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Identifying Skill Inequalities in Undergraduate Chemistry Laboratory Teaching

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1. General Information

This document contains supplementary information relating to the publication “Identifying Skill Inequalities in Undergraduate Chemistry Laboratory Teaching” including survey details, lists of key lab skills and detailed statistical analysis.

2. Survey questions

Section 1: Contextual information:

1. I have read the above statement and consent to taking part in this survey.
2. What course do you currently study?
3. Which degree programme are you registered on?
    a. If you selected Other, please specify:
4. What year did you finish/graduate from High School?
    a. If you selected Other, please specify:
5. To what extent do you feel that Covid-19 affected your laboratory training? Click on More Info for more detailed scale descriptors.
    a. Feel free to write any comments you have about how your laboratory training was disrupted by Covid-19:
6. Where did you attend your final two years of school?
    a. If other, what country did you complete your last two years of High School studied in?
        i. Did you complete your last two years of studies in English? If you did not complete your studies in English, please specify what language you were taught in.
    b. What category most accurately describes the school you attended for your final two years of study? Click on More Info for category descriptors.
    c. Do you have any comments to add about your school?
    d. Is English your first language?
        i. What is your first language?
7. What curriculum did you follow in your two final school years?
    a. If you selected Other, please specify:
    b. What grade did you get in Higher Chemistry? (Scotland)
        i. Did you complete an Advanced Higher in Chemistry?
            1. What grade did you get in Advanced Higher Chemistry?
    c. What grade did you get in your Chemistry A-level?
    d. What grade did you get in IB Chemistry?
        i. Did you complete Higher or Standard level Chemistry?

Overall perceived quality of teaching:

8. How would you rate your school-level academic experience, specifically focusing on theory and exams only? Use a scale of 1 to 7, where 1 represents a very poor experience, 4 is considered average and 7 represents an exceptional experience? Please click on More Info for detailed scale descriptors.
9. How would you rate your school-level Chemistry Academic experience, specifically focusing on practical and laboratory skills only? Use a scale of 1 to 7, where 1 represents a very poor experience, 4 is considered average and 7 represents an exceptional experience? Please click on More Info for detailed scale descriptors.
10. To what extent do you feel your school adequately prepared you for success in the laboratory? 1- Not at all, 4- Average, 7- Exceptionally. Please click on More Info for detailed scale descriptors.
11. On average, how many hours a week did you spend carrying out or observing laboratory practical work?
12. How often did you work independently in your school lab sessions?
13. Did you have additional laboratory training through any other subjects studied to an advanced level?
    a. Did you study any of the following lab-based sciences in your final two years of school studies?
        i. If you selected Other, please specify:
14. Do you have any comments to add about your labs/practicals during your final two years of school?

Section 2: Students' perceived Experience:

15. How would you rate your Experience of these various laboratory skills when you finished school?
    a. Accurate mass measurements (in mg)
    b. Make up a standard solution with exact concentration
    c. Complete a redox titration with a range of indicators
    d. Measure gas volume using gas syringe
    e. Conduct a calorimetry experiment
    f. Complete an acid-base titration with a range of indicators
    g. Use a pH meter
    h. Construct a voltaic cell
    i. Use a water bath

j. Distillation using a Liebig condenser
k. Experiment under reflux
l. Use of QuickFit glassware
m. Tests for key organic molecules and ions
n. Filtration (Filter paper)
o. Vacuum filtration with a Buchner funnel
p. Purify solid products using recrystallisation
q. Separate immiscible liquids using a separating funnel
r. Conduct melting point analysis
s. Use of thin-layer chromatography
t. Measure voltage of electrochemical cell
u. Writing risk assessments
v. Initial rate method (clock reactions)
w. Continuous analysis for rate experiments

Section 3: Students' perceived Confidence:

16. How would you rate your Confidence in these various laboratory skills when you finished school?
    a. Accurate mass measurements (in mg)
    b. Make up a standard solution with exact concentration
    c. Complete a redox titration with a range of indicators
    d. Measure gas volume using gas syringe
    e. Conduct a calorimetry experiment
    f. Complete an acid-base titration with a range of indicators
    g. Use a pH meter
    h. Construct a voltaic cell
    i. Use a water bath
    j. Distillation using a Liebig condenser
    k. Experiment under reflux
    l. Use of QuickFit glassware
    m. Tests for key organic molecules and ions
    n. Filtration (Filter paper)
    o. Vacuum filtration with a Buchner funnel
    p. Purify solid products using recrystallisation
    q. Separate immiscible liquids using a separating funnel

r. Conduct melting point analysis
s. Use of thin-layer chromatography
t. Measure voltage of electrochemical cell
u. Writing risk assessments
v. Initial rate method (clock reactions)
w. Continuous analysis for rate experiments

Section 4: Students' complementary 'soft skills':

17. To what extent do you agree with the following statements?
    a. I am competent in the lab
    b. I am confident in the lab
    c. I am independent in the lab
    d. I am safe in the lab
    e. I am accurate in the lab
    f. I am tidy in the lab
    g. I am efficient in the lab
    h. I understand the theory behind my labs
    i. I ask the demonstrators lots of questions
    j. My written English skills are strong
    k. My spoken English skills are strong
    l. I recognise hazards and risks
    m. I am confident designing my own experimental methodologies

3. Scottish Higher Specification

Candidates must be familiar with the following techniques:

- Simple filtration using filter paper and a funnel to separate the residue from the filtrate.
- Use of a balance, including measuring mass by difference.
- Methods for the collection of gases including:
    - Collection over water (for relatively insoluble gases, or where a dry sample of gas is not required)
    - Collection using a gas syringe (for soluble gases or where a dry sample of gas is required)
- Safe methods for heating using Bunsen burners, water baths or heating mantles.
- Determining enthalpy changes using $E_{h.}$
- Volumetric analysis:
    - The volume markings on beakers provide only a rough indication of volume.
    - Measuring cylinders generally provide sufficient accuracy for preparative work, but for analytical work, burettes, pipettes and volumetric flasks are more appropriate.
    - Titration is used to accurately determine the volumes of solution required to reach the end-point of a chemical reaction.
- Preparation of a standard solution.
- Simple distillation using a flask, condenser and suitable heat source to separate a mixture of liquids with different boiling points.

4. P-values obtained for Overall perceived quality of teaching using a two-tailed independent T-test

Identifying statistical significance across the three variables. Green values are identified as statistically significant ($p < 0.05$), red values were not statistically significant ($p > 0.05$). All values reflect p values obtained from a two-tailed independent T-test. See Table S1.

Table S1: P-values obtained for Overall perceived quality of teaching using a two-tailed independent T-test, comparing different student groupings for each variable.

Overall perceived quality of teaching	Private vs State	A-level vs Higher	A-level vs IB	A-level vs Other	UK vs International
Theory and exams	0.70135	0.00112	0.55518	0.01023	0.56429
Lab and Practical skills	0.16190	0.00691	0.42295	0.00691	0.83918
Prepared for the lab	0.03629	0.00940	0.69737	0.00516	0.79590

Identifying statistical significance between students perceived quality of teaching of Theory vs. teaching of Lab and practical skills or overall preparedness for the undergraduate lab. All values reflect p values obtained from a two-tailed independent T-test. See Table S2.

- Green values were identified to be statistically significant ($p < 0.05$)
- Red values were identified to not be statistically significant ($p > 0.05$)

Table S2: P-values obtained for Overall perceived quality of teaching using a two-tailed independent T-test, comparing teaching of Theory vs skills or overall preparedness for the laboratory.

Group of students	Theory vs skills	Theory vs Prep
Private	0.003039	0.00879
State	<0.0001	<0.0001
A level	0.000937	0.000431
Scottish Highers	0.000011	<0.0001
IBDP	0.201337	0.406186
Other	0.035136	0.006973
UK	<0.0001	<0.0001
International	0.004142	0.004956

5. P-values obtained for each skill using Mann-Whitney U test

P-values and statistical significance outcomes were determined for each skill across different groupings. Data was classified to be non-parametric, ordinal data. Statistical significance was determined using a Mann-Whitney U test, with significance defined as $p < 0.05$. See Tables S3-5.

