory classes involving non-majors in physics. Recently it has been validated for use on a high-achieving set of Finnish physics students (Kontro and Buschhüter, 2020). Subsequently versions were developed for chemistry (Adams et al. 2008) and biology (Semsar et al. 2011). There are 42 questions in physics, 50 in chemistry and 39 in biology. Responses are recorded on a 5-point Likert scale. Questions are grouped into a range of attitudinal factors. In physics these are Personal Interest, Real World Connection, Problem Solving General, Problem-Solving Confidence, Problem Solving Sophistication, Sense-Making/Effort, Conceptual understanding, Applied Conceptual understanding, with some questions unclassified, and similar categories in biology and chemistry as in figures 1-4 below. There is also an overall measure of agreement with experts that weights each of the questions equally.

The questions for the three disciplines were combined and surveys administered at the start and end of year 1 and at the ends of each subsequent year to each cohort of students over a period of five years. Over this time there were various changes of detail to scheduling, documentation and assessment but the basic PBL pedagogy remained the same, as largely did the science content. (The one major exception was an increase in organic chemistry and biochemistry at the expense of more advanced quantum theory and relativity in year 3 in the core curriculum.) Because surveys were returned by only a subset of students (typically around 50%) and not necessarily the same students at different survey points, we obtained a total of around 40 matched pre- and post- comparisons for each pair of survey points. (Cohorts are combined to give each survey point, for example "pre-year 1". Post- year 1 counts as pre- year 2 and so on.) The small number of responses from students completing an undergraduate masters degree in year 4 were grouped with those from responses from students completing a BSc at the end of year 3 giving us a pre-degree to post-degree picture.

There are two ways in which the data is analysed in CLASS. The first is the shift in expert-like responses on a question-by-question basis, grouped into categories. Possible responses to each question are strongly disagree, disagree, neutral, agree and strongly agree. The standard CLASS analysis combines the two agree categories and the two disagree categories and discards the neutrals. For each question therefore we present the number of agreements with expert opinion as a percentage of the maximum (the number of students answering the question) and the shift in this

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percentage. We can do the same for the totality of questions giving the overall percentage shifts in agreement as shown in the figures.

The second approach is to consider the shift in student attitudes on a student-by student basis i.e. the percentage of students who shift to greater (or lesser) agreement with experts for each question, or for the average of any number of questions (equally weighted). Ideally, these approaches should lead to the same (robust) conclusions.

Results

Shifts in Categories

Figures 1-4 show the shifts in various categories. Note that the results are averaged over the responses which are not necessarily the same group of students in each of the years. (Some students may not have returned a survey in one of the three years.) For Biology, **Figure 1** shows significant positive shifts between the start and end of the programme in several categories including overall, in real world connections, problem-solving difficulty and enjoyment. The figure on the left in each case shows the percentage of responses in each category which agree with the expert response. On the right we show the normalised changes, that is the change as a fraction of the potential change for both agreement with expert opinion (labelled favourable) and disagreement (unfavourable). The signs are chosen such that a positive change always represents a gain in student expertise. The negative value for unfavourable shifts therefore means that the number of unfavourable responses has increased.

