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Article

The Chemistry Clinic: Authentic Assessment in a Student Led Environment

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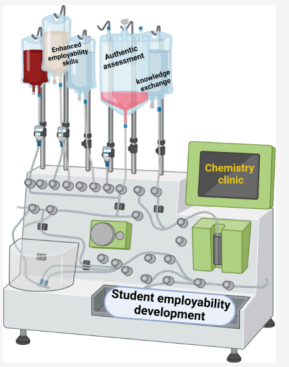
ABSTRACT: For many years, a key focus in Universities has been on ensuring that students develop employability skills as well as developing discipline specific skills during their studies. This has often resulted in the provision of work-integrated learning opportunities or embedding employability skills training within degree programmes. The Chemistry Clinic at the University of Strathclyde is an activity that seeks to incorporate industry driven, inquiry-based authentic assessment with the development of the key skills sought by employers. It also provides the opportunity for students to contribute to the Higher Education Knowledge Exchange agenda in positive ways. Evidence suggests that involvement in the Chemistry Clinic has a positive effect on encouraging students to progress to research postgraduate study in Chemistry or aligned areas. Additionally, student feedback indicates that the Chemistry Clinic has had a positive effect on students' learning outcomes related to employability. Finally, the extent of industry involvement and the feedback from industry partners illustrate that the chemical industry believes that Chemistry Clinic students provide a sustainable and efficient source of expertise. The development and implementation of the Chemistry Clinic are described in detail and have implications for practice. Other chemistry departments and a wider range of disciplines may wish to consider introducing this approach into their degree portfolios.



KEYWORDS: *Higher Education, Employability Skills, Knowledge Exchange, Authentic Assessment, Work-integrated Learning*

Ensuring students have the necessary skills to support the transition into employment has been a key focus for Higher Education for sometime.[1,2] A UK survey commented that "Employers expect the need for workplace skills unattached to qualifications—such as communication and teamwork—to increase (+41%) in the next three to five years."[3]

Two approaches are common: using internal frameworks to support the development of practical resources within the curriculum and/or ensuring that students have an opportunity to engage in work experience. A variety of frameworks has emerged to support the development of these skills, including models such as CareerEDGE[4] and Understanding, Skills, Efficacy, Metacognition (USEM).[5,6] A wide range of resources designed to support the embedding of employability skills into the curriculum has also been collated.[7]

Specifically in Chemistry, there has been much work in this area. The use of context-based learning to encourage broader skills development and ensure graduates are better prepared for the workforce is well recognized.[8,9] This often features in practical laboratory classes through individual experiments,[10,11] an entire module[12,13] or even a whole department/school.[14] Others,[15] including the author,[16,17] have introduced ways to develop these skills in the wider curriculum. The intended career path of students, however, can impact the perceived value of the usefulness of these skills[18] and it can be unclear whether students recognize these skills or understand their value.[19] The work outlined in this study allows students to engage in solving real-world problems and provides an opportunity for them to enhance their employability skills. Additionally, the assessment of this activity involves their reflections on understanding the usefulness of the skills they have enhanced and will add to the body of existing knowledge already in place.

Another way to prepare students for the transition into employment is through work experience. Comparisons[20,21] between students who had and had not participated in work experience indicated that the cohort which had participated in work experience had a higher level of employability skills. The idea of work-integrated learning (WIL), which has broader implications, has gained increased attention over a number of years. and there are numerous examples of work experience which is integrated into the curriculum.[22−25] Indeed, in a Singaporean[26] study, students stated that work experience was in their top 5 list of activities which were important in securing employment.

Graduates who have engaged in industry-facing activity during their studies are therefore better equipped to embark on their career.[27−29] Additional benefits such as enhanced

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motivation and increased maturity[30] for such graduates has also been suggested.

The Department of Pure and Applied Chemistry at the University of Strathclyde has one of the largest and longest running student industrial training placement activities in the UK.[31] Noncredit bearing placements, initially of five months duration, were introduced over 50 years ago for third year students who wished to gain industrial experience.

In response to employer feedback, this placement was extended to twelve months. This extension benefits both students and employers. Students have a longer period of time to develop authentic skills,[32,33] and as the placement attracts a salary, they can often save money to offset the requirement to work to support themselves[34] through their final year of study when they return to University. Employers can also capitalize on the training provided in the early months of the placement and ask the student to complete more meaningful tasks, thus gaining more in return from their investment in the student.

Following guidance from the Royal Society of Chemistry[35] a Professional Body which accredits our degree programmes, the placement is now a credit bearing activity and comprises 90 credits of the fourth year of the five year Integrated Masters programmes at Strathclyde. The remaining 30 credits from this year of study consist of distance learning modules in Inorganic, Organic, and Physical Chemistry to ensure students remain engaged in their studies.

