Vol 13 | Issue 3 (2025) | pp. 17-34

JOURNAL OF
Perspectives in Applied Academic Practice

https://jpaap.ac.uk/

Student perceptions of embedded employability skills in a problem-based learning natural sciences programme

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ABSTRACT

Employability has become globally an explicit graduate outcome usually, although not without challenge, articulated as a set of graduate skills or capitals. It is therefore important to consider curriculum design and pedagogies that support these outcomes. Problem-based learning (PBL) is often cited as an effective pedagogy in this regard, particularly in education for the professions. Much less attention has been paid to pedagogies for employability in the pure sciences. Here we survey student perceptions of employability skills in an interdisciplinary science degree, taught by PBL, as they develop in the course of an undergraduate programme encompassing seven cohorts over five years. We present evidence from annual surveys that students' beliefs in their acquisition of skills and in their importance grows over the years of their degrees. We emphasise the importance of conceptualising and embedding employability (as with the science content) as a developmental activity with multiple opportunities for systematic practice.

Keywords: embedding employability, problem-based learning, interdisciplinary science, graduate skills

Background

'Employability' has slowly risen up the higher education agenda over a number of years in the UK in response to employer criticisms of graduate capabilities and student demand for better value for money from their university experience. In science, technology, engineering and mathematics (STEM) the well-known surveys (Hanson & Overton, 2010a, 2010b; Sarkar et al., 2020; Rayner & Papakonstantinou, 2015) are often quoted as evidence of the mismatch between employers' needs and graduate attributes. Criticisms of the skills agenda in higher education (HE) as a lunge towards vocational training, and the resulting resistance to implementation by academics (Radloff et al., 2008), have been met by redefinitions of professional skills in terms of employability (Artess et al., 2016), and graduate attributes and graduate capitals (Tomlinson, 2017). Cook (2020), in reviewing various models of employability, proposes a much broader approach that we would call 'citizenship'. (See also Nagarajan & Edwards, 2014). Our focus here is on the more restricted understanding of employability current in the UK science community, (for example, Hanson & Overton, 2010a) but we comment on these broader aspects in the discussion. It is beyond question that degree programmes should produce employable graduates, in our limited sense, even if some employer wish-lists are unattainable in a three- or four-year undergraduate degree. The focus therefore turns to how, in the content-heavy curricula of degree programmes in pure sciences, we can or should incorporate employability.

One approach to incorporating employability is to add employability modules as part of the formal curriculum. There is evidence of difficulty in getting staff and students to engage with standalone 'skills' modules (Drummond, 1998; Cranmer, 2006; Tymon, 2013; Chan et al., 2017; Jorre de St Jorre, 2018). A further disadvantage is the lack of opportunity to transfer these skills to a meaningful context (Robley, 2007). An alternative approach that involves outsourcing the task to employers through compulsory work placements is unlikely to be universally applicable in a mass higher education system, at least within the current UK structure. Another alternative approach envisages learning for careers alongside the development of professional and transferable skills within the discipline, as in the CareerEDGE model (Pool, 2013). The traditional capstone project goes some way towards fulfilling the development of graduate skills (Demaria et al., 2018; Hart & Bone, 2022). Similarly, the Undergraduate Research Experience (Newell & Ulrich, 2022) in which students are apprenticed to university research teams for a short period, over a vacation for example, has been promoted as a means of incorporating work skills into the university environment. However, in our view, such one-off experiences do not generally provide sufficient scope for personal growth, and resource constraints mean they are all but impossible to scale.

This is where problem- (or project-) based learning comes in. Students work in groups to research problems or projects as they might in employment, but on content that systematically develops their core discipline knowledge. Problem-based learning (PBL) has been widely investigated in the context of the development of discipline knowledge and many authors comment on the opportunities for the enhancement of employability skills through PBL (Williams, 2017; Smith et al., 2013). Indeed, if PBL is aligned with authentic assessments (Ashford-Rowe et al., 2014), then the potential for the development of professional skills will be embedded in the programme (Dalrymple et al., 2022). Thus, PBL is now widely practiced in many fields of professional training.

However, much less attention has been paid to the embedding of employability within the pure sciences where professional skills have until relatively recently been aligned with a career in academic research. Thus, employability in a broader context is widely treated as a separate additional component in the curriculum. If we interpret the embedding of professional skills in pure science in terms of the emulation of real-world research projects then, with the ubiquitous exception of the capstone project, we can at least partly understand the problem: it is difficult to provide authentic research scenarios at undergraduate level. A consequence is that PBL in the pure sciences has generally been restricted to discipline content in early years or to modules focussed mainly on these bolt-on professional skills.

The research question that we now address is ‘to what extent do the students on a science programme, delivered by a form of PBL, recognise the employability skills embedded in the programme pedagogy and how does this change over time?’. By speaking of recognition we attempt to embrace both the perception of the importance of the skills and of the confidence with which they are acquired. This contrasts with studies that focus mainly on the effectiveness of PBL pedagogies for discipline knowledge (Acton, 2019) and with PBL pedagogies in vocational or professional programmes (Dunlap, 2005; Koh et al., 2008; Martin et al., 2008; Boelt et al., 2022). There is an extensive literature on employability in such problem-based pedagogies (Li et al., 2020; Balslev et al., 2018; Rahman et al., 2023; Othman et al., 2017) (framed, as in our question, as the acquisition of a list of supposedly transferable skills). In the pure sciences interventions using PBL to enhance employability are widely made at the module level (Sakar et al., 2018; Williams, 2017; Hart, 2019). However, it is by no means a given that our results will align with studies in these other contexts.

