Developing Awareness of Professional Behaviours and Skills in the First Year Chemistry Laboratory

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Abstract

Students in first-year chemistry classes come from a variety of backgrounds, with many students unaware of the qualities and behaviours of a professional scientist. Throughout their degree, students will gradually develop their cognitive skills, but they may not be adequately taught or assessed on their professional behavioural skills as a scientist until late in the undergraduate course. By assessing the professional skills of students in first-year chemistry practical classes, this innovation commenced the development of students' professional identity from the beginning of their university experience. The skills that were assessed included preparedness, cooperation in the group activities, working safely in the laboratory and time management. By engaging students with professional behaviours and what it means to be a scientist during their first semester, students can potentially carry this through their whole undergraduate degree. This task was received positively by students and staff with over 50% of students believing it increased their confidence in the laboratory. Staff also saw a significant improvement in student behaviour and engagement because of this task.

Graphical Abstract

Introduction

Introductory chemistry classes have historically focussed on assisting student learning of fundamental chemistry concepts and the development of technical skills, with little emphasis on developing a student's professional skills as a scientist. Skills such as organisation, communication, interpersonal skills and self-motivation are all highly sought by employers[1], but students may not explicitly learn how to develop these skills until late in their degree program, if at all. Development

and reflection on these skills are common in professional degree programs such as dentistry, medicine, and nursing[2-4], and are a key component in the development of health professionals. Macpherson and Kenny promoted the basic sciences as a means of initiating medical professionalism in their students[5]:

> 'The emphasis on scientific facts results in neglect of other realms of professional competence, which some believe are innate and cannot be taught. Scientists have an unparalleled opportunity [in medical education] to model and teach the integration, communication, and self-reflection required for professional competence. These can be nurtured through explicit teaching in science courses.'

Their study highlights the importance of embedding and developing professional skills into the enabling sciences, while the focus of this article was on developing competence for medical students there is no reason this development cannot occur for all science students.

There have been many approaches to developing professional skills through specifically tailored undergraduate subjects (courses) or tasks. Many of these approaches seem to focus on developing communication skills, information literacy skills, skills designed to enhance the prospect of employment, as well as science ethics [6]. Other approaches include focusing on professional skills in the final years of an undergraduate course (program) because it has been recognised that graduates had some shortcomings with respect to expectations in work ethic, teamwork, self-dependence and occupational health & safety when they entered industry. Similarly, students had not managed to effectively integrate attitude and values towards understanding of professional and ethical responsibility [7]. A 2007 UK survey reports on the knowledge and skills, which graduates have found of value when they had graduated from university, and subsequently entered into employment or further study involving chemistry [8]. The surveyed graduates deemed "Time management and organisational skills" the most valuable skills they have used since graduating, however, interestingly, this is not something typically and explicitly taught in undergraduate chemistry. A recent Singaporean study of students, academics and employers showed discrepancy between the skills students acquire during their studies and those desired by employers[9]. Moreover, students identified professional skills as important for graduate success, but did not feel they were designed into the curriculum. This highlights the importance of explicitly making students aware of the development of these skills through their learning experience.

For the majority of undergraduate science degrees, students must undertake at least one unit of chemistry – this provides chemistry educators with a unique opportunity to develop science-relevant, though not discipline-specific, professional skills in the context of chemistry. The context is relevant because it lends an authenticity to the development of professional identity as a scientist. Such skills as organisational, interpersonal and work-based skills are relevant beyond the chemistry laboratory to other disciplines and, of course, applicable beyond the context of higher education. One of the further consequences of a focus on professional skills is that students can develop confidence, self-motivation and self-efficacy, thereby being more effective learners. These attributes have been observed to be important for industry and for graduate success[1]. However, recent research has highlighted the difficulty in incorporating assessment of the development of these skills as they "require feedback and personal reflection that are often difficult to incorporate given the technically dense material of the field" [10].

