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A co-curricular inquiry-based approach to developing technical and transferrable laboratory skills in science graduates

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Laboratory-based learning experiences are critically important to develop the cognitive and technical capabilities we expect to see in our future scientists and STEM professionals. Despite the key role this environment plays in learning science, many current activities fall short in terms of providing an experience which connects the 'doing' with the 'learning'. Laboratory practicals are expensive to resource (materials, staff time, laboratory space, etc), and therefore are typically constrained and assessment focused. In addition, these activities are often 'cookbook' or predetermined in their outcomes and students are typically not allowed to explore outside of the very narrow context of the prescribed activity. Given this current model of laboratory training, it is a concern that universities are producing graduates who may not have well developed technical or transferable skills to work effectively in a laboratory environment. The Kitchen Chemistry program aims to address this training deficit in undergraduate sciences. Kitchen Chemistry is a series of inquiry based co-curricular workshops for science, health science, and education students that aims to positively influence student learning, confidence and persistence in the sciences. The workshops differ from traditional laboratory environments because they are not assessment driven and are designed as a 'safe place to fail', where failure is an opportunity to learn. The curriculum for Kitchen Chemistry was developed in partnership with academics, student support services, technical staff, and students. Here we discuss the affordances and challenges to implementing this initiative, which is grounded in the provision of timely and relevant support for learning to develop technical proficiency for STEM undergraduates, in the co-curricular space.

Keywords: inquiry-based learning, STEM (Science, Technology, Engineering and Maths), co-curricular

Introduction

There is growing recognition of the critical role that STEM (Science, Technology, Engineering and Maths) skills play in shaping the future economy (Office of the Chief Scientist, 2014; Finkel, 2018; World Economic Forum, 2018). The jobs of the future will require individuals to think creatively and strategically, be adept in problem solving and persist in challenging environments (Prinsey and Baranyai, 2015; Foundation for Young Australians, 2017). Tertiary institutions play a key role in ensuring STEM graduates are equipped to meet this demand. However, there is currently a perceived shortage of suitably qualified graduates who possess not only the discipline knowledge, but also the technical skills and mindsets necessary to thrive in this changing environment (Segal, 2016). Further, despite the hype, employment prospects for science graduates currently fall short of the push to get more students studying STEM (Norton & Cakitaki, 2016). This is especially the case for the generalist STEM degrees that lack professional accreditation.

In recent years, there has been a renewed focus on the value of authentic, experiential science education to enhance the student experience and address the perceived deficit in graduate capabilities. Laboratory-based learning experiences are essential to developing the capabilities that future employers aspire to see in emerging scientists and STEM professionals. The value of experiential learning lies in the doing; like many disciplines, the best way to learn science is to do science. Importantly, unlike other forms of curriculum reform which prioritise process skill development at the expense of content knowledge, laboratory-based learning provides opportunities to achieve both goals simultaneously. For science students, labs offer an authentic environment in which to reinforce theoretical and conceptual knowledge, develop and apply key capabilities in problem solving, critical thinking, analysis and synthesis, but also develop technical, communication and organisational skill sets. In addition, this learning environment supports the socialisation of new scientists; scaffolded in such a way as to mirror the emerging capabilities and understanding of science before building knowledge, skills and confidence for graduates to identify as STEM professionals. Not surprisingly, undergraduate science students frequently cite laboratory-based learning as being amongst the most valuable learning experiences they have at university (Boud, Dunn, Kennedy & Thorley, 1980; Ranawake & Wilson, 2016).

Despite the affordances, the extent to which the current student experience reflects the ideal is variable. Labs are expensive to resource (in terms of materials, staffing and compliance) and the 'hands-on' nature of the learning necessitates a face-to-face delivery mode. To justify the expense, labs are frequently tied to assessment to ensure students understand the importance of attendance. While it is widely acknowledged that assessment drives learning, there is a risk that students will be focused on the outcome rather than the process and be more likely to demonstrate surface learning approaches (as summarised in Carless, 2007). Traditionally, undergraduate students experience science through highly prescriptive 'cookbook' style laboratories, which are predetermined in their outcomes (Venkatachelam & Rudolph, 1974; Hofstein & Lunetta, 2004). These laboratory activities generally do not provide opportunities to explore outside the scope of the activity, nor engage in learning to understand the principles underlying the experimental approach or unpack why an activity did not work as planned. In short, these experiences fail to adequately engage students in the learning process and highlight a critical deficit in the way in which undergraduate science teaching currently operates; a lack of exposure to scientific discovery and a lack of opportunity to develop problem solving skills and persistence (Holmes & Wieman, 2018).

