

## RESEARCH DIRECTIONS

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# Informing Student Support Mechanisms through Measurement of Student Confidence in Core Chemistry Topics

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### Abstract

To inform strategies for providing effective student support in the early stages of a chemistry degree programme, a longitudinal study of first year chemistry student confidence levels in core topics was conducted at three points over a one-year period. A student-staff team co-created a confidence matrix that was used as the basis of the study. Students were asked to rate their confidence level in each of twenty core chemistry skills on a three-point scale. Student responses were converted into a normalised confidence score for each individual and each skill. The initial collection of data (at the start of the academic year) showed that the lowest student confidence levels were in Physical Chemistry topics. There were statistically significant increases in confidence levels in half of the skills following instruction. Analysis of the data collected suggests that the ability of some students to engage with the metacognitive processes necessary to complete this type of reflective exercise may improve over the course of their first year of study.

### Introduction

A range of different studies exists on the influence of different types of learning experience in chemistry on student confidence levels including: the use of classroom response technology (Bunce, et al., 2023), the use of pre-laboratory simulation software (Blackburn, et al., 2019; George-Williams, et al., 2021) and the use of learning assistants (Clements, et al., 2023).

Confidence is defined as subjective measures of one's probability of a successful outcome within a specific cognitive domain (Zimmerman, et al., 1977). Confidence judgements in STEM Education Research are often measured using two-tiered test instruments that require participants to complete tasks aligned to specific cognitive domains and then ask participants to rate their confidence in each of these tasks or competencies (Espinosa, et al., 2025; Koevoets-Beach, et al., 2023; Sands, et al., 2018). The measurement of confidence may provide insights on student metacognition (and can, indeed, be used as a means of facilitating metacognition by requiring students to reflect on their ability answer a question) or can be used to provide an indication of whether students have guessed the answer to a specific question or not (e.g. in a multiple choice concept inventory).

Self-evaluation of confidence is known to be influenced by a variety of different factors that inform the associated metacognitive processes independent of content knowledge (Koevoets-Beach, et al., 2023). Metacognitive processes are often sub-divided into two components: (i) metacognitive knowledge and (ii) metacognitive regulation (Schraw and Moshman, 1995). Metacognitive knowledge

is focused on what one knows about one's own through processes and the factors that influences these, whereas metacognitive regulation focuses on approaches used to control one's thinking and learning (Blackford, et al., 2023; Jacobs and Paris, 1987; Schraw and Moshman, 1995).

Previous studies have revealed that confidence and performance tend to be inversely correlated, particularly for low performing students (Karaca, et al., 2023).

The aims of the study were to identify barriers to progression in the early stage of introductory chemistry courses, identify where focused support may need to be provided for individual students and to verify if there was a relationship between student confidence levels and their attainment at their first year at university. This was achieved through longitudinal measurement of self-reported confidence levels of first year undergraduate chemistry students on a chemistry degree programme in the United Kingdom. The research questions were defined as:

1. How confident are students in key chemistry topics when they start their undergraduate chemistry degree?
2. How do confidence levels of students in key chemistry topics change during the first year of their degree?

## Method

This study was focused on the longitudinal measurement of student confidence levels in twenty key competencies in introductory chemistry topics throughout the students' first year of study at university. All students participating in this study were enrolled on a chemistry degree meaning they were completing a minimum of 80 out of 120 credits of chemistry. The students had all achieved the university's entry requirements meaning they had achieved UK A-level grades in the range AAA -AAB (equivalent to international baccalaureate 6,6,6 - 6,6,5 at Higher Level, including Chemistry at Higher Level, with a minimum of 32 points overall). The Birmingham chemistry curriculum is built around a structure of interactive lectures, Problem Based Learning (PBL) projects, Team Based Learning (TBL) workshops and practical classes. Lecture-based modules are primarily assessed by exam. TBL, PBL and practicals are assessed by continuous assessment (including reports, presentations, posters, etc).