- Green values were identified to be statistically significant ($p < 0.05$)
- Red values were identified to not be statistically significant ($p > 0.05$)

Table S3: P-values obtained for experience in each skill, using a Mann-Whitney U Test, comparing student groupings for each variable.

Experience	Private vs	A-level vs	A-level vs	A-level vs	UK vs
15.1. Accurate mass measurements (in mg)	0.1645	0.5755	0.9362	0.1010	0.7279
15.2. Make up a standard solution with exact concentration	0.8887	0.1770	0.2150	0.0060	0.0910
15.3. Complete a redox titration with a range of indicators	0.0164	0.1211	0.7872	0.0080	0.7039
15.4. Measure gas volume using gas syringe	0.0061	0.0031	0.8808	0.0536	0.4965
15.5. Conduct a calorimetry experiment	0.0012	0.0003	0.3472	0.1236	0.4122
15.6. Complete an Acid-base titration with a range of	0.4473	0.0801	0.9840	0.0173	0.7188
15.7. Use a pH meter	0.1141	0.0891	0.0615	0.4839	0.6031
15.8. Construct a voltaic cell	0.0588	0.0002	0.5619	0.1416	0.7279
15.9. Use a water bath	0.5961	0.4179	0.3953	0.0028	0.2225
15.10. Distillation using a Liebig condenser	0.3030	0.0005	0.0099	0.0285	0.2585
15.11. Experiment under Reflux	0.7949	0.0091	0.0019	0.0014	0.0054
15.12. Use of quick-fit glassware	0.5029	0.0238	0.0088	0.0332	0.1188
15.13. Tests for key organic molecules and ions	0.0404	0.0000	0.0083	0.0143	0.9681
15.14. Filtration (filter paper)	0.6101	0.2585	0.6892	0.0093	0.1738
15.15. Vacuum filtration with a Buchner funnel	0.2501	0.3843	0.0394	0.0006	0.0011
15.16. Purify solid products using recrystallisation	0.3953	0.1118	0.0629	0.0012	0.0836
15.17. Separate immiscible liquids using a separating funnel	0.2460	0.8259	0.5222	0.2005	0.2983
15.18. Conduct melting point analysis	0.1835	0.7039	0.6101	0.0455	0.0561
15.19. Use thin-layer chromatography	0.2937	0.8887	0.4413	0.0293	0.3576
15.20. Measure voltage of electrochemical cell	0.1645	0.0023	0.9522	0.0549	0.8572
15.21. Writing risk assessments	0.0601	0.0027	0.6892	0.0135	0.6312
15.22. Initial rate method (clock reactions)	0.5687	0.0011	0.0316	0.0008	0.8259
15.23. Continuous analysis for rate experiments	0.1676	0.0020	0.9920	0.0257	0.4715

Table S4: P-values obtained for confidence in each skill, using a Mann-Whitney U Test, comparing student groupings for each variable.