Our industrial partner portfolio currently numbers over 30 national and international companies as well as a number of government organizations, charities, other universities, and research establishments. The Placement Team places around 60 students each year into positions aligned with their subject specialization and interest.

In the past decade, an alternative to the placement to address the needs of particular students was required, and the "Chemistry Clinic" was established in September 2013.[36]

Project Design

The Chemistry Clinic was created by John Liggat and Debra Willison and operational details have previously been published.[37] This was in response to a noticeable increase in the number of students wishing to develop their business and commercial skills as well as their chemistry knowledge. There was also recognition that an alternative to the traditional placement for carers, those with young families and international students with visa issues who could not relocate for an external placement was required. Chemistry Clinic participants engage from a departmental base but interact with industry to provide solutions to their real world problems. This addresses potential barriers which some international students[38] or students from low socioeconomic backgrounds,[39] might meet if they were to relocate to a traditional external placement. The development of the Clinic was driven by three clear aims:

- Assessment had to be authentic
- The Clinic should enhance the development and reflection on students' employability skills
- The Clinic should address Higher Education's Knowledge Exchange agenda

Authentic assessment is described in many ways but is often seen as the merging of "what happens in the classroom...replicating the tasks and performance standards typically faced by professionals in the world of work".[32,33,40] The practice of utilizing what is learned in the classroom and applying it to real-world issues, is supported by many researchers.[41−44] The discussion has also been extended to include assessment with a 'professional focus'[45] that is based on these real-world scenarios and allows students to provide their reflections on the authenticity of their assessment. This definition of authentic assessment as focusing solely on work has, however, been contested[46] and a broader notion of authenticity has been suggested. There has been a shift in the focus on students being involved in a real-world problem scenario alone to focus on where such scenarios sit within a wider societal setting. A key consideration for the Chemistry Clinic was that not only would subject specific skills be developed but also a wider skill set, which could be utilized by those pursuing careers not directly related to chemistry and/or could be applied to other aspects of life outside the workplace.

While authentic assessment supports the transition from study into employment,[47] it can also enhance student well-being,[48] improve commitment and motivation[49] and increase the development of higher-order cognitive skills.[50] Indeed, it has been claimed that it improves autonomy[51] and self-reflection.[52]

It is not uncommon for industry colleagues to seek support from the Department to resolve problems or difficulties they may be facing. Staff often do not have the time to become involved in finding solutions for these problems, and valuable opportunities that could lead to larger income generating projects are lost. The Knowledge Exchange (KE) agenda[53−55] in Higher Education is a priority for research and innovation across much of the world. Reviews detailing examples from across the UK[56,57] and beyond[58] indicate the breadth of activity in this area. Despite the extensive literature,[59−61] there is a lack of evidence of students having a distinctive contribution to KE. The Chemistry Clinic provides an innovative opportunity for students to take a leading role and this appears to be unique in Chemistry as any other clinics described in the literature relate to medicine[62] and health care delivery.[63]

Desired Outcomes and Methodology. The development of the Chemistry Clinic addresses the following pedagogical goals.

(1) Does the Chemistry Clinic affect progression to postgraduate research study in Chemistry or aligned areas?
(2) Does the Chemistry Clinic have an effect on student learning outcomes related to employability?
(3) Does the chemical industry value the technical expertise of students in the Chemistry Clinic?

Initial Start-up and Operation. The first Chemistry Clinic student team successfully secured competitive funding of £10K to support the inaugural year of the Chemistry Clinic in 2013 and a Knowledge Exchange Associate (KEA) was appointed using this funding to supervise the team.

Companies send a general enquiry directly to the Department or contact is made through Interface,[64] Scotland's business support network. Interface, established in 2005, is a hub aiming to connect businesses with universities, colleges, and research institutions. The University of Strathclyde also hosts an annual Engage with Strathclyde event,[65] where industry can find out more on the services of the Chemistry Clinic. Further details on the practical operation of the Clinic[37] are outlined in a separate textbook.

FUNDING

The Chemistry Clinic was designed to be a financially self-sustaining enterprise. For some companies, this is straightfor-

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ward as they can pay from existing budgets, but others have limited or no funding available for any type of development work. There is a potential solution for companies based in Scotland with the 'Innovation Voucher' scheme which Interface facilitates. This links small- and medium-sized businesses with an academic partner. Grants of between £1000 and £5000 are available to cover any associated costs, and the company is required to make an equivalent contribution. The Chemistry Clinic has been highly effective in securing funding in this way.

Assessment

As an induction activity, the students complete the 'Wheel of Expectations' (based on the 'Wheel of Life' credited to Paul J Meyer) as illustrated (see Figure 1).

Figure 1. Wheel of Expectations.

The students are asked to indicate for each of the categories where on the wheel they feel their ability currently is, from '0' in the center to '10' on the outside. They then revisit this at the end of the Clinic and can reflect on the changes that may be in each of the categories.