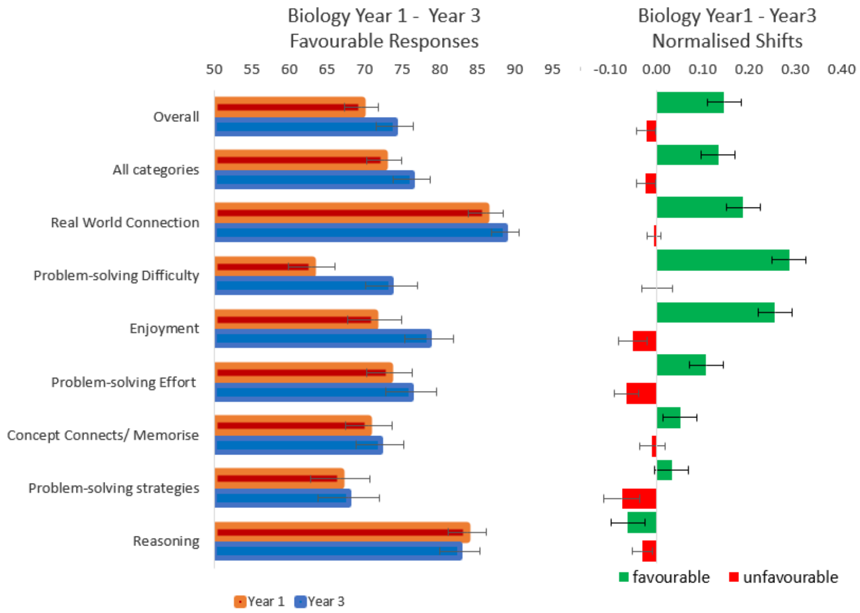

Figure 1 Left: Shifts in expert-like agreement in Biology between the start and end of the programme. Each bar represents the percentage of all responses that agree with expert opinion in that category. The lengths of the error bars are twice the standard errors in each category. Note the false origin for clarity. Right: Normalised shifts. The shifts are expressed as a fraction of the possible shift. For favourable gains (to the right of zero) this is (%post - %pre)/(100- %pre). Thus, positive values indicate increased expertise. For the unfavourable shift (the change in disagreement with expert opinion) the shift is also positive in all categories. The normalisation is therefore the same (%post - %pre)/(100-%pre), because this is again the change divided by the maximum possible change in a positive direction. Thus, negative values here indicate increased disagreement with experts. An increase in both agreement and disagreement is possible because they exclude the neutral option in the Likert scale. Error bars are standard errors also scaled by the maximum possible shift.

Figure 2 shows much larger shifts in Chemistry. This is in contrast to the negative and weak positive shifts reported by Duis et al. (n.d.) for traditionally taught modules in some North American institutions.

Further analysis reveals that these shifts occur mainly in the first year of the programme. One might think that a change in interest in the subject might be the driver for increases in other categories, but this is clearly not the case. There is little change in this category which, compared with “enjoyment” in biology remains relatively low. (Agreement of 65 per cent for personal interest in chemistry compared to almost 80 per cent enjoyment in biology).

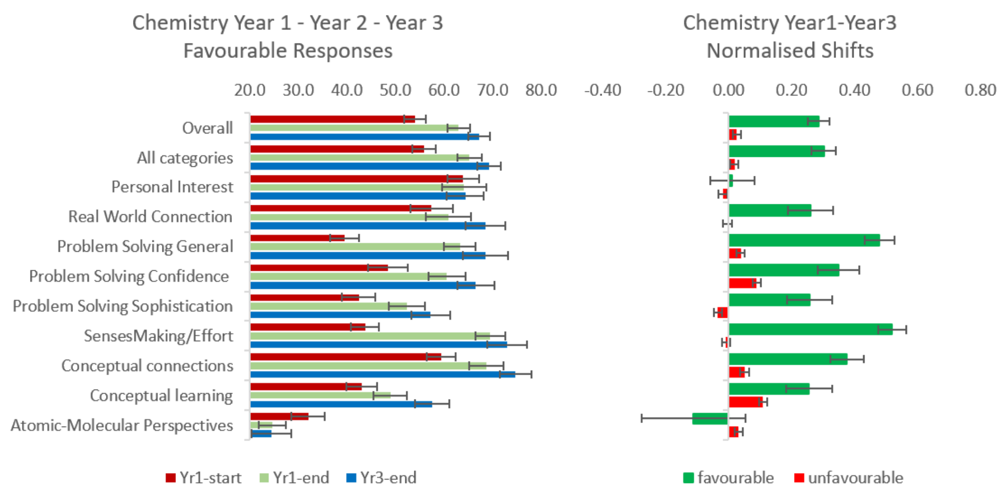

Figure 2 Shifts in expert-like agreement in Chemistry between the start and end of year one and the start and end of the programme. The lengths of the error bars are twice the standard errors in each category. Note the false origin for clarity. Note also that almost all the shifts are towards greater agreement with experts. See caption to figure 1 for an explanation of the normalisation.