While there is some disagreement on the ranking in the importance of skills, when framed in terms of a list of skills and particularly in the context of STEM, academic staff and students generally agree on what employability entails (Billing, 2003, p.346):

"employers in English cultures behave in their recruitment and training activities as if there is a common understanding of generic skills needs". See also for example the lists in Sarkar et al., (2020) and Wharton et al., (2015) and Lackovic (2019, p.193): "the dominant GE paradigm still remains at the level of enhancing graduates' skills, competences and attributes".

We have broadly adopted this set of what might be called personal and interpersonal attributes in our surveys as shown in the figures below. The list excludes some of what are more recently referred to as 21st century skills, particularly IT and data-related (Tight, 2023). However, in the context of authentic assessment, a bullet-point list of headings is inadequate. This is particularly evident in written and oral presentations, where both the audience and level of difficulty should develop over time. (What counts as a presentation skill? – give a TED talk?) Thus, by including how students' views evolve we conceptualise employability as a process: students do not so much obtain a (tick-box) skill as become skilled. This aspect is emphasised by Barnett (2011) for whom employability is a *process* of lifelong and life-wide learning and similarly by Holmes (2013) who argues for a concept of graduate identity. In a problem-based approach the process begins at the undergraduate level as students work as professional scientists in contexts designed to address employability skills. The only concession to the pure sciences is in the construction of a model problem environment rather than a strictly real-world environment. (See context section.) Lacković (2019) contends that understandings, perceptions and actions associated with graduate employability should also consider wider perspectives that question employability with respect to society, environment and technology. This indeed broadens the scope of a problem-based approach within the pure sciences wherein such issues can arise naturally.

Finally, we should note the need to help students articulate employability skills (Lock & Kelly, 2022). In our surveys students are presented with a list of skills which (informally) we find is much more extensive than items they would generate unprompted and much less significant for them than discipline content. We shall come back to this below in considering the views of graduates from the programme where we find a greater appreciation of skills development.

Conceptual Framework

As discussed above, there are multiple characterisations of what we mean, or ought to mean, by employability. Here we are concerned with a list of individual personal and interpersonal skills. It is easy to criticise this approach: graduate capitals are more holistic than just a tick list of skills, but such a list should be a minimum requirement. Given this minimum the question arises as to how these are best acquired. Our research question (on the progress over time) addresses the way skills, once taught, are developed over time by use in an authentic context.

Context

Here we look at the Natural Sciences degree programme at the University of Leicester in the academic years 2014-15 to 2019-20. Each year of the three-year BSc programme comprised five consecutive core modules taught by PBL, with one PBL problem in each module. Each core module in the programme was interdisciplinary, involving at least two of biology, chemistry, physics and earth sciences. In the pure sciences the problems are *modelled* on real world contexts, rather than being realistic real-world projects, in order to keep the content at the appropriate level. The real-world context is provided by authentic assessments (Ashford-Rowe et al., 2014). Two examples of PBL problems from the programme are "How do physics, chemistry and biology limit the maximum speed at which a human could run?” and “How can the domestication of maize, from the morphologically very different wild Mexican grass teosinte, have occurred in only 5,000 to 10,000 years?” In addition to the core discipline modules, in each year there were year-long ‘support’ modules consisting of a laboratory module, a mathematics module and a skills module, none of which used a PBL pedagogy.

The cohorts were small, typically around 20 students, most of whom were school leavers. (Three students transferred from other universities or programmes; two were mature students.) Survey responses were anonymous; because of the small cohorts we did not collect demographic data. We can however say that the cohorts largely reflected the university-wide demographics - students from ethnic minorities: 60%; IMD Q1 & Q2: 42%. (see Health Equality Evidence Centre (HEEC, no date) for the Index of Multiple Deprivation (IMD).)

The PBL curriculum was delivered by a core teaching team of five teaching-focussed academics (part-time on this programme) all of whom had previous experience in PBL. They were supported by specialist contributions in the form of lectures and workshops by about 40 research academics from across the university. There was also a small cohort of year four integrated masters students taught through project work. The programme began in 2007 and changed markedly over the first iterations. During the period from 2014-2019 to which the data in this paper refers, the main structure and delivery was largely unchanged. (There were tweaks to scheduling and documentation and changes to problem statements but not to the scientific content or main assessments).

Group assessments were designed to be ‘authentic’ in as much as they specified the intended audience and context such as might be appropriate to a practising scientist. (So, for example, not write “a report” but “a technical report for an insurance company”). Marks for the skills element of each PBL module contributed to the overall mark for the skills module. Thus, although the skills were embedded, the outcomes for skills and academic content were assessed and reported separately. There was also an individual unseen examination for each core module and one for mathematics contributing around 35% of the assessment load.

Graduates of the programme went on to research degrees in various sciences and to careers in teaching, industrial research, public service, media and management.