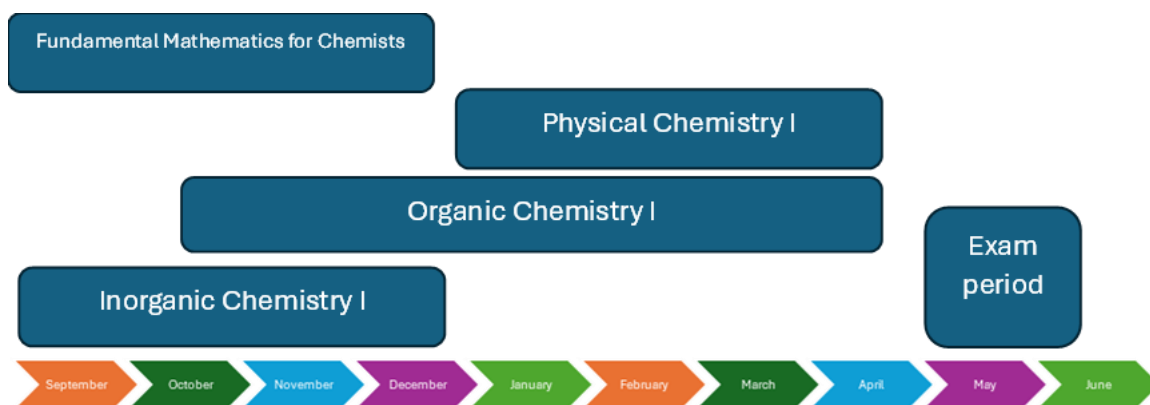
Because of the longitudinal nature of the study and the importance of being consistent and producing an instrument that would take students 30 minutes or less to complete (to minimise the impact of repeated measurements on timetabled events), the research instrument took the form of a confidence matrix rather than a multiple-choice test. This type of approach is classified in the literature as an "off-line" method of data collection (van Hout-Wolters and Schellings, 2009). The study is based on an underlying assumption that confidence is an attitude or trait and this needs to be considered when interpreting the outcomes of the study. This approach aligns with the logistical needs of this longitudinal study however it should be noted that asking students to reflect on cognitive processes they have not used at the time of measurement may influence the outcomes of the study.

The study took place at the University of Birmingham in the 2023/24 academic year. The study was approved by the University of Birmingham Science, Technology, Engineering and Mathematics Ethics Committee (Reference: ERN\_1493-Sep2023). The study focused on the collection of quantitative data based on student self-evaluation of confidence levels at three critical points in the academic year: (i) start of semester 1 (September 2023), (ii) start of semester 2 (January 2024) and (iii) end of academic year (June 2024). The same confidence matrix instrument was used at all three points. The instrument was co-designed by a student partner based on an analysis of the pre-university curricula of exam boards (including AQA, OCR, Edexcel and WJEC) in the United Kingdom. Twenty core competencies were identified spanning physical, organic and inorganic chemistry as well as key mathematics skills for chemists. The competencies selected were of significance in all the analysed curricula and were aligned with key intended learning outcomes from the first year of the University

of Birmingham's (Royal Society of Chemistry accredited) chemistry degree courses (see **Table 1** for details of the selected competencies and **Figure 1** for an illustration of when the relevant modules are delivered). The findings of the student partner were verified by two experienced members of academic staff.

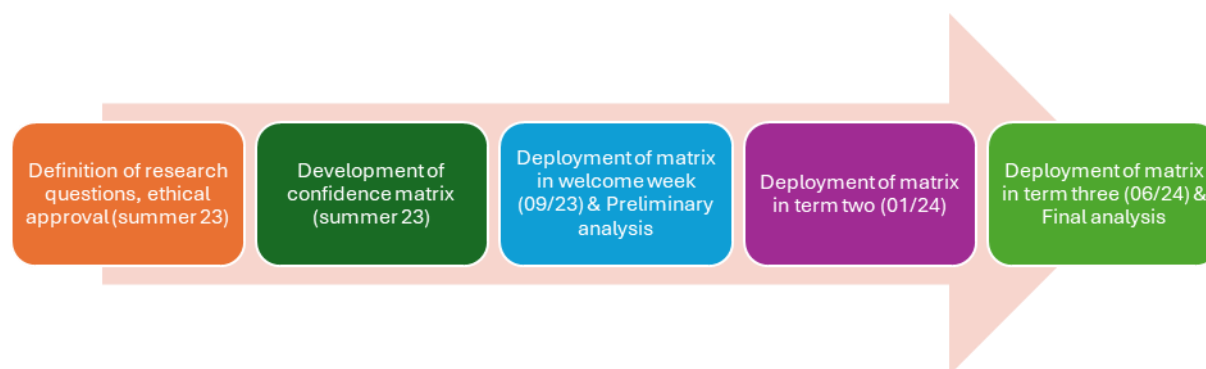
**Table 1** The 20 core chemical competencies used as the basis of the confidence matrix instrument.