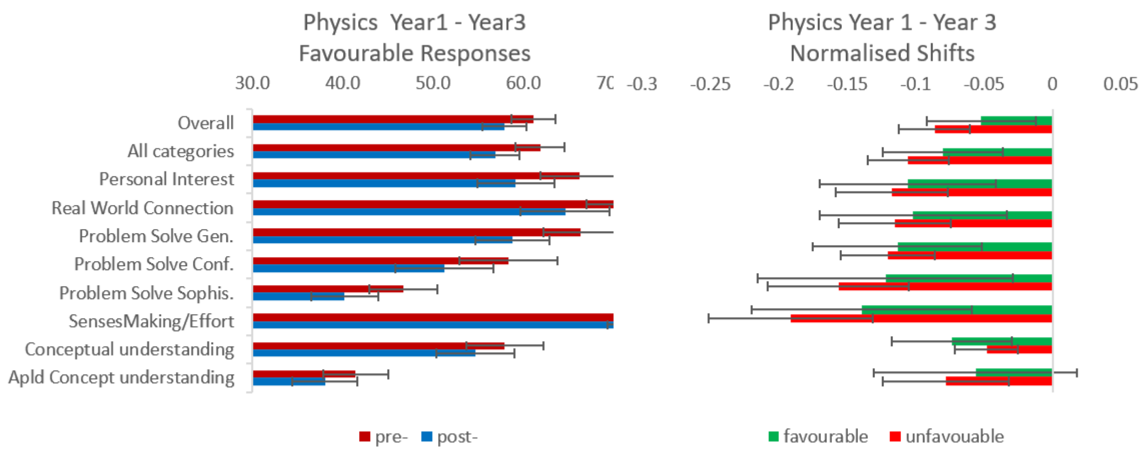

Figure 3 Shifts in expert-like agreement in Physics between the start and end of the programme. The lengths of the error bars are twice the standard errors in each category. Note that all the shifts are away from agreement with experts, although mostly within the errors. See caption to figure 1 for an explanation of the normalisation.

The results for Physics are noticeably different. The apparent shifts are all negative, although, because of the large error bars, none are significant. The reason behind the large standard error turns out to be revealing. In **Figure 5** we show the shifts in their agreement with experts over the first year of the degree for students who went on to obtain a first-class degree overall. (The discipline components are not separated in the award.) Here the shifts are all positive and several significantly so. The result over the whole programme is similar although slightly less marked. (Data not shown but compare **Figure 3**). We conclude that the physics class divides into two populations depending on the level of performance. Higher achieving students become more expert like in physics while lower performing ones do not.

Another feature of the physics cohort is that the negative shift is largely from neutrals to non-expert by about 5 percentage points in each category. In other words, most of the negativity comes from students who are not counted in the CLASS pre- analysis; it is only partially a switch towards negative attitudes of the students with previously positive views.