There are three further summative assessment activities associated with the Clinic: a literature review, a reflective essay, and a skills matrix.

Literature Review

This assessment is aligned with one of the first client projects that students undertake. At the weekly progress meetings with their supervisor, students are provided with support in this process. As the assessment takes place relatively early on in the Clinic's activity, reflection on feedback on students' writing and reviewing skills allows them to enhance their skills in this area as they progress. The literature review is graded (see Supporting Information) by their supervisor and makes up 20% of the students' final grade.

Skills Matrix

The Skills Matrix is shown in Table 1. The Matrix is used as a tool in the weekly progress meetings so that students gain feedback on their progress and can be supported to do better in any particular dimension where they or their supervisor have concerns. Additionally, students can identify skills they wish to improve or develop for a specific career path during these meetings, and this will be incorporated into their tasks. The skills matrix contributes 70% to the students' final grade.

Table 1. Assessment Skills Matrix

Category	Score
Leadership and Collaboration	
Attitude, conduct, timekeeping	x
Ability to use time and organize	x
Communication and Client Engagement	
Interaction with Clients	x
Communication	x
Synthesis and Understanding	
General chemistry knowledge	x
Specialized work knowledge	x
Practical ability	x
Innovation and Creativity	
Innovation and creativity	x
Need for supervision	x
Total	**x**

Reflective Report

The opportunity to produce technical reports for clients will present themselves throughout the time that students are engaged in the Chemistry Clinic. The final report therefore is reflective and asks students to reflect on their time in the Chemistry Clinic and how they have developed their wider skills set. This supports the notion that participating in reflective practice can enhance their appreciation of their own professional development.[50] This assessment also addresses the challenges outlined by Galloway[18] and Hill et al.[19] of students' lack of perceptions of these skills and their usefulness as they can make direct connections between the skills they have employed to address the problems they have solved. The reflective report contributes 10% to the final grade, and assessment criteria can be found in the Supporting Information.

METHODOLOGY AND ETHICS

To evaluate the impact of the Chemistry Clinic on the skills of the students, a survey was used to gather insights from participants who have engaged with the program. These results were unreported in any previous publication.[37] Ethical approval from the University was granted and ensures protection of the rights, dignity, and well-being of all participants. Prior to data collection, all participants received information about the study's purpose, procedures, and potential risks. Informed consent was obtained from each participant, ensuring their voluntary participation and confidentiality. To protect participants' privacy, all data was anonymized during analysis and identifying information was removed. The questions in the survey were designed to be value-neutral and not to suggest to participants that their answers are "right" or "wrong", thus ensuring bias did not affect student responses.

RESULTS AND DISCUSSION

The first pedagogical goal was to identify "Does the Chemistry Clinic affect progression to postgraduate research study in Chemistry or aligned areas?" 38 students have progressed through the Chemistry Clinic since its introduction in academic year 2013/14. As already mentioned, students are registered on

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a range of degree programs and therefore have differing backgrounds and specializms. The jigsaw learning they experience in their multidisciplinary teams[66−68] supports the development of their communication skills[69,70] and knowledge retention[71] as they progress through the Clinic. The students also gain experience of working as part of a team and, in some instances, taking on a leadership role, which supports their future career aspirations.[44]

It is expected that there would be 4 students each year although in some years there have been more students (2015/16, 2018/19, and 2021/22 had 8, 5, and 5 students, respectively) and in other years less students (2016/17 and 2017/18 had 3 and 1 students respectively). It should be noted that while the Chemistry Clinic was established in academic year 2103/14, the first cohort having passed through the Clinic graduated in academic year 2014/15. There also has been a change in reporting of graduate destinations through the Higher Education Statistics Agency (HESA) and figures for 2021/22 and 2022/23 are not available. A comparison of the average percentage of students who progressed to postgraduate study (defined as a research degree in a Chemistry or aligned area) from the Chemistry Clinic during the 2014/15 to 2020/21 period compared to the total number of students who have progressed to postgraduate study from the three programmes listed above[72] is 48.2% compared to 41.1%. This could indicate that the experience of participating in the Chemistry Clinic may be influencing students to consider a research career in their future, although the transferable skills students also gain through being part of the Clinic will equip them with competencies to succeed in a wider range of careers.

A thematic analysis approach was used to identify and interpret themes which arose from the data set collected from the survey completed by the students, following Naeem et al. step-by-step process.[73] This proved challenging due to the small sample size however quotes, reused from a previous publication,[37] which bring the data to life were selected and were designated by identifying recurring themes. The following quote indicates the effect that the Clinic has had on student choice.

