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Logs for acid-base chemistry: illustrating the potential of multidisciplinary learning support interventions from the third space

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Abstract

The growing accessibility of higher education over the last century is a major accomplishment and should be continuously supported. A particular barrier to widening participation is that curricula across numerous disciplines rely on assumed knowledge for enrolling students. The gaps between this assumed and actual pre-existing knowledge are dispersed throughout institutions, making them difficult to bridge. Our institution runs seven different first-year chemistry subjects, all of which require students to use mathematical logarithms to solve acid-base chemistry problems. Our case study illustrates that third-space practitioners with disciplinary expertise, such as those working in STEM support for learning, are uniquely positioned to address challenges like this. As a chemistry educator and mathematics educator employed in the third space, we co-designed and co-delivered a one-hour online workshop titled “logs for acid-base chemistry”. The session explicitly taught logarithmic concepts in context to students from four different chemistry units. Observations made during the workshop suggest that the intervention was able to efficiently improve acid-base calculation confidence in students from all attending cohorts. Finally, the broader benefits of subject specialist third-space staff in higher education are discussed in light of the case study findings. Overall, the efficiency of this intervention highlights the under-researched potential of embedding disciplinary experts in third-space learning support roles.

Keywords: acid-base calculations; chemistry education; maths support for learning; conceptual integration

Introduction

The Widening Participation agenda has radically transformed the demography of students entering higher education over the past three decades (Burke, 2002). Originally, higher education only targeted students from privileged socioeconomic backgrounds, who attended university with abundant social capital and a rich secondary education related to their chosen field. However, the traditional teaching practices that cater to these students cannot accommodate a more diverse student cohort. In Australia and the UK, the Widening Participation Agenda has successfully increased the participation of mature-aged students and students from lower socioeconomic backgrounds (Sellar and Storan, 2013; Di Miceli, 2024; OECD, n.d.). Now, there is an acknowledged need to further widen public participation in higher education to meet the demands of the technologically advanced future of work (Australian Universities Accord Review Panel, 2024).

First-year chemistry instruction particularly struggles to accommodate the diversification of its student cohorts. Given the increasing flexibility of degree transfers and alternate entry pathways (Dalley-Trim and Alloway, 2010), many students entering first-year chemistry lack traditional high-school prerequisites such as advanced mathematics and chemistry (Australia’s Chief Scientist, 2020; Chesnut et al., 2022; Australian Universities Accord Review Panel, 2024, p.266). For older students, this prerequisite study may have been completed in high-school decades ago (Stone, 2021). These factors make tertiary chemistry a notoriously difficult hurdle for students. This difficulty is compounded for students not enrolled on a chemistry degree, but rather a health sciences degree that still requires first-year chemistry knowledge (Feldt and Donahue, 1989; Grove and Bretz, 2008; Brown and Naiker, 2018).

This case study details a learning support intervention for chemistry students developed by third-space university staff. Traditionally, the third space in academia has been constructed as a post-disciplinary entity, with staff focusing on universal determinants of learning such as student belonging and academic writing capability (McIntosh and Nutt, 2022). These staff typically hold qualifications within the discipline of education. However, as the scholarship of learning and teaching has long argued, teaching and learning inquiry ‘should be conducted by academics from all disciplines, not just those with appointments in schools of education’ (Pace, 2004, p.1174). Therefore, we argue that third-space practitioners with educational expertise augmented with disciplinary knowledge should be deployed to support student success (Devine et al., 2022). This case study aims to illustrate the benefit of multidisciplinary support in addition to pre-existing generalist third-space learning support.

Context

The authors of this article work within a small STEM support for learning (STEM-SfL) team at an Australian university (for further details on the history and developmental trajectory of this team, see Lightbody et al., 2018). Joshua Wang is a biochemist and Elise Kenny is a physicist, both with PhDs in their respective fields. Additionally, both hold education qualifications. At the time of this intervention, Josh mainly supported chemistry learning within the Faculty of Health, while Elise mainly supported maths learning within the Faculty of Science. The entire STEM department would meet at least monthly. Collaborations between STEM-SfL staff and between STEM-SfL staff and faculty were encouraged. While our support is augmented by peer facilitation (outlined in Devine et al., 2022), our team also runs targeted interventions to address STEM learning support needs for students across the university. Additionally, we occasionally partner with interested faculty to develop customised learning support for the subjects they teach. As a result, we had pre-existing relationships with some chemistry teaching faculty at the time of the intervention.

