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Sign Language Incorporation in Chemistry Education (SLICE): Building a Lexicon to Support the Understanding of Organic Chemistry

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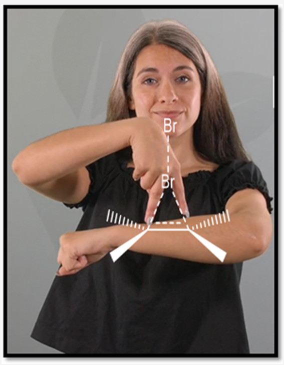
ABSTRACT: Historically, deaf and hard-of-hearing students (D/HH) who solely rely on an interpreter during organic chemistry lecture courses at the Rochester Institute of Technology consistently performed below the average in the class. A barrier attributed to this D/HH student performance is the lack of standardized methods in sign language to effectively communicate the organic chemistry terminology. As such, our group worked to address this challenge through a deliberate effort to develop a lexicon of insightful signs/classifiers that convey organic chemistry vocabulary as well as descriptive expansions to demonstrate challenging concepts. We will share our remarkable findings after the signs were developed and implemented, and the implications sign language incorporation in education could have on how we teach all students enrolled in STEM disciplines in the future.



KEYWORDS: *Second-Year Undergraduate, Organic Chemistry, Communication/Writing, Mechanisms of Reactions, Minorities in Chemistry*

Pursuing a degree in a STEM-related field is a great challenge for deaf and hard-of-hearing (D/HH) students, and much has been reported on how to best support D/HH students in both the STEM classroom[1] and the lab.[2] A 2017 survey by the U.S. Department of Education reported that only 18% of D/HH students completed their bachelor's degree.[3] Of these degrees, few are in STEM-related fields especially in the physical sciences.[3b] In addition to chemistry, most biological sciences, chemical engineering, preveterinary, predental, and premedical programs require organic chemistry and the corequisite laboratories. As such, organic chemistry has long stood as the gatekeeper to pursuing these programs or career paths. Given its pivotal role, the goal of this project was to improve methods for conveying organic chemistry concepts for the D/HH students enrolled in the course.

■ BARRIERS TO LEARNING FOR D/HH STUDENTS

Absence of Formalized STEM Language

One barrier to D/HH education in the STEM disciplines is conveying the scientific jargon using sign language. Although the vocabulary of science is new for all students in the course, there is no standardized way of signing certain concepts in organic chemistry.[4] In such cases, fingerspelling is used when interpreters have no other idea how to sign a concept. This tedious and time-consuming practice greatly adds to the cognitive overload of the D/HH student. Consider the term "steric hindrance" in organic chemistry. Since there is no standard sign for this concept, the interpreter must make 15 hand motions to spell out S-T-E-R-I-C-H-I-N-D-R-A-N-C-E until a quicker signed shortcut can be agreed upon. The shortcut for steric hindrance might be to sign "S-H", but this is not an especially useful representation of the concept.

Favoring Auditory Learning Styles

Rochester Institute of Technology (RIT) boasts the National Technical Institute for the Deaf (NTID). As a result, a larger than typical number of D/HH students enroll to earn a bachelor's degree at RIT. Despite the robust access services infrastructure and often pedagogy-forward classroom delivery methods, learning activities inadvertently favor the auditory learner. Lectures move quickly and keep the most competent interpreters on their toes. Thus, some bits of information may not be captured or are not interpreted accurately.[5]

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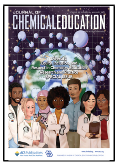

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Discussion-based pedagogies require a different rhythm given the lag time of interpretation so that the D/HH student can be engaged. A hearing student may unintentionally pace the discussion so as to not permit enough time for interpreters to catch up and allow D/HH students a chance to weigh in on the conversation.[6] Even the opportunity to answer an instructor's question when posed to a class is often out of reach if the instructor is not savvy to both the interpreter lag time and the awareness to appropriately train the students as a class to refrain from answering until the interpreter finishes signing. This training requires continual reminders and must be consistently enforced. Deaf students may also miss rich peripheral conversations given that the interpreter can only interpret one person at a time or may only be focused on interpreting the instructor and not nearby student conversations.[6]