> *My time at the Chemistry Clinic was invaluable. I was able to gain a key insight into working as a scientist while also being introduced to business and marketing considerations. Working alongside PhD students also gave me a greater understanding of what to expect and why I should and will go down this path.*
>
> Chemistry Clinic Student, 2017

The second goal was "Does the Chemistry Clinic have an effect on student learning outcomes related to employability?" To date, all students who have participated in the Chemistry Clinic have successfully passed the module with marks ranging between 51 to 89% with an aggregate grade of 71.1%. Individual aggregate grades for the literature review, skills matrix, and reflective essay were 78.9%, 68.7%, and 72.3%, respectively. Students performed well in all three activities with the score for the skills matrix being of the lowest value. This could indicate that students felt more comfortable with the written assessments they are more familiar with; however, it is clear that their transferable skills were also improved during the module.

Information gained from student feedback also indicated that involvement in the Chemistry Clinic enhanced their employability skills. They recognize the value of consolidating and applying their previous knowledge to current activities, helping them to understand what direction they would wish their future career to take.

> *The Chemistry Clinic has allowed me to develop and driven me to achieve my goals. Applying the knowledge from the earlier years of my degree has really helped me consolidate what I know, and I am confident that I will perform to my best ability in final year because of this experience. This year has taught me what I want to do in the future.*
>
> Chemistry Clinic Student, 2015.

Building on this development, they also recognize that their confidence in a range of wider skills has grown.

> *I feel my decision to join the Chemistry Clinic has been one of the best decisions I have made in my life. It has given me the opportunity to further develop my practical skills and put to use the scientific knowledge I had previously learned on my course. The opportunity to work alongside PhD students and senior researchers on client projects was my favorite aspect of the Chemistry Clinic, this also gave me a great insight into the work I would be doing in my final year project, and it allowed me to explore the opportunity of a PhD. The past nine months have had a huge impact on my personal growth, I am now much more confident in myself and that is thanks to the constant development in my group working and presentation skills.*
>
> Chemistry Clinic Student, 2021

> *My year at the Chemistry clinic has definitely been the highlight of my degree so far. I've been able to learn and develop many skills for client meetings, presentations, and problem solving. My favorite part is that I have been given so many different opportunities during this placement that I'm not sure I would have received anywhere else. I would recommend the Chemistry Clinic to anyone who wants to use problem solving and experiment every day.*
>
> Chemistry Clinic Student, 2019

The industrial placement is a paid position and will therefore remain the first choice for many students; however, the Chemistry Clinic provides the preferred option for a subset of students who cannot participate in an industrial placement for a range of reasons and therefore has a significant role in supporting the Department's KE activity and will continue. There is no expectation that the number of students participating in the Clinic will rise above double figures in future years. To date, every student who has applied to join the Clinic has engaged in an interview process and has successfully been assigned a place on the program.

> *I have thoroughly enjoyed my time at the Chemistry Clinic, it has been a fantastic experience. My favorite aspect of the Chemistry Clinic has been the technical projects where we get to collaborate with all sorts of different clients. A particular highlight of my year was when we got the chance to go on a business trip and meet one of our clients in person. As well as developing a wide range of practical skills through working on technical projects, I have also been involved in various outreach activities that have greatly benefited my communication skills, particularly public speaking. It has been a truly unique and memorable experience.*
>
> Chemistry Clinic Student, 2018

The final goal was "Does the chemical industry value the technical expertise of students in the Chemistry Clinic?"

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The inaugural Chemistry Clinic year in 2103/14 proved to be successful. The Clinic secured four contracts with industrial partners, with the income generated offering a rate of return of over 200% on the University's original funding. This encouraged the Department to make the role of the KEA permanent to successfully support the activities of a sustainable Clinic. The Clinic has a regular annual turnover of around £35,000.

More than 40 companies (see Supporting Information) have benefitted from the Clinic's services where the company has not had the knowledge and/or research skills to solve a problem they have encountered in their business to which the Clinic has found a solution. These companies range from one-man businesses through SMEs to multinational conglomerates. An example of a successful project is given below. Others can be found in the Supporting Information.

ZING ORGANICS

Feedback from companies has been overwhelmingly positive and an example, reused from a previous publication,[37] of where a chemical problem has been solved is detailed below.

Zing Organics specializes in producing candles that have naturally sourced ingredients. This company was keen to find a way of establishing that their candles were 'asthma safe' and a project was agreed upon which was focused on certifying that their candles were phthalate-free. Phthalates are commonly included in synthetic fragrances and have been linked with various adverse health effects.[74]

The students devised a testing regime and analyzed the candles supplied by the company. They then embarked on a program of work to test the individual components and ingredients, and no traces of phthalate were found in the natural products used by the company. Following this, the team employed a systematic overview of the entire manufacturing process, including all packaging and handling processes, and was able to isolate and eliminate the source of phthalate, which was found in some of the plastics used in ingredient handling. This success has led to a long-term working relationship between the company and the Chemistry Clinic, with the company founder commenting:

We learned a great deal about aspects of quality control, including the development of tighter relationships with suppliers. This led to new protocols being rolled out in our workshop. As a start-up business, it was a great benefit to have the support of the Chemistry Clinic. This helps leverage Zing Organics as being truly committed to ensuring the well-being of its customers. As of 2022, our organic skincare is now our main product line, and we are currently in discussions with The Chemistry Clinic to be able to give us an early indication of the outline SPF efficacy on a new tinted makeup cream. This is before we decide to take the product through potentially laborious and costly compliance. I would encourage any company of any size to run any research ideas past the management team at The Chemistry Clinic.