Scaffolding

The importance of support for the PBL process, commonly called ‘scaffolding’ has been emphasised (Smith & Cook, 2012; Gretton et al., 2014; Volman et al., 2010) and can take various forms. In what we might call pure PBL or the McMaster model (Barrows & Tamblyn, 1980) support is provided mainly through facilitation or supplemented by a schema of work (for example, the Maastricht 7-steps (Maastricht University, n.d.; Wood, 2003). In our implementation we went further with the provision of an on-line module handbook which specified the pre-reading, discussion questions and exercises for each contact session. There were no lectures in the traditional format, but students did have contact with relevant subject experts from across the institution for two hours a week. These were intended to be interactive rather than purely transmissive (occasionally more “honoured in the breach”). There were two group facilitation sessions a week (a total of three hours) and what were referred to as tutorial sessions provided feedback once a week on the assigned exercises. We refer to this model as ‘problem-based tuition’ (Gretton et al. 2021, Raine 2015).

Additional scaffolding was provided by the support modules in maths, practicals and skills. The skills activities were sequenced to relate to the assessment types in the concurrent core module. So, for example, if the core module assessment called for a report the parallel skills module would support report writing. Some skills were not taught formally (see below), but their acquisition was implicit in practice.

Method

The project grew out of a staff-student partnership to investigate the efficacy of PBL in two assessed capstone projects in successive years. The two students involved both found PBL challenging and were keen to investigate their peers' appreciation of the pedagogy and their views on its efficacy. Their initial hypothesis was that the results of the project would confirm their negative perceptions.

Ethics approval was covered under university approval for anonymised survey data for student educational research projects, and for anonymised graduate interview data, retained in a non-networked file store.

A paper-based survey questionnaire was given to all students in two successive years and subsequently as an on-line survey administered by academic staff over a total of five years. The first set of questionnaires were distributed in paper form in a class setting at the end of the period of formal teaching prior to examinations; subsequently the questionnaires were distributed after the end-of-year examinations. In the final three years these surveys were completed online. Consent was obtained and data was collected anonymously. To short-circuit the validation stage the survey was based on a similar project at McMaster (Symons et al., 2017). Where questions asked for a positive or a negative response, we used a 7-point Likert scale ranging between "1 = not-at-all-important/confident" through "4 = somewhat important/confident" to "7=very important/confident". In the analysis we use a linear scale to evaluate outcomes. Given that responses almost entirely avoid the extremes of the scale this assumption of linearity seems reasonable. Where our survey questions differed from the McMaster template (for example where McMaster students were asked to respond by drawing a graph) we used a 10-point scale to try to pick up in a simpler way the more graded variations.

Table 1 shows the response rates. The programme underwent substantial changes for the 2018-9 entry so data from this and the subsequent cohorts excludes students on the revised programme.

Table 1 Survey response rates. Rows are student year groups. For each academic year the pair of columns shows the total student number and the number of responses respectively. There were no recruits to this version of the programme from 2017.

	M/F	2014-15		2015-16		2016-17		2017-18		2018-19		Response rate	Overall	Overall %
Year 1	F	9	3	22	13	8	1					17/39		
	M	7	3	13	7	17	10					20/37	37/76	49
Year 2	F	8	5	7	6	12	3	4	2			16/31		
	M	12	7	7	6	12	5	13	3			21/44	37/75	49
Year 3	F	6	5	6	5	7	4	12	2	4	0	16/35		
	M	9	7	12	9	7	3	13	2	11	6	27/50	43/85	51
Year 4	F	0	0	3	3	0	0	4	0	4	3	6/11		
	M	6	5	2	2	3	3	2	1	5	4	15/18	21/29	72

The overall response rate was 83/149 for male students and 55/116 for female students. Since the questionnaires were anonymous we do not know how many students responded in more than one year, so the trends over time refer to cohort samples not necessarily the same groups of students. The number of year four masters students in each cohort was typically less than 5, so we have included these with final year BSc students in 'year 3'.

We use student confidence as a proxy for the development of skills over time. While this may be limited by the known tendency of weaker students to overestimate their abilities and conversely for stronger students (e.g. Karaca et al., 2023), the evidence refers to content knowledge and prior to feedback. This effect should be moderated by the fact that we are asking students to evaluate the changes in their confidence over time retrospectively, that is after evaluation and feedback. We divide skills into those explicitly taught skills (independent learning, research, writing, information retrieval, preparing visuals, presentations) and those that are implicit (the rest, see fig 2). This is not strategic: it is a post-hoc identification of the skills that we assess in the programme.

The data were analysed in Excel. Where error bars are shown in the histograms these are standard errors. Where statistical significance is mentioned we have used a chi-squared test or a t-test for the difference of means as appropriate. Effect sizes are Cohen's *d.*

Perceived Importance of Skills

Figure 1 shows the reported importance of skills from year-1 and year-3 undergraduate students and graduates. The graduate data, taken from Sarkar et al. (2017), is the fraction answering useful (4) or very