Statement	Area of curriculum
1 Using the periodic table to identify the electron configurations of elements	Inorganic
2 Identifying and naming the shapes of molecules, including the bond angles	Inorganic
3 Calculating pH using $K_a$ or $K_w$ .	Inorganic
4 Defining the terms Complex Ions and Coordinate Number and applying them to Transition Metal Chemistry	Inorganic
5 Identifying and rationalising trends in the periodic table	Inorganic
6 Using the IUPAC naming system to name organic compounds.	Organic
7 Drawing the skeletal and displayed formulae of organic compounds	Organic
8 Drawing 'Curly Arrow' Mechanisms.	Organic
9 Distinguishing between the various types of isomerism and identifying the isomers of various organic compounds.	Organic
10 Identifying the reactions that occur with alcohols to form Aldehydes, Ketones and Carboxylic acids.	Organic
11 Rationalise how the bonding in benzene affects the stability of aromatic structures.	Organic
12 Using collision theory to explain the fundamental aspects of a reaction.	Physical
13 Calculating the properties of gases using the Ideal gas equation.	Physical
14 Calculating Gibbs Free energy and using it to identify if a reaction is spontaneous.	Physical
15 Rearranging the Arrhenius equation to plot a graph and then using the properties of the graph to find the activation energy of a reaction.	Physical
16 Defining the key Thermodynamic terms: Entropy and the various types of Enthalpy changes.	Physical
17 Using Hess' Law to calculate the enthalpy change of a reaction.	Physical
18 Identifying rate equations and the order of reaction to find the rate of reactions.	Physical
19 Integrating and Differentiating mathematical functions.	Maths/Physical
20 Rearranging algebraic equations to change the subject of the equation.	Maths/Physical



**Figure 1** Timeline illustrating delivery of relevant modules.

Students were asked to rate their confidence in each of these competencies on a three-point Likert type scale (labelled using colours: red = low confidence, amber = intermediate confidence and green = high confidence). The survey was piloted with a small group of second year students to ensure that respondents understood the statements and knew how to respond appropriately. Students provided their names along with their responses to enable correlation between responses throughout the year. The project timeline is illustrated in **Figure 2**.