CONCLUSION

In conclusion, all three goals have been achieved. The percentage of students progressing to postgraduate research study in Chemistry or a related area from the Chemistry Clinic was higher (48.2%) than the percentage of students from the remaining cohort who did not participate in the Clinic. This is further supported by student feedback commenting that they had been influenced toward research study due to their experiences in the Clinic.

Based on students' comments of their experience and successful continuation of the Chemistry Clinic we believe we have created a sustainable triple helix activity which has had a positive effect on students' learning outcomes related to employability. Students feel more confident in their communication skills and recognize the importance of those skills in a working environment. The funding the Clinic attracts is sufficient to cover the costs of the KE Associate and the experimental costs and also pay the students a nominal stipend of £500 per semester. While this in no way matches the salary associated with an industrial placement, students who have opted for the Chemistry Clinic do not have to make any changes to their accommodation or commute to University and have been content with this amount.

For the third goal, based on the level of industry involvement (44 companies) and the positive feedback from these companies, we believe we have gained recognition from the chemical industry as a valuable source of technical expertise and acknowledgment of the vital role which students play in providing this expertise.

LIMITATIONS

One limitation is that the number of students involved in the Chemistry Clinic each year is not consistent, and it could be argued that when there is a smaller group involved they do not benefit as much from collaborative working as those in a larger team do. We can mitigate against this by ensuring that our advertising materials emphasize the benefits students will gain from being part of the Clinic.

Another limitation is that there is no control over the type of project that comes to the Chemistry Clinic and subsequently the experience of the students involved will vary from project to project. We do provide a list of expertise to employers, however, so that they understand which projects we are most likely to be able to support.

IMPLICATIONS FOR PRACTICE

The data in this article and an earlier publication[37] may provide details for other Chemistry Departments to consider introducing a Chemistry Clinic activity into their own degree programmes. Additionally, this model lends itself to other disciplines and could easily be adapted to Engineering, Law, and Social Sciences.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c01319.

Assessment, company list, and successful industrial projects (PDF, DOCX)