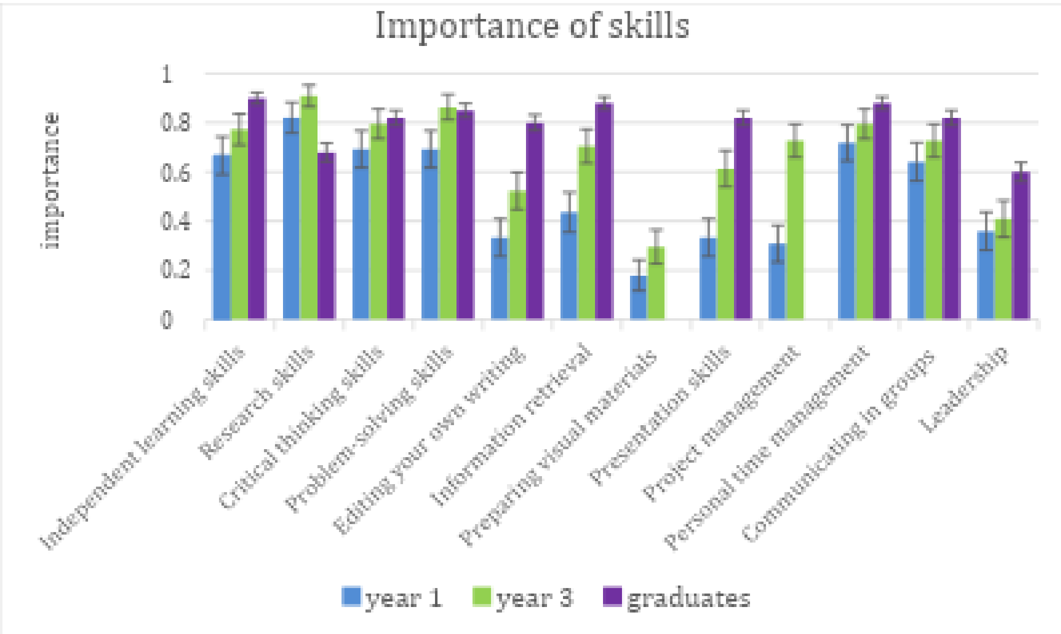

Figure 1 The Recognition of the Importance of Professional Skills. The ordinate is the overall fraction of responses that rate each skill as important. For undergraduates this is the fraction rating the skill as 6 or 7 on a 7-point Likert scale of importance. For graduates it is the fraction rating the skill as 4 or 5 on a 5-point scale. Error bars are sampling errors for proportional data . N=39 (year 1), N=44 (year 3) N= 159 (graduates)

useful (5) on a 5-point scale, using the unweighted average values for graduates in work and those in further study. (Weighting by the relative numbers 95:64 would make no difference to the discussion.) The undergraduate data is derived from responses on a 7-point Likert scale ranging between "1 = not-at-all-important" through "4 = somewhat important" to "7=very important". The "year 1" data is from

39 students and "year 3" from 44. In order to make a comparison between our undergraduate responses and the graduate data from the literature we take for the former the fraction of students responding 6 or 7. Since the scales are different, the absolute values for the graduate and undergraduate data are not strictly comparable numerically, so in particular the slightly higher values for graduates generally are not meaningful. However, the trends are clear. We see that the graduate data show a similar relative perceived importance between skills to that from our undergraduate cohorts and a similarly high value across the range. The notable exception is research skills where the PBL pedagogy appears to have an advantage.

Note the increasing realisation of the importance of almost all skills amongst undergraduates between the end of year one and the middle of year three and that by year three students attach quite a high level of importance to most of the skills found useful by graduates.

Figure 2 also shows the development of skills over the three-year programme. The ordinate in this figure is the average response on the seven-point Likert scale rather than the fraction of top responses. Note that the trends match those in figure 1, although it is interesting that they are not so pronounced (despite the false origin). We shall see later (e.g. figure 3) that this is because responses tend to be dominated by the middle ground (a well-known aspect of 7-point scales).