Shifts in Beliefs

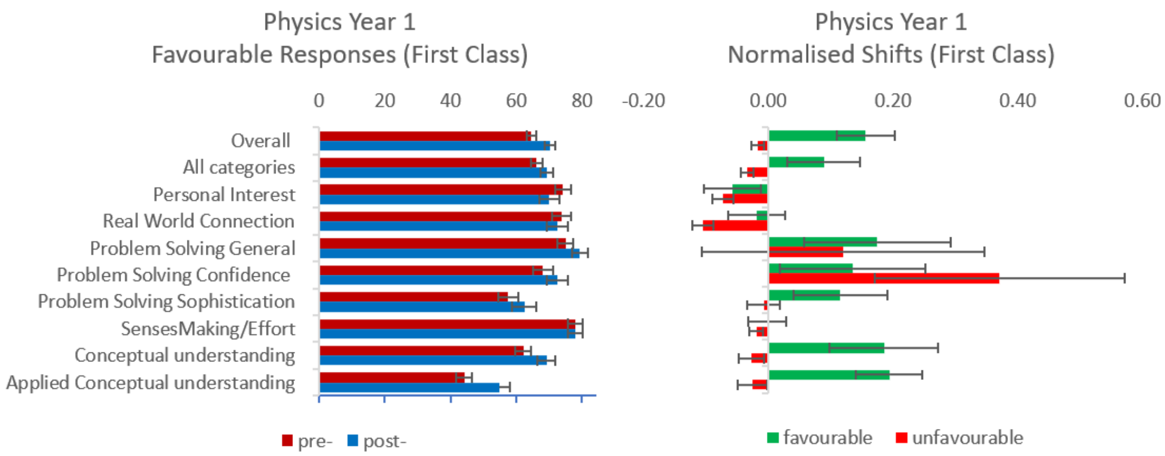

Figure 4 Students who went on to get a first-class degree overall (not necessarily first in physics component) show gains in year 1 in several categories. See caption to figure 1 for an explanation of the normalisation.

Biology

We turn now to the overall shifts in beliefs about science. The following graphs show the distribution (percentage of students) of the percentage change in the number of statements where students agree with experts between pre- and post-instruction. We start with Biology.

In **Figure 5** the changes from the start to the end of year 1 (labelled Yr1 - Yr1) are shown (N = 56) as well as the overall change from the start of year 1 to the end of year 3 (N = 61). So, for example, 30% of students changed their answers over the course of year one to agree with experts in 0 to 10% of the questions. Note that not all students will have contributed to both sets of data (Yr1 – Yr 1 and Yr3 – Yr3); the overlap is 60 per cent. The figure shows a strong shift towards expert beliefs over the longer timeframe between years 1 and 3 compared to that over the first year alone. (Grouping the data into shifts greater than 10%, more negative than -10% and between the two gives χ^2=6.67 with 2df which is significant at the 5% level). One might wonder if the relatively small shift in year 1 could be the result of a relatively small amount of biology in year 1. This appears not to be the case. Core modules in year 1 include biochemistry, physiology, and neuroanatomy comprising about one third of the core science. In contrast to Physics (Figure 7 below) the data shows no difference between higher and lower performing students. Thus attitudes (agreement with expert opinion) and attainment are not surrogates on average.

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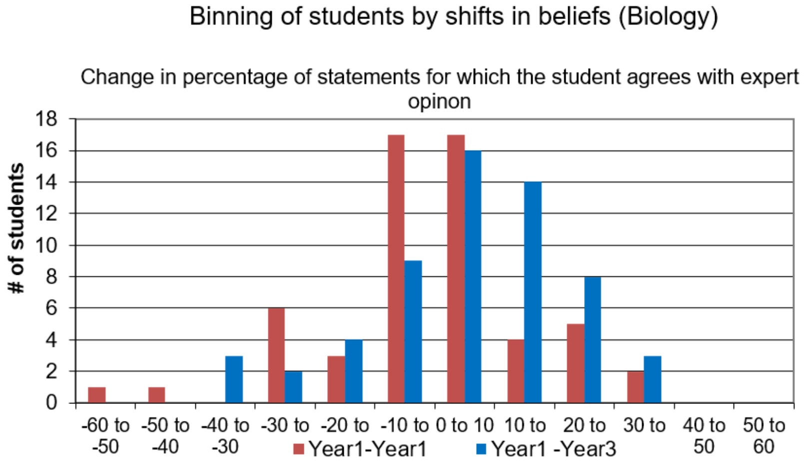

Figure 5 Shifts in beliefs about Biology. The abscissa is the change in percentage agreement between experts and students. The shifts are shown between the start and end of year 1 and over the whole programme.

Chemistry

One of the strongest effects is seen in the first year of Chemistry (Figure 7) which shows the pre- and post- distribution of beliefs across the sample.