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Notes

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■ REFERENCES

(1) Tomlinson, M. Graduate employability in context. In *Introduction: Graduate Employability in Context: Charting a Complex, Contested and Multi-Faceted Policy and Research Field*; Palgrave Macmillan: UK, 2017; pp 1−40.
(2) Succi, C.; Canovi, M. Soft skills to enhance graduate employability: Comparing students and employers' perceptions. *Studies in Higher Education* **2020**, *45* (9), 1834−1847.
(3) CBI/Birkbeck. *Skills for an Inclusive Economy: CBI/Birkbeck Education and Skills Survey Annual Report*, 2021.https://www.cbi.org.uk/media/702012684_tess-survey_2021.pdf (accessed 2024−05−30).
(4) Dacre Pool, L.; Sewell, P. The key to employability: Developing a practical model for graduate employability. *Education & Training* **2007**, *49* (4), 277−289.
(5) Knight, P.; Yorke, M. *Learning, curriculum and employability in higher education*; Routledge Falmer: London, UK, 2004.
(6) Sumansiri, E.; Yajid, M. A.; Khatibi, A. Conceptualizing Learning and Employability "Learning and Employability Framework". *Journal of Education and Learning* **2015**, *4* (2), 53−63.
(7) QAA. *Employability initiatives in universities and colleges*, 2016. http://www.qaa.ac.uk/en/Publications/Documents/SBS-chemistry-14.pdf (accessed 2024−05−30).
(8) Pilcher, L. A.; Riley, D. L.; Mathabathe, K. C.; Potgeiter, M. An inquiry-based practical curriculum for organic chemistry as preparation for industry and postgraduate research. *S. Afr. J. Chem.* **2015**, *68*, 236−244.
(9) Erhart, S. E.; McCarrick, R. M.; Lorigan, G. A.; Yezierski, E. J. Citrus quality control; An NMR/MRI problem-based experiment. *J. Chem. Educ.* **2016**, *93* (2), 335−339.
(10) Mc Ilrath, S. P.; Robertson, N. J.; Kuchta, R. J. Bustin' Bunnies: an adaptable inquiry-based approach introducing molecular weight and polymer properties. *J. Chem. Educ.* **2012**, *89* (7), 928−932.
(11) Dopico, E.; Linde, A. R.; Garcia-Vazquez, E. Learning gains in lab practices: teach science doing science. *J.Biol.Educ.* **2014**, *48* (1), 46−52.
(12) Jansson, S.; Söderström, H.; Andersson, P. L.; Nording, M. L. Implementation of problem-based learning in environmental chemistry. *J. Chem. Educ.* **2015**, *92* (12), 2080−2086.
(13) Kelly, O. C.; Finlayson, O. E. Providing solutions through problem-based learning for the undergraduate 1st year chemistry laboratory. *Chem.Educ.Res.Pract.* **2007**, *8* (3), 347−361.
(14) George-Williams, S. R.; Soo, J. T.; Ziebell, A. L.; Thompson, C. D.; Overton, T. L. Inquiry and industry inspired laboratories: the impact on students' perceptions of skill development and engagements. *Chem.Educ.Res.Pract.* **2018**, *19*, 583−596.
(15) Bennett, D.; Richardson, S.; MacKinnon, P. *Enacting strategies for graduate employability: how universities can best support students to develop generic skills*; Australian Government Office for Learning and Teaching: Sydney, 2015.
(16) Scott, F. J.; Willison, D.; Connell, P.; Thomson, L. A. Empowering students by enhancing their employability. *Journal of Further and Higher Education* **2019**, *43* (5), 692−707.
(17) Scott, F. J.; Willison, D. Students' reflections on an employability skills provision. *Journal of Further and Higher Education* **2021**, *45* (8), 1118−1133.
(18) Galloway, K. W. Undergraduate perceptions of value: degree skills and career skills. *Chem.Educ.Res.Pract.* **2017**, *18* (3), 435−440.
(19) Hill, M. A.; Overton, T. L.; Thompson, C. D.; Kitson, R. R. A.; Coppo, P. Undergraduate recognition of curriculum-related skill development and the skills employers are seeking. *Chem.Educ.Res.Pract.* **2019**, *20*, 68−84.
(20) Watkins, M. A.; Higginson, M.; Clarke, P. R. Enhancing graduate employability in product design: A case study exploring approaches taken on a BSc product design course. *Higher Education, Skills and Work-Based Learning* **2018**, *8* (1), 80−93.
(21) Kamaliah, S.; Roslan, S.; Bakar, A. R.; Ghiami, Z. The effect of supervised work experience on the acquisition of employability skills among Malaysian students. *Higher Education, Skills and Work-Based Learning* **2018**, *8* (4), 354−364.
(22) Jackson, D. Developing pre-professional identity in undergraduates through work-integrated learning. *Higher Education* **2017**, *74* (5), 833−853.
(23) Jackson, D. Developing Graduate Career Readiness in Australia: Shifting from Extra-Curricular Internships to Work-Integrated Learning. International Journal of Work-Integrated Learning. *International Journal of Work-Integrated Learning* **2018**, *19* (1), 23−35.
(24) Perusso, A.; Wagenaar, R. The state of work-based learning development in EU higher education: Learnings from the WEXHE project. *Studies in Higher Education* **2021**, 1423−1439.
(25) Ntola, P.; Nevines, E.; Qwabe, L. Q.; Sabela, M. I. A survey of soft skills expectations: a view from work integrated learning students and the chemical industry. *J. Chem.* **2024**, *101* (3), 984−992.
(26) Yasin, N.Y.B.M.; Yueying, O. Evalutaing the relevance of the chemistry curriculum to the workplace: keeping tertiary education relevant. *J. Chem. Educ.* **2017**, *94* (10), 1443−1449.
(27) Brooks, R.; Youngson, P. L. Undergraduate work placements: an analysis of the effects on career progression. *Studies in Higher Education* **2016**, *41* (9), 1563−1578.
(28) Jackson, D. Employability skill development in work-integrated learning: Barriers and best practice. *Studies in Higher Education* **2015**, *40* (2), 350−36.
(29) Rowe, A. D.; Zegwaard, K. E. Developing graduate employability skills and attributes: Curriculum enhancement through work-integrated learning. *Asia-Pacific Journal of Cooperative Education* **2017**, *18* (2), 87−99.
(30) Jones, C. M.; Green, J. P.; Higson, H. E. Do work placements improve final year academic performance or do high-calibre students choose to do work placements? *Studies in Higher Education* **2017**, *42* (6), 976−992.
(31) University of Strathclyde. *Chemistry Industrial Placement Brochure*, 2023. https://www.strath.ac.uk/media/1newwebsite/departmentsubject/chemistry/Chemistry_Industrial_Placement_A4_Brochure_2023.pdf (accessed 2024−05−30).
(32) Wiggins, G. The Case for Authentic Assessment. *Practical Assessment, Research & Evaluation* **1990**, *2* (2), 28−37.
(33) Frey, B. B.; Schmitt, V. L.; Allen, J. P. Defining Authentic Classroom Assessment. *Practical Assessment, Research, and Evaluation* **2012**, *17* (2), 1−18.
(34) Richardson, M.; Evans, C.; Gbadamosi, G. Funding full-time study through part-time work. *Journal of Education and Work* **2009**, *22* (4), 319−334.
(35) Royal Society of Chemistry. *Accreditation of Degree Programmes Retrieved*, 2023. https://www.rsc.org/globalassets/03-membership-community/degree-accreditation/accreditation-of-degree-programmes-2023.pdf (accessed 2024−05−30).
(36) University of Strathclyde. *Chemistry Clinic*, 2024. https://www.strath.ac.uk/science/chemistry/chemistryclinic/ (accessed 2024−05−30).
(37) Willison, D.; Ingram, S.; Liggat, J. J.; McMillan, B. The Chemistry Clinic: Collaborative Teamwork to Achieve Innovative Solutions. In *Perspectives on Enhancing Student Transition Into Higher Education and Beyond IGI Global*; 2023, pp 169−193.
(38) Tran, L. T.; Soejatminah, S. Integration of work experience and learning for international students: From harmony to inequality. *Journal of Studies in International Education* **2017**, *21* (3), 261−277.