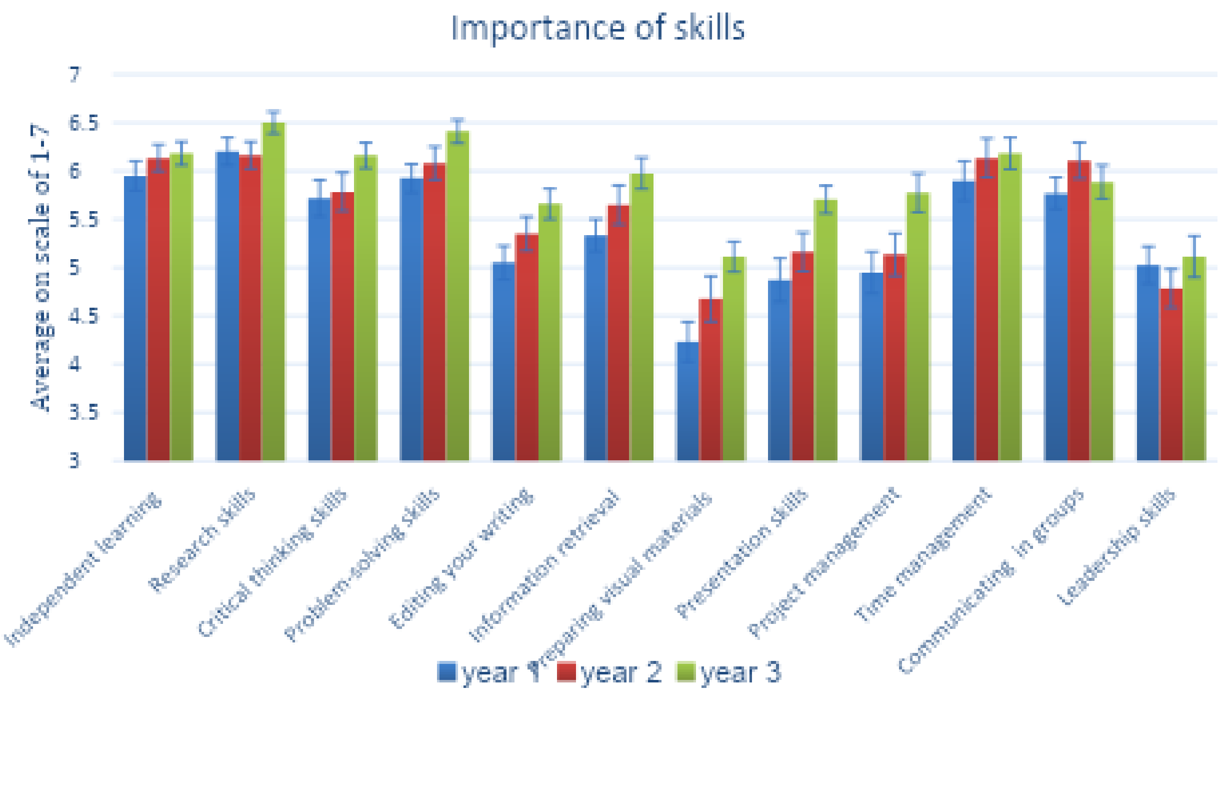

Figure 2 Changes in Importance Attached to Various Professional Skills in the Programme over three academic years N=39, 36, 43 (years –3 resp.)

It is clear from the figure that students come to university with some preformed ideas of what is expected: they expect to be independent learners, to develop research and problem-solving skills, and abilities in time management and communication. Their appreciation of the importance of such things as presentations, editing and project management develops over the course of the programme.

Effect sizes are in the range small to medium (0.2 to 0.5) with generally somewhat larger changes between years two and three than between one and two, again indicating a growing recognition of the relevance of these skills. The only significant outliers are leadership and the preparation of visual materials, which are barely deemed to be important, at least when compared with other attributes.

To see in more detail the shifts, we look as an example, at the distribution of responses for presentation skills (Figure 3) This shows more clearly the growing perceived importance. Not only does the median shift, but every student grows to recognize the importance of presentation skills to some extent. We get similar results for other skills wherever there is a significant effect size between years in figure 2.

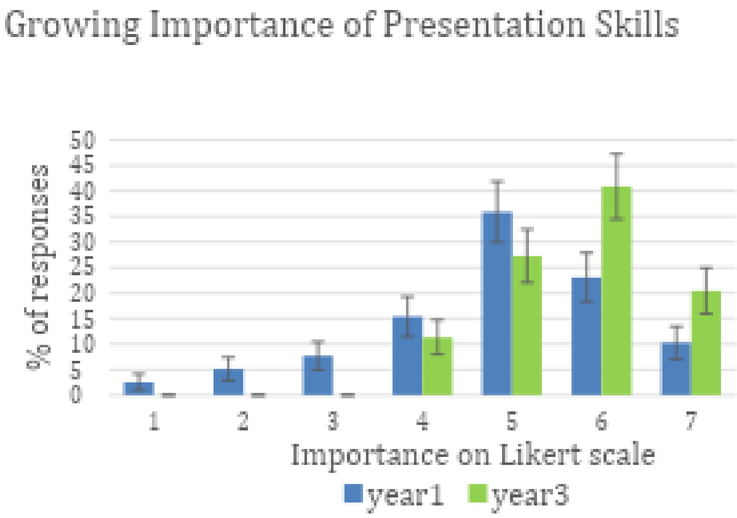

Figure 3 The Perceived Importance of Presentation Skills

Confidence in the degree

Having established students' appreciation of the importance of professional skills, we ask next the extent to which they think the degree develops these skills.

In many skills there is again a significant effect size between year one and the final year (figure 4). This is an important result in that it points to the need to develop skills over time by structuring the learning cycle to provide multiple graduated opportunities to build competence. The only significant outlier here is leadership in which students have limited confidence which does not change significantly over the years.