**Figure 2** Project timeline indicating key milestones.

## Results and Discussion

### Analysing student confidence

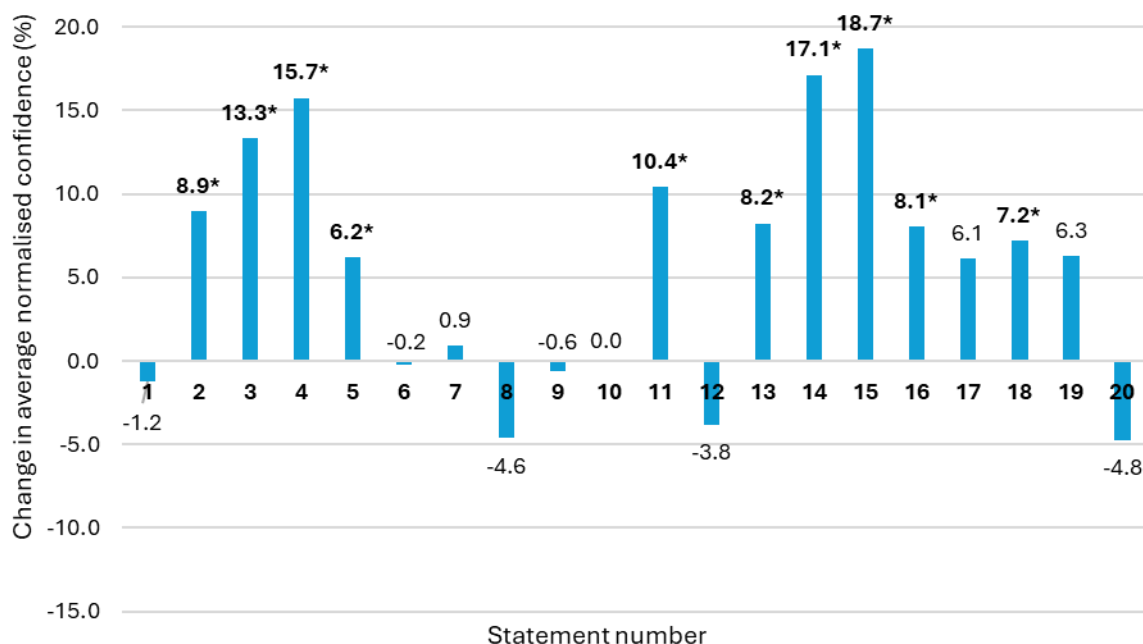
To analyse the responses, each response type was awarded a numerical score. Low confidence (red) responses were allocated one-point, intermediate confidence (amber) responses were allocated two points and high confidence scores (green) were allocated three points. A normalised average confidence rating for each competency was determined by summing the total number of points awarded by all students for each competency and dividing this sum by the maximum possible score per competency. The average normalised competency was then expressed as a percentage.

The initial collection of data took place in the students' first week of study (before instruction had commenced). 93 responses were received from 127 students in the overall cohort (73% response rate). Subsequent measurements were made in January 2024 (start of semester 2) and June 2024 (end of academic year).

To analyse the difference in student confidence over the course of the year, the difference in the average normalised confidence ratings is presented in **Figure 3**. The final implementation of the matrix took place in a scheduled session during the University's "Summer Term" in June 2024. This was after the end of year examinations (in the week following the end of the exam period) in a session that did not contribute to an assessed component of the module so it is worth noting that the number

of respondents is lower than the other implementations of the matrix and, consequently, it is possible that this specific sample may not be as representative of the population as the September sample.

To verify the statistical significance of differences in student responses between September and June, overall normalised confidence scores were generated for each student in each of the implementations of the matrix. This was achieved by summing the number of points for each of the 20 responses individuals gave (based on one point for red, two points for amber and three points for green), dividing each of these by the maximum score possible (60) and expressing the result as a percentage. An unpaired samples t-test was used to compare student responses in each of these two periods with differences being highlighted as statistically significant when  $p < 0.05$ .



**Figure 3** Change in average normalised confidence ratings between September 2023 and (start of semester 1) and June 2024 (end of year one). Asterisks denote statistically significant differences at the  $p < 0.05$  level.

Statements 1-5 relate to inorganic chemistry, 6-11 relate to organic chemistry, 12-18 relate to physical chemistry and 19-20 relate to key mathematics skills.