Recent efforts to enhance the undergraduate science curriculum through the inclusion of active learning approaches highlight the continuum of pedagogical approaches utilised in laboratory-based activities; from prescribed activities where the outcome is predetermined, through to open-ended, inquiry-based learning methods. The incorporation of inquiry-based approaches into laboratory activities provides opportunities for students to explore concepts, methodologies and even experimental design with greater freedom than in a typical laboratory environment (Furtak, Seidel, Iverson & Briggs, 2012). Despite the benefits, there are challenges to implementing this approach in the first-year undergraduate science curriculum; class sizes are often large and service diverse learners from multiple disciplines. Further, time pressures surrounding the delivery of the undergraduate curriculum often mean that there is no time to make mistakes or recover from failure. In this respect, we are potentially denying students a critical learning experience. How then do we support an increasingly diverse cohort of students to engage in, not only learning science but more importantly, doing science?

Kitchen Chemistry: a co-curricular intervention to support science skill development

The Kitchen Chemistry program was developed to address this gap in undergraduate training. Kitchen Chemistry is a co-curricular program targeting skills training and development for students undertaking programs of study in STEM-aligned disciplines, including science, health science, and education. Developed in partnership with faculty, this unique positioning in the co-curricular space addresses issues of equity and ensures all students have access to opportunities to develop their disciplinary content knowledge, skills and capabilities. The program is free for students to attend and resourcing costs are supported through the Student Services Amenities Fee (SSAF).

Offered on a weekly basis during the teaching weeks of the semester, the program provides an accessible and safe learning environment which is grounded in the nature of science and how scientists work. Students can practise a skill, test the limits of the equipment and experiment with protocol parameters and variables. In this way, the open-ended inquiry-based pedagogy nurtures their curiosity and develops confidence and problem solving skills, supporting their socialisation and transition from inexperienced undergraduate to competent STEM graduate.

As the program exists in the co-curricular space and there is an absence of assessment to drive learning, what then is the value proposition for students to give up their time to participate? For students, Kitchen Chemistry offers a low-stakes, inquiry-based learning environment where the emphasis is on developing technical proficiency, confidence, problem solving skills and scientific literacy without academic consequence. By providing a learning environment supported by STEM discipline specialists, but without the pressures of time or 'getting the right outcome', students can pause to ask the 'why' questions, appreciate the nuances of experimentation, explore how the equipment works and get a 'feel' for what the tools can do. In essence, the learning environment that Kitchen Chemistry affords for students is one in which it is 'safe to fail'.

An intentional design element of the Kitchen Chemistry program is an acknowledgement of the value of challenge and difficulty to drive deeper learning (Henry, Shorter, Charkoudian, Heemstra & Corwin, 2019; Carroll, Lodge, Bagraith, Nugent, Mattews & Sah, 2018). In the Learning Challenge model, Nottingham (2017) provides a visual metaphor of the learning journey under these conditions, from initial cognitive conflict; that is, information that challenges or contradicts prior knowledge and ideas, through to a position of clarity and deeper understanding. Central to this journey is moving into the 'Pit' and embracing the challenge (Nottingham, 2017). But what about those students that are unable to get out of the 'Pit', failing to learn and succeed? Rather than leave students to struggle in the Learning Pit indefinitely, the Kitchen Chemistry workshops offer a scaffolded pathway out. In this way, the explicit inquiry-based pedagogy which underpins the initiative supports students to construct their own meaning, whilst also developing scientific literacy, problem solving skills and persistence. Persistence has recently been identified as critical in developing confidence in undergraduate students to continue to engage in STEM research (Indorf, Weremijewicz, Janos, & Gaines, 2019).

Novelty of program

We conducted a systematic review of the literature using the key words ‘co-curricular’, ‘science’, ‘tertiary’, ‘higher education’, ‘chemistry’, ‘inquiry-based-learning' from databases including EBSCO, PubMed, Scopus, and Web of Science. Our search returned 123 papers. Of these papers the majority were theoretical in nature and did not describe a teaching intervention. Of the studies that did discuss co-curricular activities, the majority were based out of American universities where the term co-curricular largely refers to sporting and club-based activities. In fact, based on our search, we have not seen evidence of any similar skills-based training for undergraduate science students. This program is therefore well positioned to capitalise on recent discourse surrounding the need for technically proficient and skilled graduates (Foundation for Young Australians, 2017; Finkel, 2018).