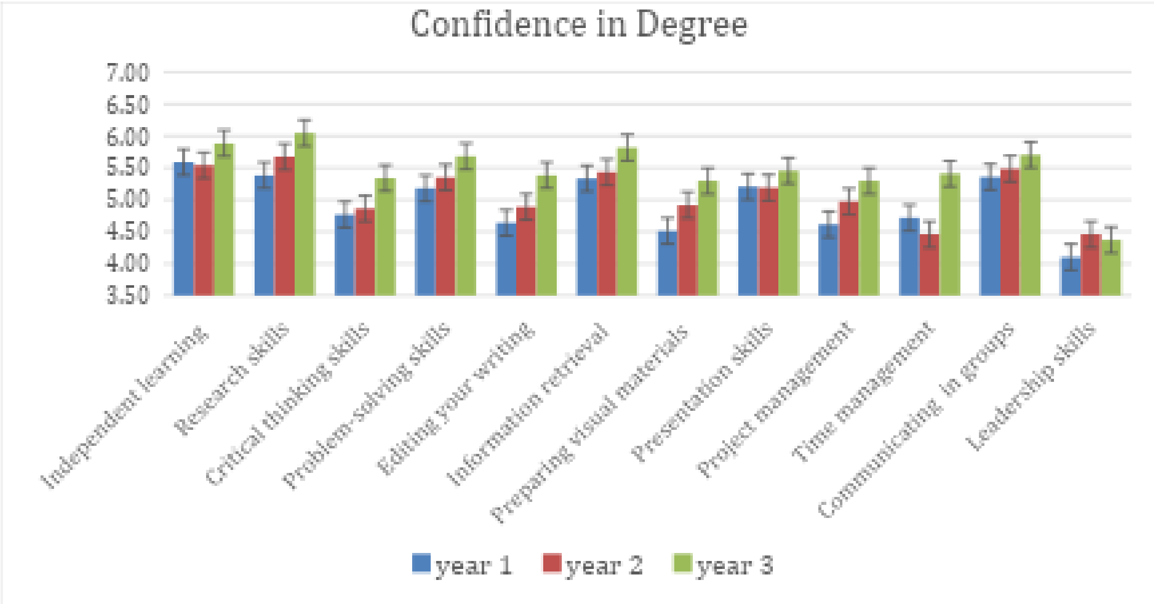

Figure 4 Confidence that the Degree is Delivering a Skill (average response on a 7-Point Likert Scale) (N= 39, 36, 43, years 1- 3 resp.)

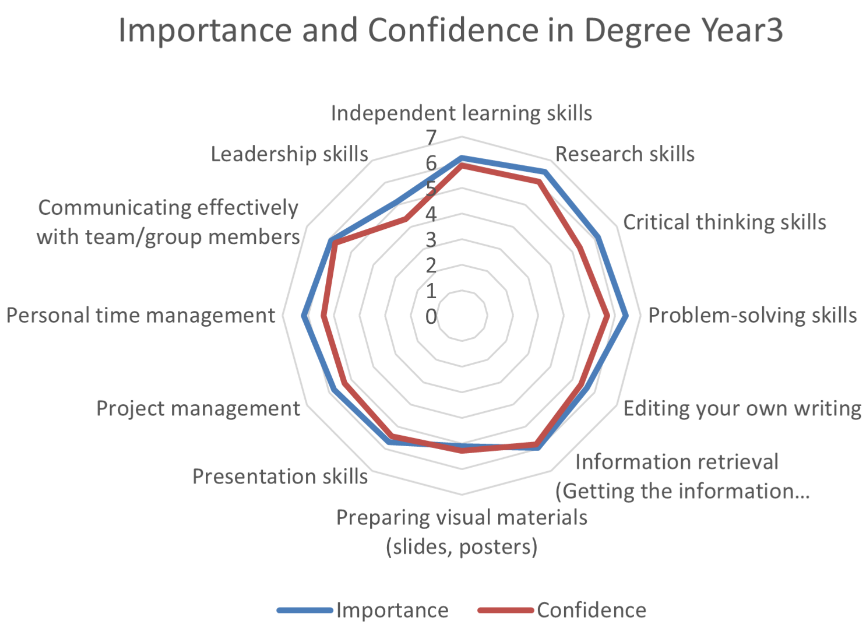

Figure 5 Perceived Importance and Confidence in Delivery Compared

We can confirm the impression that students attach equal measures of importance to the skills they are confident they are attaining with a radar plot of importance and confidence (Figure 5).

There is no statistical difference between the importance students attach to a skill and their confidence that the curriculum provides it (t-tests for differences in the means).

Explicitly Taught versus Implicit Skills

We compare confidence that the degree is delivering in explicitly taught skills (independent learning, research, writing, information retrieval, preparing visuals, presentations) with those that are implicit (the rest – as listed in figure 2). The means are 5.65 and 5.28 respectively which are significantly different ($t = 2.13$, $df = 526$, $p < 0.05$). So, students are probably more confident where they recognize that a skill is being explicitly taught. Note that the skills modules in each year were credit bearing, with the marks for the module derived from performance on core module assessments. (Recall that the authentic assessments of core modules are explicitly designed to test specific skills which are marked separately from the discipline content.)

Discipline Confidence

At this point one may question whether we have sacrificed discipline knowledge for employability (or what are sometimes dismissed as "soft skills"). Recall, that the focus is not in our evaluation from the instructor viewpoint, which can be answered by referring to the outcomes of the assessments of discipline content, but on the students' views. The anonymity of the surveys means we cannot compare the two, although as noted above it is well known that confident students tend to inflate their performance and vice versa. This is mitigated by the fact that we are looking for *changes* in confidence.

To ascertain the changes in confidence in discipline knowledge we asked students to report how their confidence in the subject has changed since undertaking the course from before they started the degree on a 10-point Likert scale from 1 = "Confidence reduced drastically", 5 = "Confidence at a similar level", 10 = "Far more confident than before". (We have corrected the actual data from the project which labelled "0 = Confidence reduced drastically", but with no "0" response allowed for.)

We can then compare the difference in the mean level of confidence between years one and three (figure 6). The shifts were: Biology: 5.7 ⟶ 7.1; Chemistry: 5.7 ⟶ 6.3; Physics: 5.7 ⟶ 5.6. It looks like physics does not change, but in fact there is a shift both to greater and lesser confidence (figure 6). This contrasts with biology and chemistry where most (and possibly almost all) the shifts are positive.

The survey anonymity means we cannot track individuals, but the general movements are clear from the figure. In biology and chemistry the bins with negative changes in the number of students clearly represent students moving into higher confidence bins where the changes are positive. In physics the picture is less clear. There is an overall loss of confidence although there are some gains. (Compare Gretton & Raine 2024). One might hypothesise that this is linked to confidence in mathematics as the more advanced physics modules become more mathematical, but this is not borne out by the data which shows a general increase in self-reported confidence in maths (data not shown).