It is important to recognise that some skills (organisational and interpersonal) are being implicitly inferred in chemistry subjects, but to ensure their adequate growth, they need to be explicitly addressed and assessed. A student's sense of being organised, or possessing good organisational skills, has been shown to impact on their feelings of competence, relatedness and autonomy, all of which determine a student's ability to be self-motivated [11]. It is important to ask students to reflect on whether their organisation for classes contributed to, or hindered their learning that day, as a means of making the student draw their own links between their success in the class, and the effort they put into being organised for that class. Work-based skills (such as teamwork, autonomy and safe work practices) are expected of students, however students are rarely given the opportunity to receive feedback to assist in the development of these skills. Of particular importance, individual awareness of laboratory safety is paramount in establishing a professional and communal attitude to safe work practice. By asking students to engage in experiential learning and reflect on these skills after class, the students are provided with a dynamic learning environment [12]. Students develop and use "soft" skills as a tool to learn the "hard" science skills.

Based on the three domains of learning [13], chemistry practical classes (laboratory section) have a significant emphasis on cognitive and psychomotor skills (titrations, synthesis, pH monitoring, as examples). However there is very little focus on the development of a student's affective skills. The aim of this study was to implement an assessment that focussed on developing students professional skills in a chemistry undergraduate laboratory. From this, it was expected that students would engage more strongly with their identity as a scientist and with the content in chemistry.

Methodology

At the University of Technology Sydney (UTS), Chemistry 1 is a large enrolment first year subject that services a wide range of degree programs (student load ~1200 across the year). This is an integrated subject, typical of Australian chemistry subjects, with both theory and practical sessions in each week of semester. Assessment from the practical classes contributes to the overall assessment of the subject

Students undertaking science degrees at UTS arrive through a variety of pathways, with significant numbers of non-school leavers, first in family and international students. An assessment around the development of professional skills was introduced into Chemistry 1, shifting the focus from solely discipline-based assessment to include assessment of professional pratice. This task provides all first-year science students with an opportunity to develop and self-reflect on their professional skills, regardless of previous laboratory experience. It allows students to become aware of the expected competencies and behaviours of professional scientists.

This assessment was carried out during five of the weekly practicals classes in the subject over the 12-week semester (weeks 3-5, 7 and 9). The laboratory classes have a staff to student ratio of 1:16, which provides laboratory staff with the best opportunity to observe student behaviour and provide guidance on performance improvement in a more managable setting (compared to lectures or tutorials(recitation)). The assessment task, referred to as Professional Practice Points (PPP), was developed. This assessment task introduced students to the expected competencies for their organisational, interpersonal and work-based skills.

Developing the rubric

A task of this nature requires students to be aware of the behaviours and attributes required to be a professional scientist. As a result a rubric (Table 1) was developed, which focussed on three skill domains being assessed. The rubric assigned four levels of competency (not evident, developing, competent, and exemplary). Each level was assigned characteristic behaviours to assist students and staff in evaluating performance. These behaviours were described in simple, accessible terms to ensure an easy understanding of the criteria throughout the diverse student cohort. A conscious decision was made to not use the usual (fail, pass, credit etc.) scheme as this may have negative connotations and students would become too focused on ‘passing’ rather than developing their skills to an optimal level. The rubric was made available to students and staff through an online criteria-based assessment and marking tool called “REVIEW”.