We encountered several challenges in implementing this program and we suspect that many of these challenges exist at other universities and would create barriers for many people attempting to implement similar style programs. Furthermore, we were in a unique position with our jobs to implement such a program. Our roles are academic positions within the Learning and Teaching Unit (LTU), rather than as faculty-based academics. In this role we are not responsible for unit coordination or assessment. Our role is to work with faculty-based academics to improve teaching practices and provide co-curricular support. Therefore, we have time and pedagogical knowledge, but are not constrained by the structures of assessment and curriculum. Additionally, our roles in the support space allow us to look at students and student support across the whole of degree and not for the single semester most unit coordinators would work with a student.

Kitchen Chemistry curriculum development and implementation

The Kitchen Chemistry program was created in partnership between faculty-based academics, students (current students and student leaders), and academic staff based in the Learning and Teaching Unit (Figure 1). This unique partnership allowed the development of a program with input from all the relevant stakeholders. Furthermore, it allowed the program to prioritise and target skills and techniques identified as critical by both staff and students.

The Kitchen Chemistry curriculum was written by academics within the Learning and Teaching Unit (LTU) as they are uniquely positioned within the partnership triad between LTU, students, and faculty academics. We acknowledge that the role of academics in LTU is non-traditional and as such creates some affordances which have likely assisted with the success and development of the Kitchen Chemistry program.

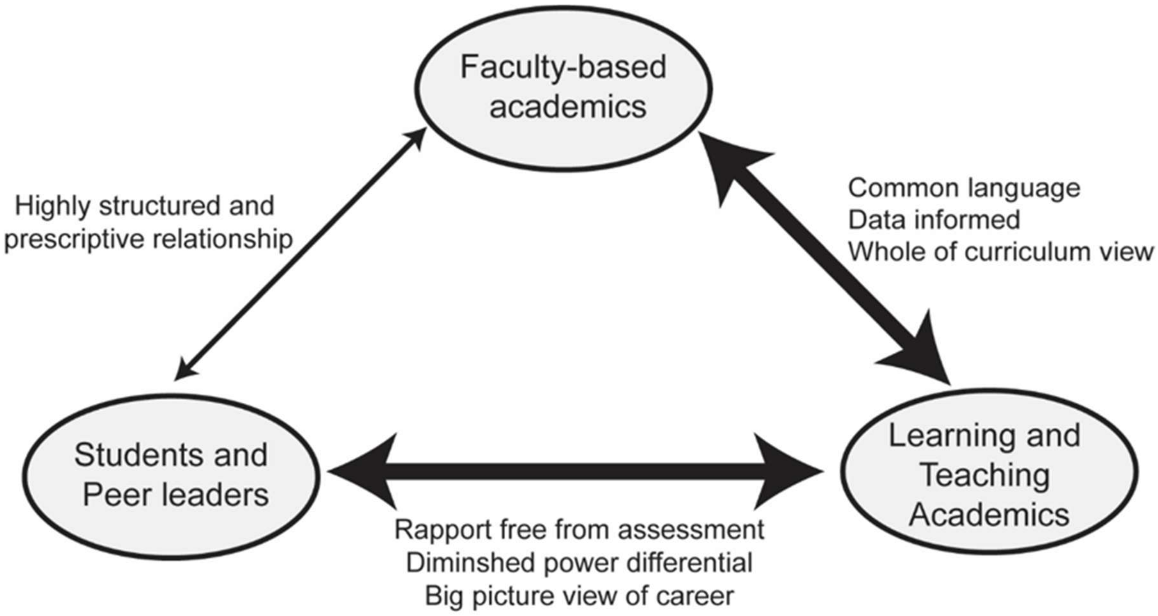

Figure 1: Learning and teaching partnerships underscore the successful implementation of a co-curricular program.