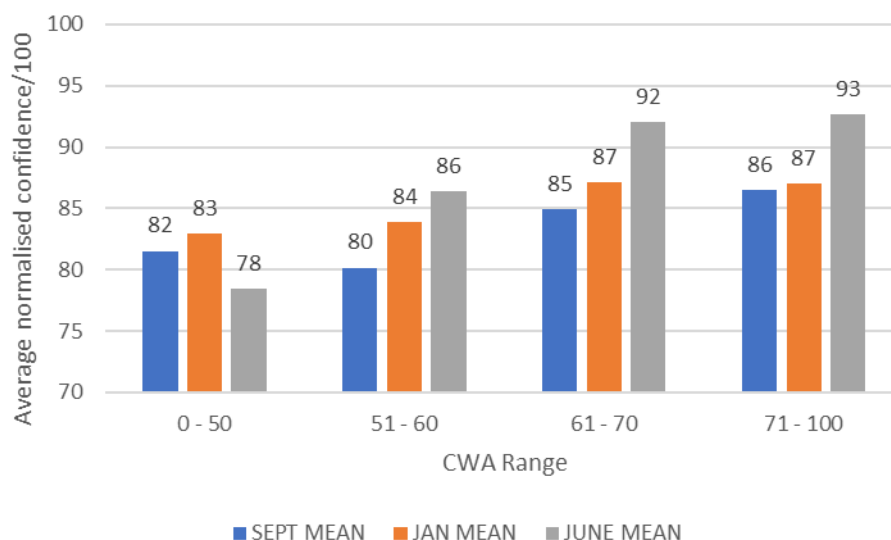
The confidence average normalised confidence increased in 14 out of 20 of the competencies with 10 of these increases being statistically significant at the  $p < 0.05$  level. There was only one statistically significant increase in organic chemistry items (item 11, related to explaining the stability of benzene/aromaticity, +10.4%). There were statistically significant increases in confidence levels in all but two physical chemistry items (item 12, related to collision theory, -3.8% and item 17, related to Hess's Law, +6.1%). The latter point is unsurprising given the fact the University of Birmingham's year one Physical Chemistry module is taught in the second half of the academic year.

The initial measurements of confidence levels were useful for instructors as they helped indicate which topics students may need most support with. Actions taken by instructors included signposting learning resources for selected areas of content and providing additional information on the structure of the academic year to help show illustrate the spiral nature of the curriculum.

### Analysing normalised confidence scores by level of achievement

A final level of analysis involved comparing the overall average normalised confidence levels (averaged across all 20 statements) for cohort sub-groups defined by credit weighted average range (shown in **Figure 4**). There were no statistically significant differences between the average normalised confidence scores of each sub-group in either September or January. The June data

revealed a statistically significant difference between the 0-50 CWA group and both the 61-70 and 71-100 groups at the  $p < 0.05$  level. This may support the above point that the experience of working through end of year exams may have a profound impact on some students' confidence levels (and may contradict some earlier published findings about the overestimation of confidence by low-performing students).



**Figure 4** Overall average normalized confidence (across all statements) versus section of cohort divided by credit weighted average range in September (blue), January (orange) and June (grey). A student's credit weighted average score is their overall mean score for the year, weighted by the credit value of modules taken.

## Conclusion

The confidence matrix instrument developed for this study provides a means of capturing the time variation of student confidence levels in a series of defined competencies. The initial measurement in September 2023 suggested that the lowest levels of confidence were associated with physical chemistry competencies. It is clear that the confidence levels increased to a statistically significant extent following instruction for at least half of the competencies included in this instrument. The findings were largely consistent with those of previous studies (i.e. that lower-performing students tend to overestimate their confidence (Karaca, et al., 2023).) but there is some indication that these students develop an improved ability to estimate their confidence by the end of their first year of study. The findings can be used to reassure students in future Birmingham year one cohorts that their lack of confidence in specific topics were shared by students in previous cohorts who, mostly, went on to gain confidence after further engagement in the course.

In the future, it would be interesting to investigate whether student's incoming pre-university grades influence their self-reported confidence levels.

This study could be followed up by a mixed methods investigation to gain a deeper insight of the factors that influence student confidence levels (as well as the metacognitive processes that students work through when self-evaluating their confidence). These factors may include confidence ratings based on individual understanding relative to the peer group rather than relative to the specific material (Koevoets-Beach, et al., 2023).

The investigation could be further developed by exploring how the factors that influence confidence judgements result in different levels of alignment between self-reported confidence and achievement (e.g. how does development of study skills influence metacognitive regulation). There is also potential

scope to further develop the confidence matrix by including practical and transferable skills or by developing a follow-up instrument that allows confidence levels in later years of study to be measured.

## References

Blackburn, R.A.R., Villa-Marcos, B. and Williams, D.P. (2019). Preparing Students for Practical Sessions Using Laboratory Simulation Software, *Journal of Chemical Education*, Vol 96, No 1, pp 153-158.