Table 1: Developed Rubric for the Professional Practice Points Assessment

Practice	Not evident	Developing	Competent	Exemplary
Organisational Skills	Disorganised	Reasonably well-organised in the lab	Used time in the lab effectively	Well-organised in the lab session
	Poor attention to task	Not always attentive to task	Kept on-task during the session	Very purposeful, strongly on-task
	Not prepared for lab session	Had prepared to some extent for the lab session	Had read background material	Had read and fully understood background material
Interpersonal Skills	Does not follow instructions	Needed direct guidance in following instructions	Acts on instructions, seeking clarification when necessary	Acted on instructions promptly
	Not contributing effectively to discussion	Sometimes offered ideas. Good communication	Offered ideas and communicated effectively	Proactive in offering ideas, communicated well
	Dealt poorly with others	Some lapses in relations with others	Dealt courteously with peers and staff	Worked well with others in the lab
Work-based skills	Disruptive in teamwork. Non-contributor	Contributed to some extent to teamwork	Was an effective member of a team	Offered some leadership in team situations
	Unable to work independently without considerable guidance	Some initiative shown in working independently	Largely self-reliant in directing own work.	Self-starter, self-reliant
	Not working safely	Needed guidance in working safely	Worked safely in the laboratory	Always worked safely with proper concern for others

Staff and student training

Before semester commenced, staff were required to attend a training session that prepared them for assessing the specified skills in students. The general aims of the project were explained to staff, and then the rubric was presented and discussed. Examples of behaviours and skills at the different competency levels were described, as well as asking staff to contribute to discussion and suggest behaviours they felt belonged in those competancies. This group discussion was facilitated and moderated by those who designed the project, to ensure consistency between the intended meaning of the competencies and those held by staff. This discussion was integral in the execution of the project, as standardisation across assessors in the task relies upon a uniform understanding of the rubric. Staff were provided with a template to assist with in-class notetaking related to student behaviours and performance.

This task was introduced to students during their induction in the first laboratory class of the semester in a standard Powerpoint presentation supplied to all staff to deliver. The task was explained to students by highlighting the importance of developing in the three chosen skill domains for life after university. The rubric was explained, giving examples of behaviour for each competency in each skill. Students were instructed in the importance of honesty and openess when completing their self-assessment, and that improvements in their professional practice relied on developing sincere self-reflection skills. The rubric was made available in the laboratory manual provided to each student, so that it was easy for them to refer to it when completing their self-assessment.

Assessment during class

During a 3-hour practical class, staff would observe organisational, interpersonal and work-based skills of individual students. Each staff member was assigned a maximum of 16 students to assess. Classes began with a brief presentation given by staff detailing the theory and practical instructions necessary in order to successfully complete the experiment assigned for that session. Students then self-directed through the experimental method given in their laboratory manuals, whilst staff circulated the room, assisting with any queries. Staff were instructed to document comments or observations in the provided template to facilitate a personalised assessment of each student after the class. These observations were based around how the student interacted with peers and staff, and took direction (interpersonal skills), their time management, preparedness and focus (organisational skills), and their ability to work safely both autonomously and collaboratively (work-based skills).

At the end of the practical, students were allocated time (5-10 minutes) to complete a self-assessment of their performance by assessing themselves against the criteria contained in the rubric (Table 1). They were also able (and encouraged) to leave comments on their performance and give justification for why they graded themselves in a particular way. By giving students the opportunity to self-reflect, they were able to identify their own strengths and weaknesses, which then empowered them to focus on skills to develop for future classes.

Assessment after class

Following the class, the teaching staff would individually assess each student (2-4 minutes per student) using the same criteria (Table 1). Staff were unable to see the student's self-assessment until they had submitted their own assessment. This prevented the staff from being influenced by the student's self-assessment. Staff were encouraged to write personalised comments to the students relating directly to their individual performance, and select from a range of pre-written comments for efficiency and standardisation. This allowed students to receive individualised weekly formative feedback from the staff and consciously develop their own behaviours over the semester. Individualised feedback, particularly when assessing skills of this nature is of critical importance. Findings from a study at the University of New South Wales (Sydney, Australia) found that individualised feedback particularly in skill development (in the Faculties of Law and Social Sciences) is vital at first year level[14]. Once staff had submitted their assessment using the REVIEW system, they could then visualise on a slider scale their individual assessment overlaid with that of each student's assessment. This allowed staff to see how their expectations of student behaviour differed from those of the students, encouraging conversations between staff and students to better align expectations in regards to professional practice.