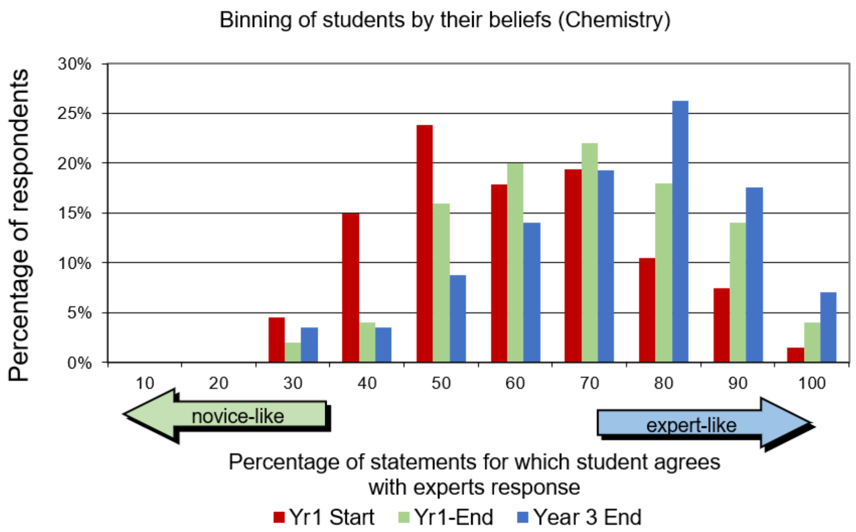

Figure 6 Percentage agreement between students and experts in Chemistry at the start and end of year one and the end of year 3.

The CLASS data in **Figure 6** show a strong shift to more expert-like opinions over their first year, which continues throughout the programme.

Perhaps we conclude that while students develop an insight into chemistry in year 1 it takes longer to develop an understanding of biology beyond a collection of facts. Evolution, genetics and population genetics, which constitute some of the more conceptual aspects of biology are taught in years 2 and 3 while chemistry naturally begins with the periodic table and reaction mechanisms.

Physics

Figure 7 shows the shifts for Physics over year 1 for students who went on to obtain a first class degree and for the remaining students. There appears to be a small difference with higher achieving students becoming more expert-like but the result is not significant. (Re-binning the data to distinguish small shifts around zero (-5 to 5) as effectively zero and thereby separating out the larger shifts into bins (±5 to ±15) and so on does give a significant shift but of course with small effect size.)

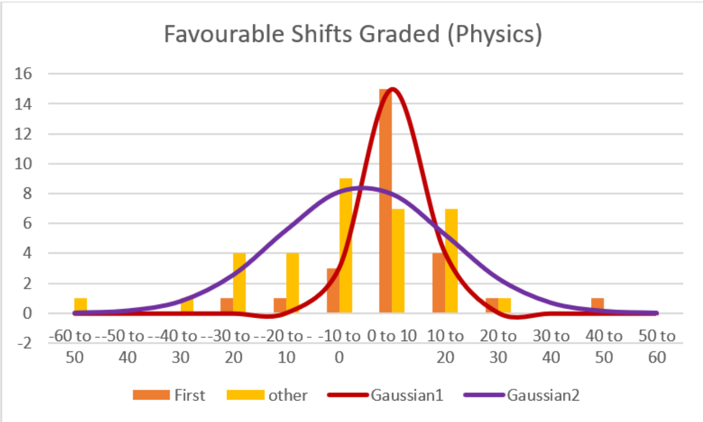

Figure 7 Shifts in beliefs about physics over year 1 compared. The "upper" group (in red) comprises students who went on to obtain a first-class degree; the "lower" group (in blue) comprises the remaining students. The best fits to a normal distribution are shown.

The weak move towards expertise in the combined data (for both the upper and lower groups of students) is also not significant.

In the UK, the absence of shifts to expert-like beliefs in a physics class has been reported by Slaughter et al., (2011). This being the case in this highly selective institution it is perhaps not surprising that we do not see significant positive shifts for physics in our cohorts which are not selected on aptitude for physics. One might hypothesise that the difference between physics and the other disciplines is the mathematics content. One can dispute this on the basis of the common mathematics curriculum in the programme examined here-for the most part the mathematics content (differential equations and linear algebra) is common between the disciplines and diverges only with the vector calculus required solely for physics in year 3. But in any case, the self-reported gains in confidence in mathematics from a separate survey of a subset of the same student cohorts show a small positive shift over the years (effect size 0.23). Only two students in year 1 and three in year 3 thought that mathematics was making no contribution. It is not an overwhelming vote of confidence, but nor is it an obvious source of the issue with physics.