Preservation and Propagation of a Language

On one hand, the advent of the internet has made the D/HH community more connected, improved communication methods, and aided the dissemination of a sign language repository.[7] On the other hand, the few websites that have been created to address the STEM lexicon in sign language are not largely consistent and are not regularly updated as signs evolve. There appears to be a growth in online videos pertaining to topics in the biological sciences[8] due largely to the fact that, of the D/HH students who pursue a STEM field, 28% study biological sciences in contrast to the 3% of D/HH students choosing to pursue a degree in the physical sciences.[3b] Specifically, an organic chemistry lexicon is noticeably sparse on the internet, and largely inconsistent.

Nonexpert Interpretation

There is a false assumption among hearing instructors that when providing interpreting services for D/HH students in a traditional classroom, the information conveyed is in a manner comparable to that of their hearing peers.[9] This inequity intensifies as a D/HH student moves from secondary to postsecondary education and the fields of study become more complex.[10] There is a strong correlation between the success of the D/HH student and the content knowledge of the interpreter.[11] For example, a typical interpreter for an organic chemistry course has never taken organic chemistry, nor did they major in chemistry. Thus, seasoned interpreters assigned to organic chemistry have been without a standardized lexicon to convey content, and we recognized how little information was out there to help them hone their sign language skills for STEM courses.

■ PROJECT DESIGN

Process of Formalizing an Organic Chemistry Lexicon

The process for developing and vetting the organic chemistry vocabulary and sign expansions adhered to the following protocol: (i) D/HH student-informed concept selection, (ii) D/HH student sign creation, (iii) content expert feedback, and (iv) D/HH student revision when necessary. It was very important to our team that the new organic chemistry sign language lexicon be created by its Deaf users.

The team consisted of six D/HH students (all of whom are coauthors) and the instructors for the course. The D/HH students identified the terminology and concepts that lacked a commonly accepted way of signing. Once the menu of concepts and vocabulary was collected, the team investigated whether each sign had been considered by others in the community. If the concept lacked a standardized sign, it was then discussed to either suggest a way to sign or leave it as a finger spelled word. In cases where the concept was too complex for a singular sign, a descriptive expansion was created to describe the term. The team focused on conceptual accuracy and mechanistic representation as applicable while developing signs. Revisions were then made with the goal of increasing accuracy with respect to organic chemistry content, conforming to some ASL classifiers and grammar parameters, and comfort with repetitive use as reported by interpreters and D/HH students.

Creation of the Organic Chemistry Sign Language Lexicon

Sign language has the ability to compact complex ideas into singular gestures. As such, we aimed to develop *descriptive* signs for organic chemistry terminology. An example that demonstrates the incredible ability of ASL to rapidly convey a large amount of information can be seen in the signed classifiers for "steric hindrance" and "anticoplanar", two terms that had no standardized sign other than fingerspelling the words.

Steric hindrance is a term in organic chemistry that describes the concept of spatial interactions between two electron clouds. When bulky molecular components draw closer to each other, their electron clouds repel causing steric interactions. Our signed classifier represents each surface as the back of the signer's hands, and the motion of physically bumping the hands together represents the extent to which the two electron clouds approach each other and undergo electron repulsion (Figure 1). Further cues as to the size of the interaction are conveyed by nonmanual signals on the face. For large groups, the cheeks are puffed out and the teeth are gritted to show the interaction's intensity (Figure 1a). For a larger group, these nonmanual signals will be more pronounced than for a smaller group. Steric hindrance is often denoted in textbooks and on figures as two red arcs faced in opposite directions and overlapping in the middle (Figure 1b).

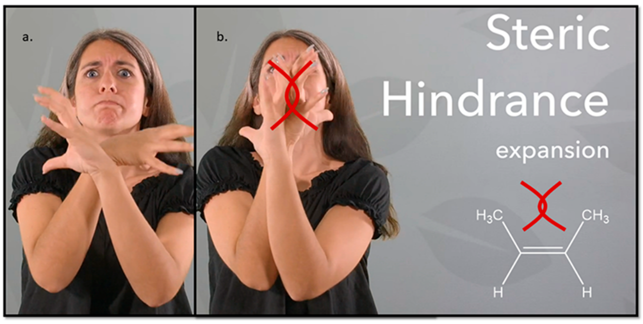

Figure 1. Method for signing the concept of steric hindrance using facial cues to denote a large steric interaction with the rationale for the chosen steric interaction handshape as denoted by the widely used overlapping parentheses. Panel a denotes the starting point of the signer's hands, and panel b indicates the direction of movement and final position of the signer's hands.