Description of situation requiring intervention

Our institution has multiple first-year subjects that cover fundamental chemistry principles across many faculties (Table 1). Importantly, student enrolment in these subjects and degrees requires no secondary education prerequisites. Therefore, the level of prior exposure to mathematics and chemistry concepts in these cohorts varies considerably. The concurrent delivery of numerous chemistry subjects is designed to ensure that students' chemistry learning is contextualised to their desired professional field. However, most subjects loosely follow an 'atoms-first' chemistry curriculum design, which focuses on beginning at smaller levels of analysis (i.e. atoms) and then slowly moving to larger levels of analysis (i.e. large biomolecules) as the curriculum progresses (Esterling and Bartels, 2013). Therefore, except for one subject that also delivers physics content (Experimental Sciences 1), all subjects at our institution introduce acid-base chemistry between weeks 2-4 of the semester.

Table 1. Overview of subjects covering introductory acid-base chemistry at our institution.

Subject name	Faculty	Cohort Description	Week	Number of registrations for intervention
Experimental Sciences 1	Science	Combined introductory chemistry/physics unit completed by bachelor of science students	8	0
General Chemistry		Foundational general chemistry course taken by all Science Faculty students, taken after experimental sciences 1	3	1
Fundamentals of Chemistry		First chemistry unit completed by bachelor of science (advanced) students instead of the above 2 subjects	3	0
Chemistry for Medicines	Health	Introductory chemistry and biochemistry subject with a pharmacology context for pharmacy/podiatry students	2	2
Chemistry for Health Sciences		Introductory chemistry and biochemistry subject for nutrition and optometry students	4	45
Foundations of Biochemistry		Introductory chemistry and biochemistry subject for biomedical science and medical laboratory science students	3	23

Introductory Chemistry for Educators	Education	Introductory chemistry and biochemistry subject for secondary education students specialising in chemistry teaching	4	0
Non-chemistry subjects				11

Acid-base chemistry is a particularly challenging topic that heavily contributes to student failure and attrition at the undergraduate level (Kampamba, 2023). Part of this difficulty is due to acid-base concepts employing a logarithmic scale to present information. For example, pH is the negative logarithm of the concentration of hydronium ions (H3O+) in a solution. This scale can often contradict dichotomous rules taught in more junior chemistry learning environments (Cros et al., 1986; Romine et al., 2016). For instance, there is a common misconception that pH ranges from 1-14, but it is possible to have a solution with a negative pH. Understanding mathematical logarithms is therefore essential to meet the learning objectives of typical university-level acid-base chemistry curricula.

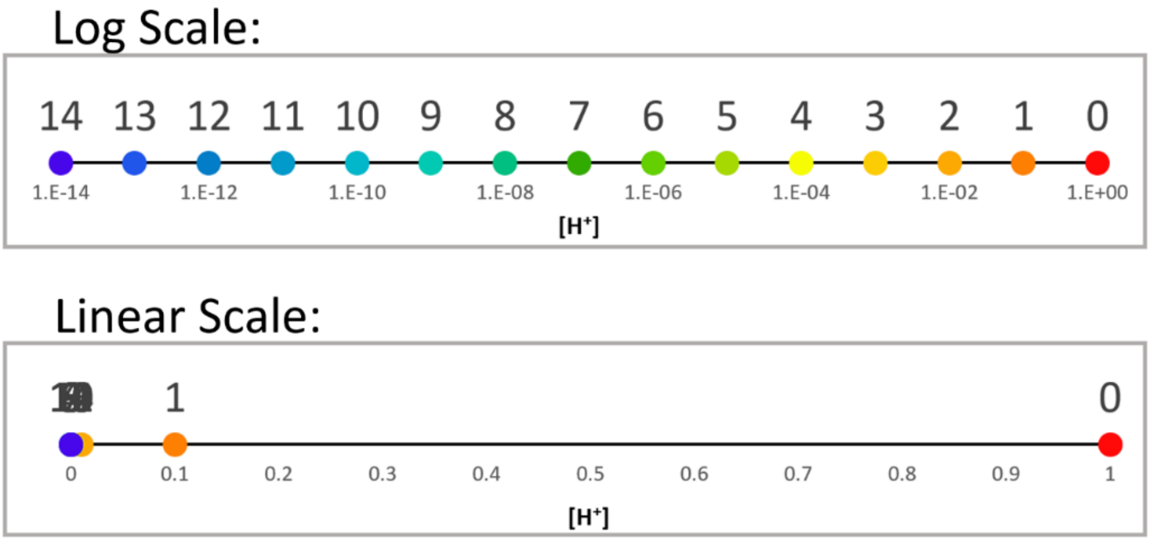
The teaching of acid-base chemistry is a classic example of where the so-called “Mathematics Problem” (Lawson et al., 2020) makes an impact. This problem can be summarised as the mathematical under-preparedness of undergraduates in the physical sciences. Students experience difficulties learning logarithms even when they are taught as a dedicated topic within a mathematics class (Kenney and Kastberg, 2013). Chemistry curricula is already content heavy, and therefore lacks capacity to explicitly teach logarithm mathematics. Together, these factors contribute to chemistry students’ shallow understanding of logarithms reported in chemistry education studies (Cros et al., 1986; Watters and Watters, 2006). It has been shown that mathematics interventions, specifically in the context of chemistry and other physical sciences, have a significant impact on the retention of students in these fields (Ní Fhloinn et al., 2014). Therefore, this was the perfect opportunity to combine our expertise in mathematics and chemistry support to develop a targeted logarithm mathematics support session for all first-year chemistry subjects at our institution.

