Influencing College Chemistry Success Through High School Chemistry Teaching

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Abstract

The connection between high school chemistry pedagogical experiences and introductory college chemistry performance has been a topic researched in published science education literature since the 1920s. However, analysis techniques have limited the generalizability of these results. This review discusses the findings of a large-scale, multi-institutional research study addressing many of these previous limitations. The findings reveal that high school experiences are significantly associated with college performance. The implications indicate that high school chemistry teachers may have a positive impact in preparing their students for future success in introductory-level college chemistry. (This paper is a summary of Tai, Sadler, & Loehr, 2005)

Introduction

Preparation for college is a goal shared by many high school students and their high school teachers. For many teachers, preparation for introductory college science is an important consideration in their decisions about what and how to teach. An analysis of trends in college performance associated with particular high school teaching and learning experiences may therefore offer some insights for high school teachers seeking better preparation of their students for introductory college chemistry courses as one of their instructional goals. In fact, this connection has been explored in chemical education research as early as the 1920s, in the *Journal of Chemical Education*. However, despite repeated analyses of this connection over the past 9 decades, the existing studies typically studied only students at a single college or university, making the results specific to these particular college courses.

To address this issue, we performed a study that surveyed 1,531 introductory college chemistry students from 12 different baccalaureate-granting colleges and universities from across the United States (Tai, Sadler, & Loehr, 2005). Using a statistical technique called multiple linear regression analysis with course-wise identifiers to account for differences in grading practices across colleges, we were able to account for students' demographic differences to offer results that are a step closer than previously existing research. For those readers seeking more details regarding our research study and analytical approach, please refer to our published study. In this manuscript, we offer a discussion of our findings and their implications for high school chemistry teaching and learning.

Overview of Our Data Set

We begin with a brief overview of the data we used to perform our analysis. We administered a self-report survey to introductory college chemistry students, asking them about their high school chemistry learning experiences. This survey technique took advantage of two important characteristics of introductory college chemistry students. First, students were surveyed during their college chemistry course time, a period of time in which the relevance of the questions we were asking them on the survey was evident and in many cases at the forefront of their minds. Second, students were surveyed in the Fall semester, which for 63 % of our survey participants was their first semester in college and therefore the earliest time possible between high school chemistry experiences and college chemistry performance.

As the outcome for our study, we chose to use final course grades which were provided by the students' college instructors. While grades are certainly limited in their capacity to reflect deep understanding, there is little doubt regarding their impact on students' future career options. This fact is readily apparent to all students taking introductory college science courses in general and, as a result, we expect that most students will make concerted efforts to succeed in these courses. Since we surveyed 12 different colleges, we needed to account for differences in grading practices across schools. We accomplished this task by including a variable in our analysis to absorb these institutional differences, a technique common to the analytical approach we chose for our study. In the end, nearly 60 % of the students in our survey were from highly-selective colleges (based on institutional, standardized, admissions test scores), 87 % were enrolled in public colleges, and 67 % were from colleges enrolling more than 15,000 undergraduate students.

With regard to student demographics, our sample was 53 % female, 64 % Freshman, and 74 % white. In terms of high school mathematics backgrounds, 52 % of our surveyed students had taken some form of high school calculus.

Findings and Implications

Next, we turn our attention to the primary analysis searching for associations between high school chemistry pedagogical experiences and college chemistry performance. Here we used statistical techniques that allow for inferential analysis, which means that our findings may be interpreted in term of associations and trends between the outcome variable (introductory college chemistry final grades) and the predictor variables that included both the student background variables discussed in the previous section and the high school chemistry pedagogical experiences, to follow. Simultaneously accounting for a variety of predictors in a model of college grades offers the opportunity to compare the relative impact of the predictors on their capacity to inform the outcome. However, the approach we took in this analysis offers a broad, comparative overview of these predictors. For a more in-depth statistical analysis, offering greater detail on the associations between college performance and high school chemistry experiences, we have undertaken more focused analyses (Tai & Sadler, 2006; Tai, Sadler, & Mintzes, 2006; Tai, Ward, & Sadler, 2006).