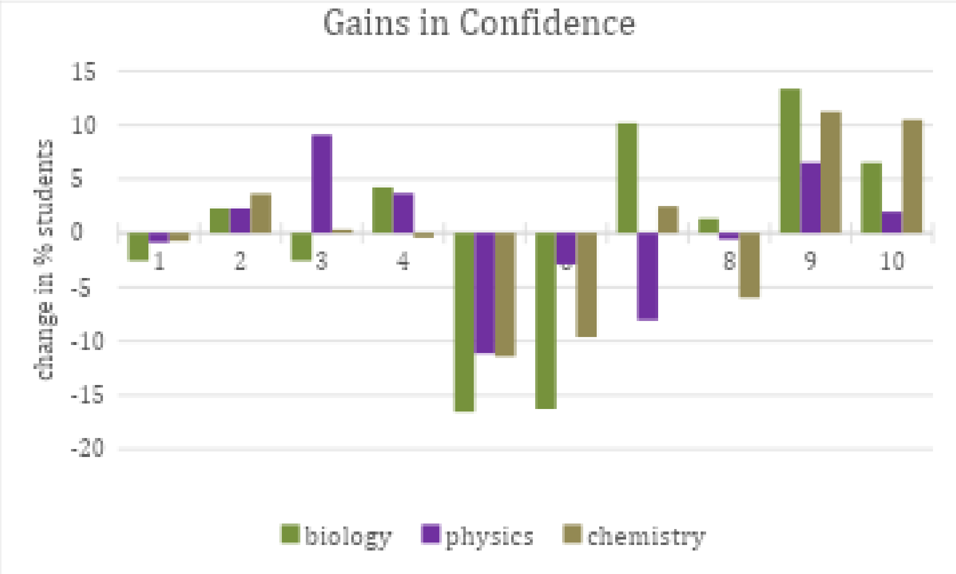

Figure 6 Gains in Confidence from year 1(end) to year 3(end) scaled to 100 Students. The histogram shows the change in the number of students in each confidence bin (low to high) in each subject between the end of year 1 (N=39) and the end of year 3 (N=43).

Graduate Views

The data on graduate views comes from six interviews with recent graduates conducted as part of one of the undergraduate projects. Interviewees were recruited by emails to recent graduates and are therefore probably not a random selection. We have not conducted a systematic thematic analysis but the following points emerged from the answers to a scripted set of topics (as indicated in the headers):

Problem Solving: All respondents agreed that the programme had provided a basis for the solution of problems in the workplace. From the context it was clear that by “problem solving” they were thinking of open-ended “messy” problems and not discipline-based exercises.

Group and Team work: All respondents mentioned this as a positive outcome of the programme, without distinguishing between groups and teams. One graduate suggested that there should be more emphasis on the teaching of group roles.

Leadership: Interestingly in view of the low importance attached to this in the undergraduate survey, this was also mentioned positively by three graduates. They believed that their current ability to take leadership roles in workplace teams was directly attributable to the group work in the degree. This may indicate a selection effect whereby the graduates responding to the request for interviews were the most proactive in group work.

Interviewees were asked if they thought that PBL was more suitable for graduate education rather than at undergraduate level. The responders were unanimously opposed to this idea arguing that this simply delayed the acquisition of necessary skills. The only proviso was that more guidance could be provided on difficult topics.

Time management: All responders mentioned how the training in time management had been beneficial in their work. They referred to multiple deadlines and parallel assignments. If this is a benefit it is to some extent unintentional: the timetable for these students was designed to sequence the assignments and to provide sufficient study periods to complete them. The student responses perhaps reflects one aspect of open-ended problems, namely that the open-endedness – the vagueness of a definitive end-point – conflicts with the finite time allowed for their execution and intensifies the student workload.

Some interviewees did raise issues with the programme. On the discipline aspects more help was needed on computing (mentioned by four graduate students) and some of the harder topics such as quantum mechanics (two graduates). Interestingly, laboratory practicals were the best aspect of the course for one graduate and the worst for another. On the skills side, more help was needed with regard to guidance with employment (one graduate). Three graduates mentioned that they had been in groups with students who did not avail themselves of all the opportunities to learn, and who relied on other group members for topics they found difficult; they felt such students needed more support. Nevertheless, the overall impression is that once they are in employment graduates recognise much more the value of the PBL pedagogy in providing employability skills or graduate capitals as the following quotations signify (not their real names, our italics; quotation marks indicate actual responses – otherwise we have paraphrased for brevity):

Hugo, now grad student: “With hindsight, PBL has been spot-on.”

Donna, Finance Manager: “Without my degree I do not believe I would have progressed as far as I have in the short space of time I have been with [my company]. A degree in science does not mean you are ever restricted in pursuing a career in a completely different field.”

Suzanne, IT company: Her current project involves computer coding, getting a tablet product out and monitoring its quality. She says that the key to where she is today is the research nature of the degree.

Louise is a research scientist and civil servant: originally shy, Louise says that as a result of the degree she now feels confident at delivering information in front of large crowds. Overall, she feels more of a strong character in these high-pressure working environments.

Antony (Clinical research): “With hindsight, I have realised just how many skills that the [Natural Sciences] course and staff there have instilled in me.”

We have quoted these responses at length because we believe they carry an important message for curriculum evaluation: only with the hindsight of experience in employment have these students fully understood the value of the degree pedagogy.