An example of a sign modeling the 3D nature of molecular structure can be observed for the term anticoplanar. This important concept is described in conformational chapters of an organic textbook but plays a larger role when revisited in the elimination (E2) chapter. The necessity in understanding this concept is grounded in three-dimensional thinking in order to see that the acidic proton and the leaving group are aligned in the same plane along with its connecting two carbons (Figure 2).

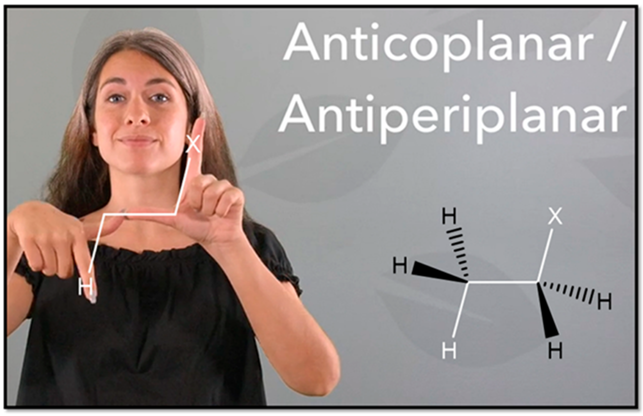

Figure 2. Descriptive sign showing the sign for "anticoplanar".

Organic Chemistry Sign Expansions

While some signs convey foundational concepts, other hand movements show that compound signs can work as a collective and be used to express a transition state model. These hand movements may take more time and are thus referred to as expansions. As these expansions were created, it was recognized that the same hand movements that described a transition state could be used for a variety of reactions. As such, categorizing reactions by sign expansion made reaction chemistry easier to discuss. Commonly, S_N1, S_N2, E1, and E2 are already named and categorically used, and it was straightforward to derive sign language expansions that represented the transition states for these terms. However, we recognized that some reactions follow transition state patterns that would naturally be recognized when using expansions but were not formally named. To simplify efforts, we took liberties in naming these categories so as to more easily define and organize transition state trends and cue the interpreter. For instance, the chemistry of a π-bond addition was neatly categorized into expansions that refer to the transition state leading to the intermediate or final product.

For example, we coined the term syn-3 for the sign expansion shown in Figure 3. We use the syn-3 expansion to model the transition state and intermediate formation when forming a brominium bridge across a π-bond (Figure 3). The transition state of this reaction can be represented through a concerted movement to show the approach of each molecule toward one another when forming the brominium bridge. The planar nature of the alkene functional group (represented by the forearm) can further demonstrate the approach from either the top face or bottom face of the π-bond.

The same syn-3 expansion is also used when describing oxymercuration, epoxidation, and cyclopropanation since all have similar transition states (Figure 4). In each of the reactions, one atom of the reagent (your knuckle) and π-bond (forearm) approach one another showing the involvement of the three most important atoms in the transition state. The transition state signs are used by interpreters when the instructor is describing the electron pushing formalism for each reaction thus making the trends clear to D/HH students. As a result, when D/HH students are introduced to the name, reagents, and mechanism for each reaction, they are trained to group these reactions together as undergoing a similar process because the concept for syn-3 is used to describe all of them. A hearing student may see these reactions as individually unique despite the electron pushing formalism trends emphasized by the instructor due to the varying reagent composition and very different products formed.

Similarly, the concept syn-4 was adopted as a sign language expansion to describe the transition states representing multiple reactions. Hydroboration, hydrogenation, dihydroxylation, and ozonolysis all have similar molecular approaches (Figure 5). In general, two atoms of the reagent (two knuckles) and π-bond (forearm) approach one another showing the involvement of the four most important atoms in the transition state. Thus, D/HH students will group these reactions together as syn-4 while their hearing peers again may miss the mechanistic correlations between them. In cases such as dihroxylation and ozonoloysis, it is noted that a larger transition state ring is formed and syn-4 in these cases is simply a mnemonic. The movement is still the same for these reactions since two atoms are added in a concerted manner from either face of the π-bond.