During any subsequent classes, staff were encouraged to reflect on the feedback given to the student from the previous assessment(s), and promote continual improvement. The improvement in organisational, interpersonal and work-based skills was achieved through reinforcement of appropriate and ideal behaviour.

Sustainability of the assessment

The staff group who facilitate learning in the laboratories consists largely of PhD students in science, usually chemistry or forensic science for Chemistry 1. In each class, one staff member is assigned as the "supervisor" and one less experienced staff member as the "demonstrator," who can eventually progress to supervisor. These staff usually will teach in the subject for 1-5 years, and so turnover is not particularly high. When a new task is implemented, proper training of the entire staff group is paramount, as this training is then propagated in further iterations of the subject from supervisor to demonstrator. Traditionally prior to the commencement of any session of Chemistry 1, staff are gathered to discuss any changes to be implemented. During this meeting, the PPP assessment task is explained and any queries from staff are discussed in an open forum. The task is easily sustainable due to the pre-semester training undertaken by staff, as well as the ability of the more senior supervisors to provide peer-to-peer support to the demonstrators during semester.

Evaluation

A total of 1876 students were surveyed online (819 Autumn session 2015, 149 Spring session 2015, 908 Autumn session 2016) and asked to provide their opinion on this task. The survey was administered online using mQlicker, and had appropriate ethics approval from the university (UTS HREC REF NO. 2014000659).
Questions found in Table 2 were answered by students using a Likert scale (strongly agree – strongly disagree). The following questions were open-ended questions where students could provide their own specific comments or recommendations.

1) What was most useful about the Professional Practice Points for you?

2) If you could make improvements to Professional Practice Points, what would they be?

Additional small focus groups were run for both staff and students to gain perspective on the scheme; this was performed by an independent assessor. The groups consisted of 5-8 students/staff and one assessor. The focus group sessions were recorded and notes were taken on responses. Students and staff participating in these focus groups were rewarded with movie tickets for their time and contribution. Statistical analyses comparing the results for each session were found to have no significant differences, and as a result all data was combined.

Results

Student self-evaluations at the beginning of semester tended to fall into two categories, students who were over-confident in their abilities '*Today we demonstrated exemplary skills and organisation during the experiment.*', and students who were under-confident '*My lack of chemistry knowledge may be slowing us down…*'. Students who were confident in their chemistry knowledge, tended to grade themselves at the exemplary level for all criteria, with little thought put into the evaluation (very few left comments or justification of their self-assessment). It is believed that these students align their ability to work 'professionally' with their knowledge of the discipline, while this is no doubt a factor, it is important that students realise that subject matter competence is not the only factor in graduate success. After receiving feedback from the staff in the first week they began to readjust their self-assessments and more accurately reflected on their performance and understanding of what was required of them to achieve an exemplary level. These students made it a personal goal to achieve an exemplary grade in all criteria and would work a lot harder in later weeks in order to achieve that goal, which would not have occurred had the students not been made aware of the expected level of performance in the laboratory.

> Student Comment: '*Over the semester my partner and I have greatly increased our organisational, communication and work-based skills to the point where we work efficiently together and are able to independently offer our abilities to get the work done accurately. I feel that we have both offered each other criticism of the semester to allow for improvement and during this last practical it definitely showed that we have come a long way since the beginning of the semester*.'

More interesting were the students who were under-confident in their ability. These students tended to be mature age or students with a limited background in chemistry. Their belief was that since they did not fully understand the content, or had issues with the pre-laboratory exercises they had performed poorly in the lab. However, these students tended to display a higher level of professionalism than other students (more organised, well prepared for class, listen to instructions, courteous to peers and staff). As a result, their staff rating would be higher than the self-evaluation, in turn, this resulted in a confidence boost for these students, which was valuable as these would be our most at-risk students from dropping the course or out of university. Example student and staff comments are below;

> Student comment: *I still need improvement with working independently in the lab as I had made a mistake during the experiment by accident with the indicator. However, I was able to complete*

the tasks with no assistance and was able to follow instructions in a safe and effective manner. I was consistently on task.