Discussion

The research presented here provides support for our hypothesis that PBL (suitably scaffolded) over an extended time frame provides a natural pedagogy for the embedding of employability (narrowly defined here as transferable skills) in a pure science discipline (or disciplines) without compromising discipline knowledge. This work extends the evidence base connecting PBL and employability from mainly vocational or applied disciplines to pure science. The growth in student confidence in their graduate skills over repeated opportunities across the programme is an important result that points to the advantage of developing skills over time and not through orphaned skills sessions.

Students recognized the importance of most skills over the programme and were overall confident in their acquisition of these skills, but they did not generally recognize PBL, and the associated authentic assessments, as the means by which those outcomes were delivered. The student focus, in contrast to that of the graduates, was on discipline content, despite the recognition of the importance attached to skills and the marks attached to the assessment of skills. As additional evidence, the majority of responders said they would like a mixture of lectures and PBL rather than PBL. A lot of free text comments referred to "providing information" (i.e. discipline content) with the implication of a more passive style of learning.

Subsequently we attempted to address these issues with the following actions:

First, greater support was provided in adjusting to PBL. The initial, formative, induction PBL project was extended from a day to a week. We emphasised the gym analogy whereby one does not get fit by simply paying the membership fee. We also disseminated the alumni views about realising the importance of PBL post-graduation.

Second, we exploited the experience of our graduates in a careers' symposium, delivered online with breakout rooms for small group and individual mentorship. The online format, rather than a face-to-face event, allowed us to involve a larger number of alumni.

Finally, degree credit for the skills module is no longer derived from core activities simply because of the associated complexity and lack of transparency. Instead, students were required to keep a portfolio, with consultations with a personal tutor twice a semester in year one and once each semester in year 2, in which they reflected on and evaluated their learning experiences and skills (Carpenter et al., 2024). The portfolio content is aligned with the module assessments and marked on a pass/fail basis and although this comprises only a small number of credits in a larger skills module (including computing and mathematics) the fact that it is assessed at all contributes to student engagement (Chan et al., 2017).

This investigation has some obvious limitations. The sample size is small such that the trends across years become apparent only when aggregated over cohorts. In addition, it is difficult to extract the relevant aspects of PBL. Does it have to be across all modules? How important is the authenticity that arises from the use of problems that cross disciplines or could this be achieved within a single discipline? A much larger research programme would be required to answer these questions.

Another issue that could be raised is that the assessments were designed around our own prescribed syllabus. In claiming that discipline knowledge was not compromised, either by PBL or interdisciplinarity, are we therefore guilty of marking our own homework? We would counter that the distribution of marks for the programme assessments was in accordance with other science programmes and similar programmes at other institutions. In addition, the programme was nationally accredited to be of the same rigour and depth as single-subject disciplines in the UK and that the level of assessments was verified by external examiners. Finally, students on the programme often undertook capstone projects in research groups alongside single discipline undergraduates, where they performed to the same standards.

It is also the case that our definition of employability in terms of a list of (inter-)personal skills is rather narrow (e.g. Tight, 2023), even though this minimal skills requirement is not universally met, or understood, in the context of pure science programmes that are not vocationally oriented. The modern university was always intended to be more than a training for employment, but that larger intention was generally thought to be realised through the informal curriculum by a vague process of osmosis. Building on what we have learnt from the programme described here, we can envisage problem contexts within our overall framework that broaden the curriculum to address issues of citizenship with respect to society, environment and technology (Lacković, 2019) and integration of employability with other university strategic change agendas (e.g., sustainability; diversity, inclusion and equality)(Cook, 2022).

Conclusion

This research provides evidence for the hypothesis that, with support and scaffolding, employability can be successfully embedded in a pure science programme taught by problem-based learning, and that the benefits accrue over the years of study. We believe these results may extend beyond PBL to any pedagogies that aim to embed employability skills or graduate capitals over time within the core discipline and that the approach can be readily expanded to encompass much wider definitions of employability.

Acknowledgement

We thank Patrick Conboy and Sam Seneviratne for carrying out the research as undergraduate final year projects.

Biographies

Derek Raine is Emeritus Professor in the School of Physics and Astronomy at the University of Leicester where he founded the Natural Sciences programme. Professor Raine was awarded the Bragg Medal of the Institute of Physics for his work on curriculum development through problem-based learning, and an MBE for services to science education. He is a National Teaching Fellow and a Principal Fellow of Advance HE. Professor Raine is currently CEO of the national Society for Natural Sciences, which he helped to set up and teaches at the London Interdisciplinary School. His latest book is *Problem-Based Approaches to Physics: Changing Perspectives in Higher Education*.

Sarah Gretton is a teaching-focused professor at the University of Leicester, UK. She initiated the Research Theme of Teaching and Learning in the College of Science and Engineering in 2014 and became Director of the Centre for Interdisciplinary Science and the Natural Sciences programme in 2015. Under her leadership the Centre for Interdisciplinary Science won the UK's Collaborative Award for Teaching Excellence in 2017. Sarah was awarded a University Teaching Fellowship in 2014, and was a finalist for HE Bioscience Teacher of the Year, won the University of Leicester's Teaching Excellence award in 2017 and was awarded a National Teaching Fellowship in 2021. She is currently Director of the University of Leicester's Education Academy and the Education for Sustainable Development Academic Lead.

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