Confidence	Private vs	A-level vs	A-level vs	A-level vs	UK vs
16.1. Accurate mass measurements (in mg)	0.4593	0.8259	0.7039	0.5485	0.5485
16.2. Make up a standard solution with exact concentration	0.6171	0.3173	0.5961	0.0658	0.2113
16.3. Complete a redox titration with a range of indicators	0.1074	0.1868	0.8966	0.0873	0.8650
16.4. Measure gas volume using gas syringe	0.0096	0.0076	0.2543	0.2670	0.3735
16.5. Conduct a calorimetry experiment	0.0128	0.0128	0.9045	0.1585	0.8493
16.6. Complete an Acid-base titration with a range of	0.8572	0.4777	0.3789	0.3125	0.3524
16.7. Use a pH meter	0.2757	0.1188	0.3843	0.6101	0.8103
16.8. Construct a voltaic cell	0.0160	0.0026	0.7872	0.0500	0.9840
16.9. Use a water bath	0.5353	0.8415	0.6892	0.2041	0.2670
16.10. Distillation using a Liebig condenser	0.1443	0.0128	0.2077	0.4122	0.4593
16.11. Experiment under Reflux	0.1585	0.0751	0.0394	0.0300	0.1211
16.12. Use of quick-fit glassware	0.0324	0.0549	0.1285	0.4533	0.4179
16.13. Tests for key organic molecules and ions	0.0042	0.0000	0.0143	0.0549	0.3125
16.14. Filtration (filter paper)	0.6965	0.7566	0.4593	0.5823	0.1118
16.15. Vacuum filtration with a Buchner funnel	0.3371	0.4965	0.0357	0.0160	0.0007
16.16. Purify solid products using recrystallisation	0.0512	0.0588	0.0751	0.0601	0.3524
16.17. Separate immiscible liquids using a separating funnel	0.3030	0.9283	0.4902	0.3222	0.2543
16.18. Conduct melting point analysis	0.1645	0.9203	0.5287	0.5552	0.5892
16.19. Use thin-layer chromatography	0.2891	0.9681	0.9442	0.0500	0.2077
16.20. Measure voltage of electrochemical cell	0.0549	0.0013	0.6312	0.1010	0.6171
16.21. Writing risk assessments	0.0349	0.0004	0.8572	0.0071	0.4839
16.22. Initial rate method (clock reactions)	0.2983	0.0023	0.7642	0.0173	0.9045
16.23. Continuous analysis for rate experiments	0.1835	0.0021	0.7039	0.0574	0.9362

Table S5: P-values obtained for each soft skill, using a Mann-Whitney U Test, comparing student groupings for each variable.

Soft Skills	Private vs State	A-level vs Higher	A-level vs IB	A-level vs Other	UK vs International
17.1. I am competent in the lab	0.1585	0.9920	0.1074	0.0257	0.0251
17.2. I am confident in the lab	0.9362	0.3030	0.6745	0.0183	0.8572
17.3. I am independent in the lab	0.5755	0.1285	0.0488	0.0357	0.4354
17.4. I am safe in the lab	0.4295	0.5892	0.1471	0.2713	0.3125
17.5. I am accurate in the lab	0.5961	0.9362	0.8026	0.6241	0.7188
17.6. I am tidy in the lab	0.3898	0.6672	0.5961	1.0000	0.7795
17.7. I am efficient in the lab	0.5485	0.9045	0.9124	0.1236	0.6171
17.8. I understand the theory behind my labs	0.5485	0.0385	0.0466	0.1499	0.5419
17.9. I ask the demonstrators lots of questions	0.1310	0.1236	0.5157	0.8729	0.5222
17.10. My written English skills are strong	0.0214	0.4354	0.9522	0.4839	0.0036
17.11. My spoken English skills are strong	0.0767	0.0930	0.7414	0.5892	0.0023
17.12. I recognise hazards and risks	0.4295	0.4122	0.7795	0.2150	0.5619
17.13. I am confident designing my own experimental	0.0051	0.2891	0.8493	0.0226	0.0226

6. Cronbach Alpha Values obtained for scale reliability

As discussed in Section 2.4 Data Analysis, Cronbach Alpha values were calculated to assess the reliability of the four scales utilised. A threshold of 0.7 was set to indicate a 'good, reliable' scale. While all scales surpassed this benchmark, the data for each individual skill was treated as non-parametric and ordinal due to observed non-normal distribution and unequal variance. This decision was further influenced by the utilisation of non-equidistant scale descriptors and the inclusion of a '0' value, allowing students to express no perceived experience or confidence in a given skill, thereby rendering the data non-parametric and ordinal in nature. See Table S6.

Table S6: Cronbach Alpha values obtained for each Likert Scale used to determine scale reliability.

Item	Cronbach Alpha	Std. Alpha	Average R	Used
Overall perceived quality of teaching (1-7 bipolar Likert Scale)	0.7872	0.7772	0.5376	Yes
Perceived Experience (1-5 unipolar Likert Scale)	0.8612	0.8585	0.2087	No
Perceived Confidence (1-5 unipolar Likert Scale)	0.9045	0.9043	0.2912	No
Perceived 'Soft Skill' assessment (1-5 bipolar Likert Scale)	0.8182	0.8271	0.269	No

7. Scale descriptors used in survey

Scale descriptors were used for all Likert scale questions to minimise ambiguity and ensure that the collected data was consistent and standardised. This allows for more robust data analysis and reduces response bias.