To develop the curriculum, academics from the LTU created a list of priority research skills based on their experience as disciplinary scientists in research labs and as unit coordinators. This list was then circulated to academics and technical staff in the education, science, and health science faculties. Faculty based academics and technical staff were asked to rank the importance of the identified skills and there was an additional narrative section for any skills not contained on the original list. LTU academics then consulted with student leaders (Peer Learning Facilitators; PLFs) who provide drop-in support for learning for STEM content knowledge to assess the nature of the questions from the students seeking assistance (Wilson et al., 2017). While the initial list from the LTU academics contained all of the technical skills the academics prioritised, the academics as well as the peer leaders identified a need to scaffold scientific literacy and numeracy into the workshops. It is not surprising in retrospect that these skills were identified as needing further support. Queensland University of Technology (QUT) does not have prerequisites for any of the degree programs in science and health sciences. The university operates on a system of ‘assumed knowledge’ meaning that it is assumed that students who gain entry to the university will have a certain level of fundamental knowledge before commencing their studies. This is problematic as many of the students do not have the necessary ‘assumed knowledge’. QUT has a diverse cohort of students, including many who are not school leavers and may never have seen the content before, or are several years removed from study and may not remember the content.

The Kitchen Chemistry curriculum consists of seven two-hour workshops (Table 1). The final workshop is run over two weeks (2 x two-hour sessions) to allow enough time for data analysis and synthesis. The workshops are designed to be light-hearted and have been given creative titles to signal this intent to the students. Workshops are scaffolded and build week to week over the semester, yet they also stand alone as students will not necessarily attend the full sequence of workshops. There is a worksheet to guide each workshop, however, the design of the worksheets is to help students think through the process rather than populate tables or short answer questions. Additionally, since the workshops are not bound by assessment, it is not necessary to complete the entire worksheet. This means that students are free to spend as much time as they would like on priority sections based on their needs or take time to follow up on an unexpected or interesting result. It is this aspect of Kitchen Chemistry that provides a truly unique and authentic learning experience, especially for first year students.

The workshops are front-loaded in the semester and conclude before the mid semester break (Week 8 in Semester 1). This strategy minimises conflict with end of semester exams and assessment. The weekly offerings are aligned with key pieces of assessment in target units. For example, for health science students taking chemistry in their first semester of study, there is a titration practical in week 5. Feedback from academics and student leaders indicated that this is problematic for many students. Therefore the Kitchen Chemistry workshop on titration is run in week 4 of the semester to allow students to practise the technique, understand the process and conceptualise the type of data collected in advance of doing the practical for a grade (arrowheads in Figure 2; note the higher attendance in Weeks 4 and 6 when Kitchen Chemistry workshops constructively aligned to assessed laboratory activities).

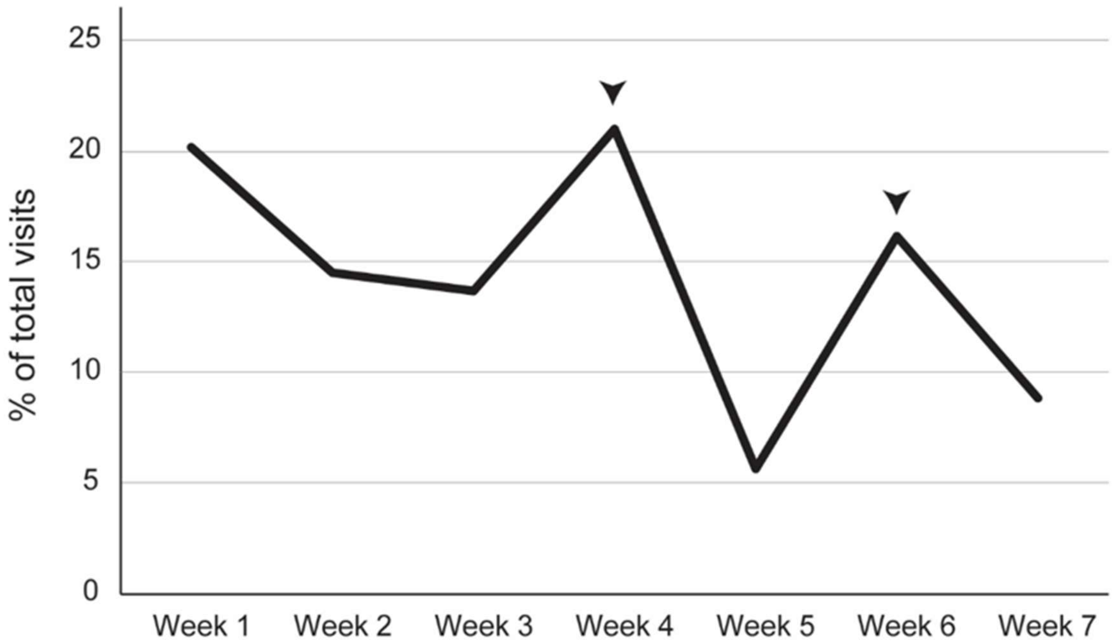

Figure 2: Attendance at Kitchen Chemistry workshops (expressed as % of total attendance) highest when constructively aligned to the undergraduate curriculum.