Our survey asked students a variety of questions regarding their instructional experiences in high school chemistry that included practical work, independent projects, typical quantity and type of assigned problems, and high school chemistry content. After developing a set of significant predictors based on students' demographic and general educational backgrounds, we included variables accounting for these particular instructional experiences. Our final statistical model included 10 variables describing various pedagogical experiences in high school, which fall into 5 areas which we label in this manuscript as 1) general classroom instruction, 2) practical work and laboratory experiences, 3) independent projects, 4) problems on assignments and tests, and 5) chemistry content topics.

Concerning general classroom instruction. In this category, we considered several different overarching approaches to instruction and daily classroom practice. This category represents a mix of pedagogical practices that did not appear to us to fit neatly into the other four categories. Our survey queried students on how frequently they recalled working in groups, individually, or as a whole class. Our analysis revealed that students who reported working more frequently on an individual basis were predicted to earn lower college grades, while differences in frequencies related to group work and whole-class work did not appear to be significant. In addition, we asked students to report on the emphasis their high school class placed on rote memorization of facts versus development of full understanding of concepts. We found that students reporting a focus on the development of full understanding of concepts were more likely to earn higher college grades, while high school courses emphasizing rote memorization typically earned lower grades.

Practical work and laboratory experiences. Our analysis of practical work included a variety of different pedagogical approaches. We considered the various instructional phases of practical work and developed survey questions to pursue student experiences in these areas. We began with general aspects such as the typical number of laboratory experiences student recalled having each month. In our understanding, most high school science teachers typically follow patterns in their practice, choosing to use similar procedures in introducing, carrying through, and debriefing from laboratory activities. As a result, we asked questions regarding the implementation of laboratory experiences beginning with preparation and proceeding through to debriefing and post-laboratory activities.

Our analysis revealed three variables significantly associated with college performance: reading and discussing lab procedures the day before, students' reported understanding of laboratory procedures, and frequency of repeating laboratories for furthering understanding. The first two variables reveal an emphasis on practical work procedures in high school chemistry and the results indicated that students reporting greater emphasis on procedure tended to have lower grades in introductory college chemistry. On the other hand, students reporting greater frequencies of repeating labs to enhance understanding tended to earn higher college grades.

Independent projects. Our survey included questions aimed at gathering information on the frequency of independent projects in high school chemistry. We found that students reported being assigned greater numbers of independent projects typically earned lower grades in college chemistry. This result should give pause to teachers seeking to shift their teaching practices to emphasize project work over teacher-guided learning. However, this result is not evidence that independent projects are somehow counter productive experiences for students in their preparation for college chemistry. Instead, a general trend of lower performance with greater frequency of independent projects indicates that we should turn our attention toward how independent projects are implemented as a pedagogical practice.

Problems on assignments and tests. Most high school chemistry courses require students to solve a variety of problems, ranging from multiple-choice/true-false questions to those requiring calculations to be clearly shown, to receive full credit. These problems commonly appear on tests and homework assignments. Our analysis discovered two types of problems to be significantly and positively associated with college performance: the number of assigned problems with calculations and test questions requiring memorization of terms/facts. This result seems to be counter intuitive, unless one takes the view that proficiency in both calculations and recall of facts/terms are important. Note that we did not find that taking class time to promote memorization was positively associated with college performance. Rather, we found that holding students responsible for recalling facts and terms on tests was valuable. In fact, there are instances when holding students to account for the recall of particular facts and terms pushes them to pay closer attention to their work and tests are the most common venue for this type of accountability. Regardless, it appears that requiring students in high school chemistry to perform calculations and holding them responsible for possessing knowledge of facts and terms appears to be useful preparation.

Chemistry content topics. Against the backdrop of pedagogy and classroom structure stands the content of high school chemistry. Questions regarding what to teach inform responses about how to teach. In our study, we asked students to estimate the emphasis their high school chemistry courses placed on a series of content topics which included Atoms and the Periodic Table, Chemical Reactions and Equations, Solutions, Gases and Gas Laws, Stoichiometry, Nuclear Reactions, Biochemistry, and History/People of Chemistry. Among these eight general content topic areas, we found two significant associations. Students reporting greater emphasis on stoichiometry typically earned higher grades, while students reporting greater emphasis on nuclear reactions typically earned lower grades in college. We did not find significant associations among the other topics. This non-finding may have been due to a number of reasons. For example, regarding very common topics, such as Atoms and the Periodic Table and Chemical Reactions & Equations, there was very little variation, since all students reported having a relatively strong emphasis on these topics compared with the other topics.