Overall perceived quality of teaching (Survey section 1):

Theory and exams:

- A **very poor experience (1)** indicates that you felt that you received minimal support from your school in day-to-day lessons and exam preparation. You felt substantially unprepared for your final school exams as a result and perceive your school's assistance as significantly below the expected level.
- An **average experience (4)** implies that your school took some measures to support you during lessons and exam preparation. However, you don't perceive these efforts as surpassing what most other students received.
- An **exceptional experience (7)** signifies that you believe your school consistently exceeded expectations in providing support during lessons and exam preparation. You felt consistently supported and considered your school's assistance to be significantly above the norm throughout your studies.

Lab and practical skills:

- A **very poor experience (1)** indicates that you felt that you received minimal laboratory or practical training. You felt substantially unprepared for the first-year lab as a result and perceive your school's assistance as significantly below the expected level.
- An **average experience (4)** implies that your school took some measures to support your laboratory and practical skill development. However, you don't perceive these efforts as surpassing what most other students received.
- An **exceptional experience (7)** signifies that you believe your school consistently exceeded expectations in providing rigorous laboratory and practical training. You felt consistently supported and considered your school's assistance to be significantly above the norm throughout your studies.

Overall lab preparedness:

- **Not at all (1):** You feel your school provided minimal to no preparation for success in the laboratory, leaving you significantly underprepared for the challenges.
- **Average (4):** You believe your school offered moderate preparation for success in the laboratory. The support received was perceived as standard, comparable to what most other students received.
- **Exceptionally (7):** You feel your school went above and beyond in preparing you for success in the laboratory. The support provided is considered outstanding, significantly exceeding expectations.

Impact of Covid-19

- 1 = Not at all disrupted
- 2 = Slightly disrupted
- 3 = Moderately disrupted
- 4 = Significantly disrupted
- 5 = Severely disrupted

Perceived Experience self-assessment (Survey Section 2):

- 0 = I did not do this at school
- 1 = I have very limited experience in this skill
- 2 = I have limited experience with this skill
- 3 = I have experience in this skill
- 4 = I have a lot of experience in this skill
- 5 = I am highly experienced in this skill

Perceived Confidence self-assessment (Survey Section 3):

- 0 = I did not do this at school
- 1 = I am not confident at all. I would require a lot of guidance and supervision to perform this in the laboratory
- 2 = My confidence in this skill is limited. I would require some guidance and supervision to perform this

- 3 = I am fairly confident in this skill, but would still require some occasional guidance/supervision
- 4 = I am confident in this skill. I would only require guidance/supervision when performing advanced applications of this skill
- 5 = I am very confident in this skill and never require guidance or supervision. I feel confident applying this to a range of scenarios and feel comfortable teaching others how to perform this safely and effectively.

Perceived 'Soft Skill self-assessment (Survey Section 4):

- 1 = Strongly disagree
- 2 = Disagree
- 3 = Neutral
- 4 = Agree
- 5 = Strongly agree

8. Other Alternative Curricula

9 respondents studied other alternative curricula, typically native to their country of study. Whilst the sample size was limited, statistically significant differences were observed across perceived teaching of theory and exams; lab and practical skills; and overall preparedness for the lab, when compared to A-levels. Additionally, these students reported feeling statistically less experienced across 16 skills and less confident in four skills. Statistically significant differences were also observed in 4 'soft skills' (see Table S7 below).

Table S7: Statistically significant skill gaps, where A-level students scored higher than respondents who studied other alternative curricula.