Student comment: *I felt like at first, I was completing what was told in the instructions, but gradually became more disorganised during the end of the experiment, but once I laid out all of my equipment, took a deep breath, and re-read the instructions provided, my organisation improved.*

Staff comment*: Don't be so harsh on yourself/team! For some unknown reason, you have been hit with the most unexpected of circumstances and have still prevailed. This is the important lesson in science; when things go pear shaped, you can still triumph. I like how you/partner teach/learn off each other. It's good to see. Keep it up.*

The weekly comments provided staff an opportunity to develop a strong rapport with students throughout the semester. Students who felt they were struggling were able to share their concerns with the staff in the PPP comments, and staff members were able to help them through any issues they had with the course or their transition to university. This dialogue in the comments section of the PPP assessment also allowed a non-confrontational communication channel between staff and student. The provision of this relatively informal exchange medium allowed students to also say things to the staff that they might be too shy to discuss in person, or things that may not warrant a formal email. An example correspondence between staff and student is below:

Student Comment: *While we initially found the instructions somewhat confusing, after collaborating with [staff member] we were able to set up and our equipment and get organised quite quickly and knew what needed to be done. There was an abnormality with one of our sample concentrations, however a repeat was conducted and the correct reading obtained. Overall I was quite happy with how this lab session went and the communication between my partner and me.*

Staff Comment: *Mistakes happen all the time, you acted professionally by owning up and offering assistance to your peers, well done!*

The task allowed alignment and benchmarking between student and teaching staff understandings of the meaning of professional practice and professionalism within the laboratory. The adjustment of the student's notions of professionalism, in terms of organisational, interpersonal and work-based skills, was an excellent teaching and learning tool. It made students not only think about the development of these skills on a weekly basis, but also encouraged their conscious growth and improvement. Focus groups also found that throughout the semester, students became more confident in differentiating between performing well based on their discipline knowledge (not what was being assessed by this task), and performing well in the laboratory in regards to their professional practice (what was being assessed).

Numerous comments made in the focus groups by students drew comparison between the exercise of self-evaluation each week, and the more common use of retrospective self-evaluation at the end of an entire subject. Students felt that by consistently self-evaluating, they could set personal goals to lift their tutor (TA) designated marks, and try to meet them throughout the class. Surveyed

students unanimously enjoyed having the opportunity to increase their performance each week based on their own and their tutor's assessments of their performance.

An analysis of the student and staff evaluations across the three surveyed semesters (Figure 1) found that student and staff evaluations became more closely aligned as the semester went on, after the third experiment however, the staff were actually rating the students higher than the students self-evaluation. This is an interesting result where initially students were overconfident in their professional skills; students gradually became aware of the necessary professional skill level required. This is reflected in the decrease in the range of self-assessment values across the semester which initially are broad, however as the semester progresses, the student's ability to judge their own performance against the rubric improves. An interpretation of the data could be that students over time became more critical of their own performance than the staff were. This indicates a growing capacity for self-criticism and reflection as a means of continual improvement and as a sign of developing professional attitudes. The development of a capacity for self-assessment is an important professional skill in itself[15]. The upwards trend in staff evaluations across the semester demonstrates an increase in the professionalism of the students. This reaffirms the focus group information where students were 'rising to the challenge' of gaining the best evaluation from the staff.