https://doi.org/10.1021/acs.jchemed.3c01319
J. Chem. Educ. 2024, 101, 2703−2709

(39) Dunn, L. A.; Schier, M. A.; Hiller, J. E.; Harding, I. H. Eligibility requirements for work-integrated learning programs: Exploring the implications of using grade point averages for student participation. *Asia-Pacific Journal of Cooperative Education* **2016**, *17* (3), 295−308.
(40) Villarroel, V.; Bloxham, S.; Bruna, D.; Bruna, C.; Herrera-Seda, C. Authentic assessment: Creating a blueprint for course design. *Assessment and Evaluation in Higher Education* **2018**, *43* (5), 840−854.
(41) Jorre de St Jorre, T.; Oliver, B. Want students to engage? Contextualise graduate learning outcomes and assess for employability. *Higher Education Research and Development* **2018**, *37* (1), 44−57.
(42) Boud, D.; Ajjawi, R. The Place of Student Assessment in Pursuing Employability. In *Education for employability (Vol 2): Learning for future possibilities*; Brill: Leiden, The Netherlands; pp. 167−178.
(43) Ajjawi, R.; Tai, J.; Huu Nghia, T. L.; Boud, D.; Johnson, L.; Patrick, C.-J. Aligning assessment with the needs of work-integrated learning: The challenges of authentic assessment in a complex context. *Assessment and Evaluation in Higher Education* **2020**, *45* (2), 304−316.
(44) Blaj-Ward, L.; Matič, J. Navigating assessed coursework to build and validate professional identities: The experiences of fifteen international students in the UK. *Assessment and Evaluation in Higher Education* **2021**, *46* (2), 326−337.
(45) Sotiriadou, P.; Logan, D.; Daly, A.; Guest, R. The role of authentic assessment to preserve academic integrity and promote skill development and employability. *Studies in Higher Education* **2020**, *45* (11), 2132−2148.
(46) Ajjawi, R.; Tai, J.; Dollinger, M.; Dawson, P.; Boud, D.; Bearman, D. From authentic assessment to authenticity in assessment: broadening perspectives. *Assessment & Evaluation in Higher Education* **2023**, 499−510.
(47) Saher, A.; Ali, A. J.; Amani, D.; Najwan, F. Traditional Versus Authentic Assessments in Higher Education. *Pegem Journal of Education and Instruction* **2022**, *12* (1), 283−291.
(48) McArthur, J. Rethinking authentic assessment: work, well-being, and society. *High. Educ.* **2023**, *85*, 85−101.
(49) Nicol, D.; Thomson, A.; Breslin, C. Rethinking Feedback Practices in Higher Education: A Peer Review Perspective. *Assessment & Evaluation in Higher Education* **2014**, *39* (1), 102−122.
(50) Ashford-Rowe, K.; Herrington, J.; Brown, C. Establishing the Critical Elements That Determine Authentic Assessment. *Assessment & Evaluation in Higher Education* **2014**, *39* (2), 205−222.
(51) Raymond, J.; Homer, C.; Smith, R.; Gray, J. Learning through Authentic Assessment. An Evaluation of a New Development in the Undergraduate Midwifery Curriculum. *Nurse Education in Practice* **2013**, *13* (5), 471−476.
(52) Vanaki, Z.; Memarian, R. Professional Ethics: Beyond the Clinical Competency. *Journal of Professional Nursing* **2009**, *25*, 285−291.
(53) Abreu, M.; Grinevich, V.; Hughes, A.; Kitson, M.; Ternouth, P. *Universities, Business and Knowledge Exchange. The Council for Industry and Higher Education*, 2008. https://www.researchgate.net/publication/262818526_Universities_Business_and_Knowledge_Exchange (accessed 2024−05−30).
(54) Kitagawa, F.; Lightowler, C. Knowledge Exchange: A comparison of policies, strategies and funding incentives in English and Scottish Higher Education. *Research Evaluation* **2013**, *22* (1), 1−14.
(55) Johnson, M. T. The knowledge exchange framework: understanding parameters and the capacity for transformative engagement. *Studies in Higher Education* **2022**, *47* (1), 194−211.