From a technical standpoint, all the workshops have been designed to be minimal risk. This means that all the chemicals that are used are commonly found at home (e.g. table salt, water, sugar, boiled cabbage, vinegar). Furthermore, plastic ‘glassware’ is used wherever possible. This minimised risk means that the workshops can be held in normal classrooms and do not require laboratory space nor personal protective equipment (lab coats, gloves and safety glasses; though these items are carried by the program and available should students request them). This is critical in the design of Kitchen Chemistry as we want the workshops to be accessible to all students and also means that students can drop in at any time and do not need to be prepared for the workshops.

Table 1: Kitchen Chemistry Curriculum

Introduction to working in the lab. We have chocolate!	Skills: Observation skills, keeping a lab notebook, lab safety, team work, communication, labelling samples, collecting and recording data
Hitting the bull's eye – all about measurement	Skills: Precision vs accuracy, pipetting, using analytical balances for both liquids and solids, using volumetric flasks, using graduated cylinders, lab safety, recording data
Colour changing unicorn solutions	Skills: Titration, calibrating a pH probe, using a pH probe, lab safety, recording data, calculations
Making potions: solutions and dilutions	Skills: Pipetting, dilutions, preparing reagents, using balances, unit conversions, rearranging equations and algebra fundamentals
Connect the dots: Can your dilution make a perfect line?	Skills: Chlorophyll extraction (basic principles), dilutions, using a spectrophotometer, creating a standard curve, using a standard curve to determine unknown, calibrating equipment, algebra fundamentals
Exploding marshmallows (and other experiments)	Skills: Experimental design, hypothesis testing, null and alternate hypothesis, recording data, graphing, analysing and interpreting data, descriptive statistics, outlining a scientific report

Challenges with working in the co-curricular space

Working in the co-curricular space comes with several challenges. We overcame many of these, with varying levels of success, and are still working to address others. With teaching in the co-curricular space, it is important to acknowledge that we are working within an already crowded curriculum. Students are busy with curricular units and time poor, therefore, anything offered in the co-curricular space must provide a high value proposition for the students. In the case of Kitchen Chemistry, this was achieved through alignment with the curricular units and affording students an opportunity to work deeply with the content in a way they may not achieve in their curricular units. We know that this value proposition was well articulated for mature aged and international students as they comprised the majority of the students attending the workshops. Furthermore, many of these students attended the workshops regularly, so we know that they saw benefit from their time in the workshops.

Running the Kitchen Chemistry workshops is time and labour intensive. Workshops are intentionally staffed with three individuals to ensure that there are low student to staff ratios. This model of instruction comes under careful scrutiny in a system where universities are looking to minimise costs by increasing ratios and moving support resources online. How do we articulate the magnitude of the benefit students attending Kitchen Chemistry gain in a system focused on attendance as a key metric? We are actively conducting empirical research on this model and we are working through this program as an iterative model with the relevant stakeholders (unit coordinators, peer leaders, technical staff) to improve each subsequent offering. It is still too soon to know if these strategies will be successful in articulating the benefits of this program. Additionally, we have yet to develop a strategy to engage with external students. Given the hands-on nature of these workshops, there is no digital analogue for Kitchen Chemistry workshops. So can we bring the chemistry to their kitchen? Maybe. However, there are several technical and logistical issues to address before that would be an option.

Interaction with students and feedback from unit coordinators suggest that Kitchen Chemistry is working well in the co-curricular space. The program addresses a 'problem worth solving' in helping to create technically proficient science graduates and to provide students with rich, authentic learning experiences. While we acknowledge that our non-traditional academic roles have helped in the development of this program, we would suggest similar programs could be developed in other contexts with support of disciplinary academics and technical staff.

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