On the other hand, it is well-known that many students find it difficult to transfer what they have learnt in a mathematics class to a physics context. This may well be contributing to the results we see here despite the close alignment of the mathematics and physics teaching.

An alternative hypothesis is a "cliff edge" effect where students who are having difficulty will selectively abandon certain topics, although we cannot investigate that further here.

Several further points about Physics may be relevant. First, the problem seems to be mostly between years 1 and 2 where overall agreement in physics questions declines from 62.8 ± 1.6% at the end of year 1 to 58.3 ± 1.9% at the end of year 2. Second, the overall agreement amongst those students who go on to obtain first class degrees (without regard to their performance in the embedded physics component) goes from 64.6 ± 1.8% to 70.2 ± 2.4% over the first year. This endpoint is close to that for science majors in the Edinburgh survey (which did not change over their first year). Nor is it much different from the average in the final year of 68.1 % overall agreement in physics for this subset of our students. It may be (Gire et al., 2009) that students' expert-like attitudes to physics are largely a pre-existing trait of students who choose to be a physics major rather than something that can be

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changed through courses. If this is true, this “pre-existing” trait has been developed in early education and may point to a need to look at early experiences with physics.

Summary

Figure 8 shows a summary of the results. The box plot shows the percentage overall agreement between students and experts at the start of year 1 and the end of the final year. The large shift in chemistry, the positive shift in biology and the negligible shift for students in physics.

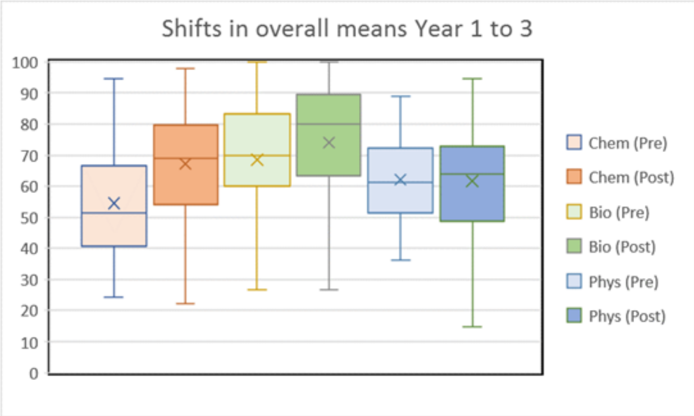

Figure 8 Box and whisker plot of the % overall agreement between students and experts at the start of year 1 and the end of the final year.

Gender Gap

There is no statistically significant difference in the distribution of entry qualification between male and female students surveyed and in the distribution of their degree outcomes as a function of entry qualifications. We can therefore make direct comparisons between the attitudes to science of male and female students. We again find no statistical difference in any of the disciplines: there is no discernible gender gap.

Discussion

A lot of research in science takes place in the interdisciplinary domain whereas at secondary and undergraduate levels in the UK science is highly siloed into disciplines. There appears to be no research on the transition of graduates from a discipline focussed background moving on to interdisciplinary postgraduate research, but even if the transition were to be unproblematic there are strong reasons to believe that greater interdisciplinarity throughout STEM education would be beneficial. These include greater engagement through more relatable real-world relevance, greater freedom of delayed choice and increased general scientific literacy. A counter-argument often offered is the need for an extended period of study to develop expertise in any one field, let alone several. It was not our intension in undertaking this research to dispute the need for extended study. The results suggest however that for the most part attitudes to science (as opposed to content knowledge) are formed in the first undergraduate year with perhaps somewhat longer for our biology curriculum and with the exception of the decline in physics in year two for weaker students. Our principle research question was whether expert attitudes could be fostered while studying multiple disciplines in the absence of direct instruction in what an expert attitude comprised. The absence of explicit instruction in the nature of the discipline allows us to make direct comparisons with single subject programmes which generally do not contain a compulsory instruction on the nature of science.