Intervention design

In week 5 of the 2022 semester 1, we ran a single one-hour online “logs for acids and bases” workshop for first-year chemistry students across the university. Approximately one week prior to the intervention, posts were sent to each chemistry subject’s learning management system announcement portal advertising a “logs for acids and bases” workshop. The timing of the workshop was chosen to ensure no clashing commitments for full-time, first-year students from each cohort. Students who registered for the workshop also received a reminder email 24 hours before the event. A total of 82 students registered to attend, with 62 students ultimately attending.

The content of the workshop was developed to prioritise the fundamental understanding of a log scale. This includes an understanding of the utility of the log scale in the context of concentrations and an intuition for how the log function works mathematically. The workshop began by introducing logarithmic concepts. Figure 1 shows an image that was used during the workshop to justify the use of a log scale in the context of pH and concentrations in chemistry. The top panel displays a set of pH values and corresponding concentrations plotted along a log scale, where they are equally spaced. In contrast, the bottom panel shows the same values plotted on a linear scale. In this case, they are all bunched up towards the smaller end of the scale and difficult to distinguish. In showing this image, the hope is that students will understand why a log scale is used in this context, providing them with motivation to learn the mathematical model. The rest of the workshop was dedicated to interactive worked examples complimented by short questions to serve as knowledge checks (Table 2). The solutions to each question were also provided following the knowledge checks. In this way, the bulk of the workshop consisted of the students or the instructors doing acid-base calculations.

Figure 1. Image used in the workshop to demonstrate the usefulness of the log scale in the context of pH and H+ concentration.

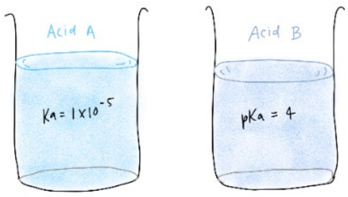
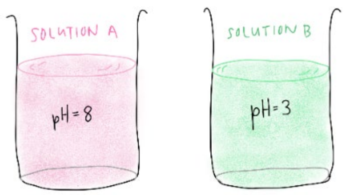


Teaching a mathematical concept alongside a chemistry context is a form of conceptual integration or blending, which has been shown in cognitive science to improve understanding of both topics involved (Fauconnier and Turner, 1998; Coulson and Oakley, 2001). Conceptual integration has been explicitly recommended for chemistry education (Bain et al., 2019). Being purposeful about teaching an understanding of logarithms increases the possibility that the students may also better perform calculations with, and interpret, logarithms in the context of acid-base chemistry. Our third-space collaborative approach therefore allowed for pedagogically informed, and chemistry-contextualised logarithm teaching.