Conclusions

Linking these results into a cohesive chain offers a picture of how particular high school chemistry instructional practices may impact college chemistry performance. The results most striking when juxtaposed are the findings that, on the one hand, rote memorization of facts is negatively associated with college performance and, on the other hand, that emphasis on test questions requiring memorization of terms and facts is positively associated, appear to be contradictory. However, consider the case of teachers who focus class time on developing students' full understanding, using the facts and terms of chemistry as one would use a "language." Students being held accountable for learning the words of the language, and then coming to classes where the language is used as a means for developing deeper understandings, would respond positively to both questions and it seems not unlikely that these students would be very well prepared for the rigors of college chemistry. Therefore, an initially contradictory result offers a clue to a subtlety of effective pedagogy.

The negative results regarding lab procedure instructional practices and frequency of independent projects suggests that there appears to exist a middle ground for most effective guidance in pedagogical practice. Overemphasis on procedure may alleviate the responsibility of students to actually understand the purpose of the steps in a laboratory experiment, leading to an algorithmic exercise in direction following. On the other side, independent projects offer students a great deal of freedom. However, freedom to explore without the experience to take advantage of this latitude may only lead to confusion. Our analysis suggests a middle ground of guided learning with opportunities for independent exploration. The negative association of higher frequencies of individual work also suggests that guidance may not only come from teachers, but from peers as well.

The significance of stoichiometry as a positive predictor, and nuclear reactions as a negative predictor, suggest that greater emphasis on fundamental skills over a faster-paced approach covering many topics is more useful. The imbedded characteristic of calculations in understanding stoichiometry matches well with the focus on higher frequencies of class problems using calculations.

These results offer evidence for the long-term impact of high school chemistry. It appears that high school chemistry instruction does have some significant association with college chemistry performance and our analysis suggests that a definition of rigor in high school chemistry includes: 1) an emphasis on fundamental topics, 2) a facility with calculations, 3) opportunities for independent investigations after well-grounded guidance as opposed to algorithmic procedures, and 4) a requirement that students know the "language" of chemistry.

References

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Students' Alternative Conceptions

Students' alternative conceptions have been variously called misconceptions, prior conceptions, preconceptions, preinstructional beliefs, alternative frameworks, naive theories, intuitive ideas, untutored beliefs, and children's science. The tasks in this regular section of *SER* are based on the literature and may be used at the beginning of a constructivist learning segment to arouse the curiosity of students and to motivate them, while simultaneously eliciting their ideas or beliefs. They are designed to address areas about which students are likely to have an opinion, based on personal experiences and/or social interactions, prior to a specialist learning sequence, or areas that might be considered important for the development of scientific literacy.

Cloning

For each of the following, please indicate if you *agree*, *disagree*, or are *not sure*.

A. Cloned organisms are grown in a laboratory.
B. Human clones are produced to supply transplant organs for the donor.
C. When a clone is produced, it is the same age as the donor.
D. A clone has the memory of the host and/or acts the same as the host.
E. It is possible to clone extinct, prehistoric species.
F. Cloning is a relatively easy, and highly successful, process.

Commentary. All of the above are false, yet these misconceptions are being communicated by popular media such as the following films: *Alien Resurrection*, *Star Wars Episode II: Attack of the Clones*, *The Island*, *Multiplicity*, *Parts: The Clonus Horror*, *Godsend*, and *Jurassic Park*.

Cloned animals are gestated within a surrogate animal. While whole-organ cloning is in the experimental stages, it does not involve growing tissues or organs within a human clone for transplanting to the donor human. Like any other animal, cloned animals are born as infants, and no technology exists for ageing clones more rapidly than the natural ageing process. Scientists widely dispute the concept of cellular memory, whereby cells--or a DNA sample, in this case--have the memory of the donor. While a clone and donor are genetically identical (nature), a significant proportion of personality and behaviour is due to environmental influences (nurture). The DNA required for cloning must be preserved extremely well. So, while species that have become extinct relatively recently may be cloned (e.g., after their cells have been preserved by