The extended time frame of the study enables us to distinguish between the intensity of the discipline content and the developing maturity of the students over the whole degree in favour of the greater importance of the latter in developing expert-like attitudes where these are not explicitly taught. Thus, fears in the UK specifically, that interdisciplinary undergraduate science programmes might fail to provide a solid foundation in any of the disciplines appears to be unfounded, although we cannot rule out the research nature of the pedagogy as a contributing element to the case presented here. For physics, the results are not so encouraging. It is particularly disappointing that the departure from the standard curriculum, for example putting clearly applicable thermal physics before the more mathematically intense Newtonian dynamics, has failed to fully engage these students. Further work is required here to understand this more fully.

Our conclusion from the research is that extension across disciplines does not necessarily exclude gain of expert attitudes: even after one year of undergraduate study across the three main disciplines our students are no more confused about the nature of the different sciences than their single subject peers.

Of course, there is a need to repeat this work with a larger sample under different pedagogies, but our preliminary conclusion is that the development of expert-like attitudes to the individual sciences are possible within a highly interdisciplinary curriculum.

References

Abaniel, A. (2021). Enhanced conceptual understanding, 21st century skills and learning attitudes through an open inquiry learning model in physics, *Journal of Technology and Science Education*, JOTSE, Vol 11 No1 pp30-43.
https://doi.org/10.3926/jotse.1004

Adams, W.K., Perkins, K.K., Podolefsky, N.S., Dubson, M., Finkelstein, N.D. and Wieman, C.E. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey, *Phys. Rev. ST Phys. Educ. Res.*, Vol 2, p 010101 (2006).
https://doi.org/10.1103/PhysRevSTPER.2.010101

Adams, W.K., Wieman, C.E., Perkins, K.K. and J. Barbera, J. (2008). Modifying and validating the Colorado Learning Attitudes about Science Survey for use in chemistry, *J. Chem. Educ.*, Vol 85, No 10, p1435.
https://doi.org/10.1021/ed085p1435

Bates, S.P., Galloway, R.K., Loptson, C. and Slaughter, K.A. (2011). How attitudes and beliefs about physics change from high school to faculty, *Physical Review Special Topics - Physics Education Research*, Vol 7.
https://doi.org/10.1103/PhysRevSTPER.7.020114

Barbera, J., Adams, W. K., Wieman, C. E. and Perkins, K. K. (2008). Modifying and validating the Colorado Learning Attitudes about Science Survey for use in chemistry, *Journal of Chemical Education*, Vol 85, No 10, pp1435-1439.

Brewe, E., Kramer, L. and O'Brien, G. (2009). Modelling instruction: Positive attitudinal shifts in introductory physics measured with CLASS, *Physical Review Special Topics - Physics Education*, Research Vol. 5.
https://doi.org/10.1103/PhysRevSTPER.5.013102

Carolan, J., Deslauriers, L. and MacDonald, A. (2014). Longitudinal Physics Attitude (CLASS) Data, https://cwsei.ubc.ca/sites/default/files/cwsei/outcomes/EOY/Carolanetal_PhysicsAttitudeData_CWSEI-EOY2014.pdf (accessed 26/01/23).

Ding, L. and Mollohan, K.N. (2015). How College-Level Introductory Instruction Can Impact Student Epistemological Beliefs, Journal of College Science Teaching, March/April 2015, Vol. 44, No. 4, pp. 19-27.
https://www.jstor.org/stable/43631861

Duis, J.M., Wieman, C. and Schafer, L.L. (n.d), General chemistry students' beliefs about chemistry and learning chemistry: An international comparison.
https://cwsei.ubc.ca/sites/default/files/cwsei/outcomes/EOY/JenniferDuis_intl_comparison.pdf

Geller, B. D., Turpen, C. and Crouch, C. H. (2018). Sources of student engagement in Introductory Physics for Life Sciences, *Physical Review Physics Education Research*, Vol 14.
https://doi.org/10.1103/PhysRevPhysEducRes.14.010118