<https://doi.org/10.1021/acs.jchemed.8b00549>

Blackford, K.A., Greenbaum, J.C., Redkar, N.S., Gaillard, N.T., Helix, M.R. and Baranger, A.M. (2023). Metacognitive regulation in organic chemistry students: how and why students use metacognitive strategies when predicting reactivity, *Chemistry Education Research and Practice*, Vol 24, pp. 828-851.

<https://doi.org/10.1039/D2RP00208F>

Bunce, D.M., Schroeder, M.J., Luning Prak, D.J., Teichert, M.A., Dillner, D.K., McDonnell, L.R., Midgette, D. P. and Komperda, R. (2023). Impact of Clicker and Confidence Questions on the Metacognition and Performance of Students of Different Achievement Groups in General Chemistry, *Journal of Chemical Education*, Vol 100, No 5, pp 1751–1762.

<https://doi.org/10.1021/acs.jchemed.2c00928>

Clements, K.A., Zepeda, C.D., Hilbun, A.L., Todd, T., Clements, T.P., Johnson, H.J., Watkins, J., Friedman, K.L. and Brame, C.J. (2023). “They Have Shown Me It Is Possible to Thrive within STEM”: Incorporating Learning Assistants in General Chemistry Enhances Student Belonging and Confidence, *Journal of Chemical Education*, Vol 100, No 11, pp 4200–4211.

<https://doi.org/10.1021/acs.jchemed.2c01224>

Espinosa, A.A., Koperová, D., Kuhnová, M. and Rusek, M.(2025). Preservice Chemistry Teachers’ Conceptual Understanding and Confidence Judgment: Insights from a Three-Tier Chemistry Concept Inventory, *Journal of Chemical Education*, Vol 102, No 1, pp. 53–65.

<https://doi.org/10.1021/acs.jchemed.4c01146>

George-Williams, S.R., Blackburn, R.A.R., Wilkinson, S.M. and Williams, D.P. (2022). Pre-laboratory Technique-Based Simulations: Exploring Student Perceptions of Their Impact on In-Class Ability, Preparedness, and Emotional State, *Journal of Chemical Education*, Vol 99, No 3, pp. 1383–1391.

<https://doi.org/10.1021/acs.jchemed.1c01116>

Karaca, M., Geraci, L., Kurpad, N., Lithander, M.P.G., Balsis, S. (2023) Low-Performing Students Confidently Overpredict Their Grade Performance throughout the Semester. *J. Intell.* 11(10):188.

<https://doi.org/10.3390/jintelligence11100188>

Koevoets-Beach, C., Julian, K. and Balabanoff, M. (2023). “I guess it was more than just my general knowledge of chemistry”: exploring students’ confidence judgments in two-tiered assessments, *Chemistry Education Research and Practice*, Vol 24, pp 1243-1261.

<https://doi.org/10.1039/D3RP00127J>

Sands, D., Parker, M. Hedgeland, H., Jordan, S. and Galloway, R. (2018). Using concept inventories to measure understanding, *Higher Education Pedagogies*, Vol 3, No 1, pp. 173-182.

<https://doi.org/10.1080/23752696.2018.1433546>

Schraw, G and Moshman, D. (1995). Metacognitive Theories. *Educational Psychology Review*, Vol 7, No 4, pp. 351-371.

<https://doi.org/10.1007/BF02212307>

van Hout-Wolters, B. and Schellings, G. (2009). Measuring Learning Strategies - Different measurement methods and their usability in education and research (Leerstrategieën meten. Soorten meetmethoden en hun bruikbaarheid in onderwijs en onderzoek). *Pedagogische Studiën*, Vol 86, No 2, pp. 110-129.

Winne P. H. and Perry N. E., (2000), Measuring Self-Regulated Learning, in Boekaerts M., Pintrich P. R. and Zeidner M. (ed.), *Handbook of Self-Regulation*, San Diego: Academic Press, ch. 16, pp. 531–566. <https://doi.org/10.1016/B978-012109890-2/50045-7>

Zimmerman, J., Broder, P.K., Shaughnessy, J.J. and Underwood, B.J. (1977). A recognition test of vocabulary using signal-detection measures, and some correlates of the work and non-word recognition, *Intelligence*, Vol 1, No 1, pp. 5-31.