Experience	Confidence	Soft Skills
Make up a standard solution with exact concentration		
Complete a redox titration with a range of indicators		
Complete an Acid-base titration with a range of indicators		
Use a water bath		
Distillation using a Liebig condenser		
Experiment under Reflux		
Use of quick-fit glassware	Experiment under Reflux	I am competent in the lab
Tests for key organic molecules and ions	Vacuum filtration with a Buchner funnel	I am confident in the lab
Filtration (filter paper)	Writing risk assessments	I am independent in the lab
Vacuum filtration with a Buchner funnel	Initial rate method (clock reactions)	I am confident designing my own experimental methodologies
Purify solid products using recrystallisation		
Conduct melting point analysis		
Use thin-layer chromatography		
Writing risk assessments		
Initial rate method (clock reactions)		
Continuous analysis for rate experiments		

9. Chemistry versus Biological Chemistry Lab Discipline

The survey was taken by students registered on first year chemistry laboratory courses at the host institution. This included students on the Chemistry specific course (n = 102) and those on the related Biological Chemistry course (n = 33) (Table S8).

Table S8: List of responses for Overall perceived quality of teaching separated by lab discipline (Chemistry versus Biological Chemistry)

		Number of Responses								
	Likert Scale (1-7)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**	**Mean**
Theory and Exams	Chemistry	0	2	3	13	18	49	17	102	5.57
	Biological Chemistry	0	1	3	4	12	7	6	33	5.18
Practical and Laboratory Skills	Chemistry	5	7	9	25	23	21	12	102	4.62
	Biological Chemistry	1	3	6	8	9	5	1	33	4.21
Preparation for the Lab	Chemistry	6	6	10	23	27	16	14	102	4.60
	Biological Chemistry	0	3	7	12	5	4	2	33	4.18

No statistically significant differences were observed between the Chemistry and Biological Chemistry students with respect to the overall perceived quality of teaching criteria (Table S9) and subsequently these cohorts were combined and analysed together.

Table S9: P-values obtained for Overall perceived quality of teaching using a two-tailed independent T-test, comparing different student groupings for each lab discipline. Green values are identified as statistically significant ($p < 0.05$), red values were not statistically significant ($p > 0.05$).

Overall perceived quality of teaching	**Chemistry vs Biological Chemistry**
Theory and exams	0.134
Lab and Practical skills	0.170
Prepared for the lab	0.146

10. Impact of Covid-19

Table S10: List of responses for "To what extent do you feel that Covid-19 affected your laboratory training?". Likert scale ranging from 1-Not at all disrupted to 5-Severely disrupted. Results are presented in three separate groupings based on Country of Study, Type of School and Curriculum Studied.

	Number of Responses						
Likert Scale (1-5)	**1**	**2**	**3**	**4**	**5**	**Total**	**Mean**
England/Wales	13	17	7	1	1	39	1.97
Scotland	8	19	21	15	3	66	2.79
International	12	8	4	6	2	32	2.31
Independent/Private School	11	13	7	2	1	34	2.09
International School	4	3	1	4	2	14	2.79
Independent/Private School with a significant scholarship/bursary	2	1	3	1	0	7	2.43
Independent (Overall)	17	17	11	7	3	55	2.31
Non-selective State School	16	25	21	14	4	80	2.56
Selective State/Grammar School	1	1	0	1	0	3	2.33
State (Overall)	17	26	21	15	4	83	2.55
A-levels	0	17	11	4	3	35	2.80
Scottish Highers/Advanced Highers	8	19	19	15	3	64	2.78
International Baccalaureate	2	5	1	2	0	10	2.30
Other	4	3	1	1	0	9	1.89

P-values obtained for the impact of Covid-19, using a Mann-Whitney U Test, comparing student groupings for each variable. Green values are identified as statistically significant ($p < 0.05$), red values were not statistically significant ($p > 0.05$).

Table S11: P-values obtained for the impact of Covid-19, using a Mann-Whitney U Test, comparing student groupings for Country of Study.

	England/Wales	**Scotland**	**International**
England/Wales		<0.001	0.452
Scotland			0.046

Table S12: P-values obtained for the impact of Covid-19, using a Mann-Whitney U Test, comparing student groupings for Type of School.

	State
Independent	0.292

Table S13: P-values obtained for the impact of Covid-19, using a Mann-Whitney U Test, comparing student groupings for Curriculum Studied.

	A-levels	**Scottish Highers**	**IB**	**Other**
A-levels		0.008	0.519	0.468
Scottish Highers			0.307	0.035
IB				0.263