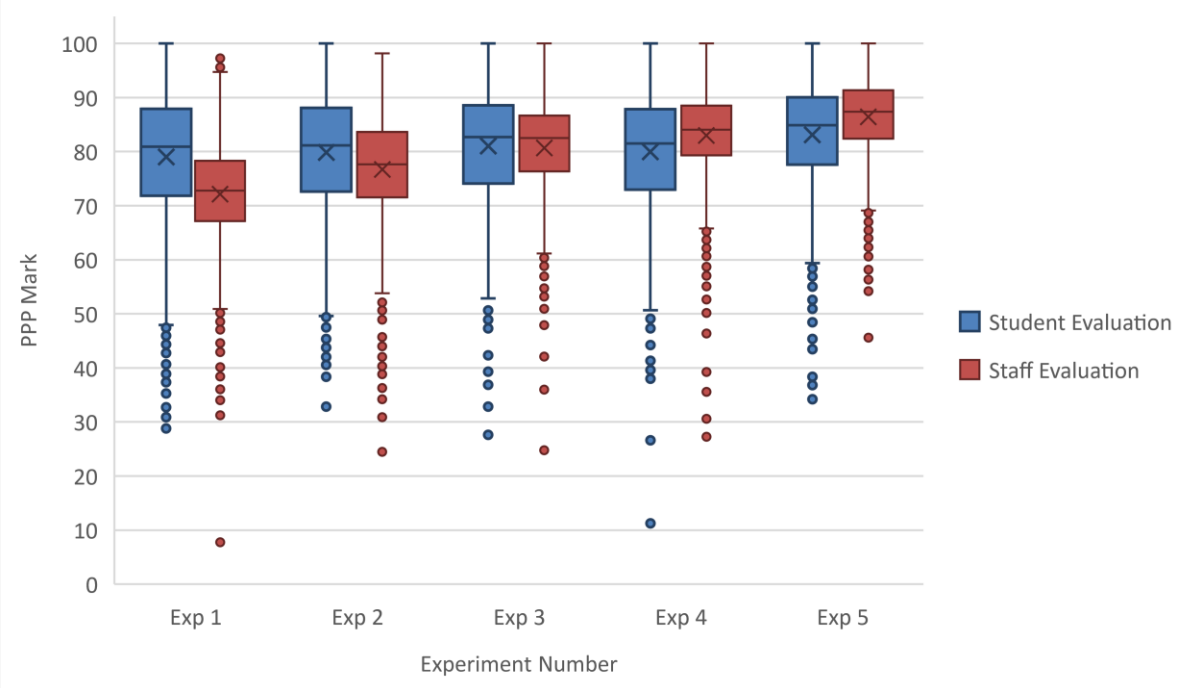

Figure 1: Weekly evaluation scores for student self-evaluations and staff evaluation of professional practice. Data collated for the three surveyed semesters n = 9544

From the survey results (Table 2), students tended to be positive or indifferent to the task itself. Over 50% of students found that PPP helped them feel more confident, this result is significant in a first year subject as it has implications for student retention in the subject. The data for the statement 'Professional Practice Points helped me to do better in the practical classes' returned the lowest positive result. It is believed that at this point in their educational journey, students are quite

focused on developing their knowledge or practical skills rather than their own professional identity. Since this task did not necessarily help the students be more 'accurate' or obtain a better yield they may not believe it helped them. It is important to note that first year university students may not yet have developed the metacognitive skills to understand the significance of the task.

Table 2: Comparative Survey Results for Students' Perceptions of Professional Practice Points

Statement for Student Response	**Student Selecting a Response Category, %(*n*);Total *N* = 1876**				
	Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
Professional Practice Points helped me understand what was expected of me in Chemistry 1	11.1 (209)	48.9 (918)	27.1 (509)	10.0 (187)	2.8 (53)
Professional Practice Points helped me feel more confident	11.1 (209)	41.9 (786)	31.6 (593)	12.8 (240)	2.6 (48)
Professional Practice Points helped me to do better in the practical classes	9.7 (182)	39.1 (734)	32.9 (618)	14.7 (276)	3.5 (66)
Overall I was satisfied with the Professional Practice Points assessment	11.4 (214)	52.3 (981)	26.1 (490)	7.3 (137)	2.9 (54)

Another factor which impacted the students perception of the task was the amount of personalised feedback given to them by the staff. While comments were not compulsory for staff or students, most staff would write specific comments for each student. While this increased the time taken to mark the students, staff found this to be the most helpful in assisting the student's engagement with the task. Feedback on professional behaviours strengthened the dialogue between students and demonstrators. Having 'broken the ice' through these discussions related to professional skills, better help-seeking behaviour was observed by the teaching staff.