(56) Zhang, Q. Theory, practice and policy: A longitudinal study of university knowledge exchange in the UK. *Industry and Higher Education* **2018**, *32* (2), 80−92.
(57) *Knowledge Exchange Concordat*, 2022. https://www.universitiesuk.ac.uk/what-we-do/policy-and-research/publications/knowledge-excha,nge-concordat-review (accessed 2024−05−30).
(58) Wain, M.; Rosemberg, C.; Farla, K.; Seth, V.; Maki, N.; Dijkstal, F.; Sutinen, L. *D'hont, J Technopolis Group, KE and place: A review of the Literature*, 2021. https://www.ukri.org/wp-content/uploads/2022/05/RE-270522-KnowledgeExchangePlaceReviewLiteratureFinalReport.pdf (accessed 2024−05−30).
(59) Vaivode, I. Triple Helix Model of University−Industry−Government Cooperation in the Context of Uncertainties. *Procedia - Social and Behavioral Sciences* **2015**, *213*, 1063−1067.
(60) Wilkins, T.; Cooper, I. Lessons from coordinating a knowledge exchange network for connecting research, policy and practice. *Research for All* **2019**, *3* (2), 204−17.
(61) Alberti, F. G.; Belfanti, F.; Giusti, J. D. Knowledge exchange and innovation in clusters: a dynamic social network analysis. *Industry and Innovation* **2021**, *28* (7), 880−901.
(62) Meah, Y. S.; Smith, E. L.; Thomas, D. C. Student-run health clinic: novel arena to educate medical students on system-based practice. *Mount Sinai Journal of Medicine A Journal of Translational and Personalized Medicine* **2009**, *76* (4), 344−56.
(63) Briggs, L.; Fronek, P. Student experiences and perceptions of participation in student-led health clinics: a systematic review. *J.Soc.Work Educ.* **2020**, *56* (2), 238−259.
(64) *Interface*, 2024. https://interface-online.org.uk/ (accessed 2024−05−30).
(65) University of Strathclyde, 2024. *Engage with Strathclyde* https://www.strath.ac.uk/workwithus/engage/ (accessed 2024−05−30).
(66) Karacop, A. The Effects of Using Jigsaw Method Based on Cooperative Learning Model in the Undergraduate Science Laboratory Practices. *Universal Journal of Educational Research* **2017**, *5* (3), 420−434.
(67) Jainal, N. H.; Shahrill, M. Incorporating Jigsaw strategy to support students' learning through action research. *International Journal on Social and Education Sciences* **2021**, *3* (2), 252−266.
(68) Willison, D.; Corson, L. Multidisciplinary perspectives of sustainable development: achieving the SDGs in higher education through OBE. In *Development of Employability Skills Through Pragmatic Assessment of Student Learning Outcomes*; IGI Global: Hershey, 2022; pp 167−190.
(69) Hart, J. Interdisciplinary project-based learning as a means of developing employability skills in undergraduate science degree programs. *Journal of Teaching and Learning for Graduate Employability* **2019**, *10* (2), 50−66.
(70) Miller, A.; Rocconi, L.; Dumford, L. Focus on the finish line: Does high-impact practice participation influence career plans and early job attainment? *Higher Education* **2018**, *75* (3), 489−506.
(71) Van Dat, T. The Effects of Jigsaw Learning on Students' Knowledge Retention in Vietnamese Higher Education. *International Journal of Higher Education* **2016**, *5* (2), 236−253.
(72) Higher Education Statistics Agency. *Higher Education Graduate Outcomes Data*, 2024. https://www.hesa.ac.uk/data-and-analysis/graduates (accessed 2024−05−30).
(73) Katsikantami, I.; Sifakis, S.; Tzatzarakis, M. N.; Vakonaki, E.; Kalantzi, O.-I.; Tsatsakis, A. M.; Rizos, A. K. A global assessment of phthalates burden and related links to health effects. *Environment International* **2016**, *97*, 212−236.
(74) Naeem, M.; Ozuem, W.; Howell, K.; Ranfagni, S. A Step-by-Step Process of Thematic Analysis to Develop a Conceptual Model in Qualitative Research. *International Journal of Qualitative Methods* **2023**, *22*, 1−18.

https://doi.org/10.1021/acs.jchemed.3c01319
J. Chem. Educ. 2024, 101, 2703−2709