Lee, S. W.-Y., Luan, H., Lee, M.-H., Chang, H.-Y., Liang, J.-C., Lee, Y.-H., Lin, T.-J., Wu, A.-H., Chiu, Y.-J., and Tsai, C.-C. (2021). Measuring epistemologies in science learning and teaching: A systematic review of the literature, *Science Education*, Vol 105, No 5, pp 880-907.
https://doi.org/10.1002/sce.21663

Lindsey, B.A., Hsu, L., Sadaghiani, H., Taylor, J.W. and Karen Cummings, K. (2012). Positive attitudinal shifts with the Physics by Inquiry curriculum across multiple implementations, *Physical Review Special Topics-Physics Education Research*, Vol 8, 010102.
https://doi.org/10.1103/PhysRevSTPER.8.010102

Hansen, M.J. and Birolm G. (2014). Longitudinal Study of Student Attitudes in a Biology Program, *CBE-Life Sciences Education*, Vol. 13, 331–337.
https://doi.org/10.1187/cbe.13-06-0124

Milner-Bolotin, M., Antimirova, T., Noack, A. and Petrov, A. (2011). Attitudes about science and conceptual physics learning in university introductory physics courses, *Physical Review Special Topics -Physics Education Research*, Vol 7, 020107.
https://doi.org/10.1103/PhysRevSTPER.7.020107

Nissen, J.M., Horses, I.H.M. and Dusen, B.V. (2021). Tools for identifying courses that support development of expert like physics attitudes, *Physical Review Physics Education Research*, Vol 17, 013103.
https://doi.org/10.1103/PhysRevPhysEducRes.17.010116

Presley, T.D., Harp, N.A., Holt, L.S., Samuel, D. and Harp, J.J. (2021). Incorporating Physics Principles in General Biology to Promote Integrative Learning and Thinking, *International Journal of Innovative Teaching and Learning in Higher Education*, (IJITLHE) Vol 2 No 1.
https://doi.org/10.4018/IJITLHE.20210101.oa5

Robinson, A., Simonetti, J.H., Richardson, K. and Megan Wawro M. (2021). Positive attitudinal shifts and a narrowing gender gap: Do expert like attitudes correlate to higher learning gains for women in the physics classroom? *Physical Review Physics Education Research,* Vol 17, 010101.
https://doi.org/10.1103/PhysRevPhysEducRes.17.010101

Raine, D J., (2013). Scaffolding PBL in For the Love of Learning: Innovations from Outstanding University Teachers Ed. Tim Bilham (Palgrave Macmillan).

Raine, D. J., (2020). Problem-Based Approaches to Physics: Changing Perspectives in Higher Education, Institute of Physics (UK), iopscience.iop.org/book/978-0-7503-2224-9.

Reid, N. (2008). A scientific approach to the teaching of chemistry: What do we know about how students learn in the science, and how can we make our teaching match this to maximise performance? *Chemistry Education Research and Practice*, 9, 51-59.

Reddy, L. (2019). The measurement of the impact of teaching on attitudes by use of the Colorado learning attitudes about science survey in physics, in 27th Annual Conference Of The Southern African Association For Research In Mathematics, Science And Technology Education, ed Edited by N Govender, R Mudaly, T Mthethwa and A Singh-Pillay, pp187-199.

Sahin, M. (2010). Effects of Problem-Based Learning on University Students' Epistemological Beliefs About Physics and Physics Learning and Conceptual Understanding of Newtonian Mechanics, *J Sci Educ. Technol*., Vol 19 pp266–275.
https://doi.org/10.1007/s10956-009-9198-7

Semsar, K., Knight, J.K., Birol, G. and Smith, M.K. (2011). The Colorado Learning Attitudes about Science Survey (class) for use in biology, *CBE Life Sci. Educ*., Vol 10, p268. Published Online:13 Oct 2017.
https://doi.org/10.1187/cbe.10-10-0133

Slaughter, K.A, Bates, S.P and Galloway, R.K. (2012). A longitudinal study of the development of attitudes and beliefs towards physics, PERC 2011, AIP Conf. Proc 1413, 359.
https://doi.org/10.1063/1.3680069