The open ended questions from the evaluation revealed that students responded well to the feedback given to them by staff. Students who liked the task also recognised that it was a useful tool to help them improve their performance. Examples of student comments include:

Student Survey Comment: 'It was used to motivate me towards achieving something in that lab session, it allowed for me to self-assess to see which sections need improvement'

Student Survey Comment: 'We could get feedback or relay any queries we had with the practical to the lab demonstrators. The PPP allowed me to find out how well I was performing in the lab as well as give me the opportunity to self-evaluate my own work.'

A student during the focus group session remarked "*It's like a personal goal. You set the bar at where you're aiming for, and knowing that you're being marked on something means that you know you have to work towards something."* This type of comment reflects that this type of assessment was often seen as a motivating tool for students to perform better. The ability for the students to receive timely feedback (within 48 hours) on their performance and implement changes throughout the semester was a prevalent theme in the student responses.

As for the open-ended question 'If you could make improvements to Professional Practice Points, what would they be?' it was interesting to note that while students appreciated the feedback given to them, they wanted it to be more specific. During the focus groups it was remarked that "*[they] recognise the difficulties in providing individualised feedback, however when it was more personal it was very much appreciated*". It should be noted that students were given a combination of directive (an instruction for improvement) and supportive (encouragement and rapport building) comments from staff. Engagement with the task will be dependent on the feedback students receive, which is something that should be considered when designing these types of assessments. Moving beyond a numerical evaluation is important for students who are used to being awarded a 'mark' that for them represents their value in a discipline or their understanding of a topic. By exposing students to a task that evaluates performance, it also helps to prepare students for similar evaluations they would be subject to once they leave university, since most workplace appraisals are based around competencies and behaviours rather than a numerical evaluation.

Prior to the implementation of this task, varying levels of laboratory behaviour were observed, particularly in regards to laboratory safety. Since the students were never assessed on behaviours and performance of tasks in the laboratory (just on their completion of the activities), there was an attitude amongst the students that what they said and did, did not matter, only what they wrote in their reports (since that's all they were being marked on). In order to ensure a safe learning environment staff were obliged to adopt a disciplinarian role, rather than a facilitator of learning. As a result of the implementation of professional practice points (PPP), students were being held accountable for their actions and behaviours and student behaviour significantly improved. This created a more collaborative learning environment for the students to engage with the practical classes in both the cognitive and affective sense. Reports from staff found that students adopted safe working practices without consistent prompting and were a lot more respectful having been made aware of the expected professional conduct. The ability to instruct students on their expected conduct was powerful for staff, as they had to expand their understandings of what the students were learning in the classes to now include (traditionally implied) soft skills, that were being explicitly assessed. Staff members also commented that this task allowed them to become more aware of their own professional behaviours in the laboratory both in the class and in their own laboratories. By being role models for student behaviour, staff tended to take their duties more seriously. Overall this task had a positive effect on the student experience, it has helped to develop the student's professional behaviour and assisted them in shaping their own professional identity.

Conclusion

A task introducing the concept of professional practice in a large first year chemistry subject was monitored over three semesters. The task aimed to develop student's awareness of professional conduct in a laboratory setting. By allowing students to self-evaluate and receive feedback on their

organisation, work-based and interpersonal skills, students acquired a greater understanding of the competencies required to be a professional scientist. As seen in the staff evaluations, this was reflected by a continual improvement of student performance ratings across the semester. From survey responses, over 50% of the students believed the task made them confident and better prepared in the laboratory. The development of a professional identity is something that students must craft over the entirety of their degree, of which the skills assessed here form a small part, but by increasing student awareness early and providing them with guidance and support, the development of these skills can be enhanced.

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