To help students develop an intuitive understanding of logarithms, we dedicated significant time during the workshop to calculating and estimating pH, pKa, pOH, and concentration values without the use of a calculator. This included comparing and estimating. Table 2 shows the questions that were used as knowledge checks for students throughout the workshop. Only two out of eight questions required the use of a calculator. In addition to encouraging a deep understanding of the log function, teaching the mathematics in this estimation-based manner also allows students to develop more understanding of scientific notation and the meaning of negative indices in this context (Berger et al., 1987).

The questions were delivered to students with an online platform, where they could each anonymously enter their own answers. Delivering the questions in this way served to make the session more engaging for students, but also allowed us to monitor how the students were engaging with the session. Having students' answers enabled us to check understanding in real-time and adjust our explanations or include extra examples where needed. After each delivery of the session, we spent time reflecting on how we could make changes to improve the outcomes. This often resulted in adjusting the number of example questions or the time spent on each topic.

Table 2. Overview of practice exercises performed during the workshop.

Question Type	Example 1	Example 2	Pivotal Concepts
Determining values without a calculator	What is the pH if $[H^+] = 1 \times 10^{-12}$ M?	What is the pOH if $[OH^-] = 0.01$M?	The interpretation of a log function as a power.
Estimation of range	Estimate the pH if $[H^+] = 0.2$ M	Estimate the pKa if Ka $= 3 \times 10^{-8}$ M	The interpretation of a log function as a power. The meaning of negative indices and scientific notation.
Comparison of values	 Which acid is the strongest?	 Which solution has the highest concentration of H^+?	The link between the negative logarithmic scale and the properties of acids and bases.
Determining values with a calculator	What is the pOH if $[OH^-] = 3.5 \times 10^{-3}$ M?	What is the $[H^+]$ if pH $= 8.65$?	Using logs and scientific notation on a calculator.

As third-space practitioners, we are especially and advantageously positioned to deliver teaching that features conceptual integration. Collaboration between discipline-based academics has been demonstrated to be highly advantageous for the development of cross-curriculum mathematics interventions (Jackson and Johnson, 2013). Not only do we have the time to collaborate and design targeted interventions such as this, but we are also able to co-deliver the workshop. This allows the students to experience real-time explanation and feedback on both the chemistry and mathematics-based concepts as well as witness clarifying conversations between experts from each field. Additionally, our central positions allowed us to end the session with referrals to other maths or chemistry workshops run by our team.

Evaluation and conclusion

Universities have many first-year subjects with overlapping STEM curricula designed for specific major cohorts. However, recent trends towards higher education access have led to many students missing what was once considered essential prerequisite knowledge. Therefore, learning acid-base mathematics is one of the many barriers to Chemistry students' success that the modern higher education context presents.

In this case study, we have demonstrated the potential of third-space educators to intervene in what would otherwise be numerous diffuse gaps in student support unable to be addressed within curricula. As interdisciplinary courses continue to develop, complex curricula will benefit from disciplinary third-space staff stitching shut gaps in students' assumed knowledge/competencies. For example, multidisciplinary collaborations between learning support staff would likely address students' challenges within emerging disciplines such as the digital creative industries (Leung and Bentley, 2017) or bioinformatics (Saunders et al., 2018). By utilising our roles in a multidisciplinary, centrally-located student support department, we were able to design a single one-hour intervention that provided students across all chemistry subjects with contextualised, prerequisite calculation skills to understand acid-base chemistry.

Our case study provides two contributions to the learning development field. Firstly, samples of all teaching materials used have been provided to facilitate other chemistry and mathematics educators to replicate the intervention at other institutions. More generally, this case study provides an illustrative example of third-space practitioners with disciplinary expertise. Chemistry expertise was required to identify and understand the threshold concept of acid-base calculations in students across the institution. Mathematics expertise was then required to dissect the specific numeracy learning objectives present within this threshold concept. When combined, our workshop provided targeted support to a large group of students across the university. We argue that our broader positions in the third space contributed to our ability to recognise and address this barrier for all of our institutions' cohorts who learn chemistry. Such an approach is more scalable when compared to faculty teaching staff expending equivalent resources to provide an intervention to a single cohort of students. Therefore, this case study provides preliminary evidence that subject-specialist learning support can address barriers to student learning that would otherwise be impractical under similar resource constraints. Whilst acknowledging the limited institutional support for third-space practitioners' research (Bickle et al., 2021; Whitchurch, 2023), we hope that this case study encourages other third-space staff providing discipline-specific support to publish their findings.

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