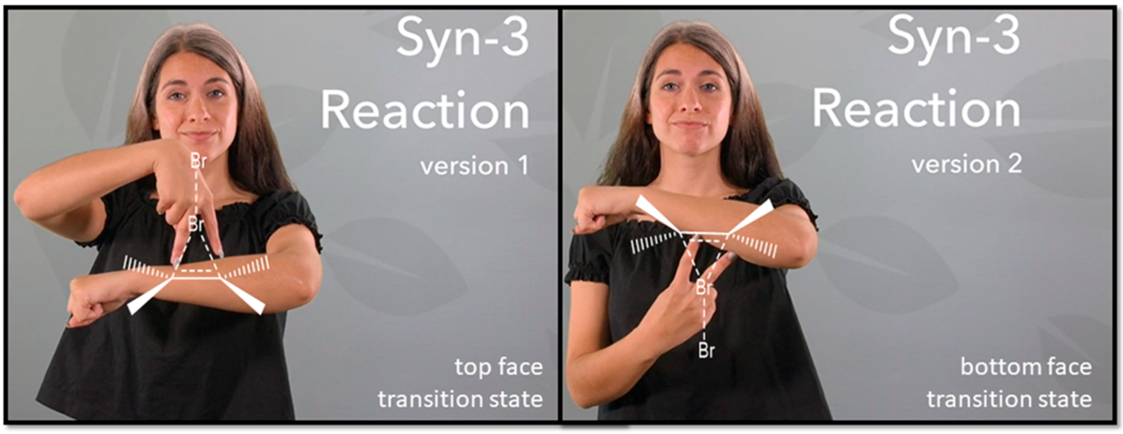

Figure 3. Syn-3 transition state sign language expansions for the formation of the brominium bridge for both the top face approach or bottom face approach relative to the alkene.

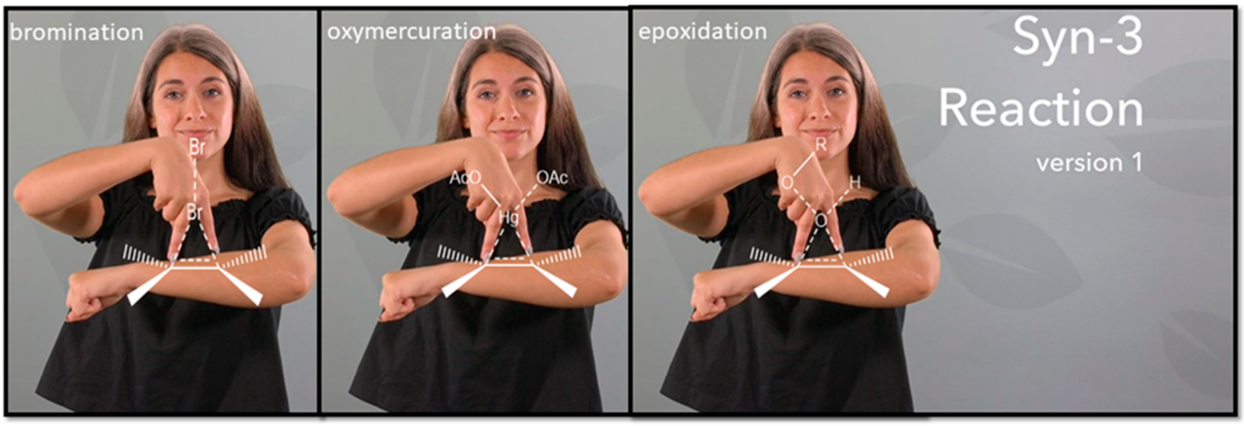

Figure 4. Sample of reaction transition states that can be categorized as a syn-3 addition reaction of an alkene. The transition states for bromination, oxymercuration, and epoxidation are shown, respectively.

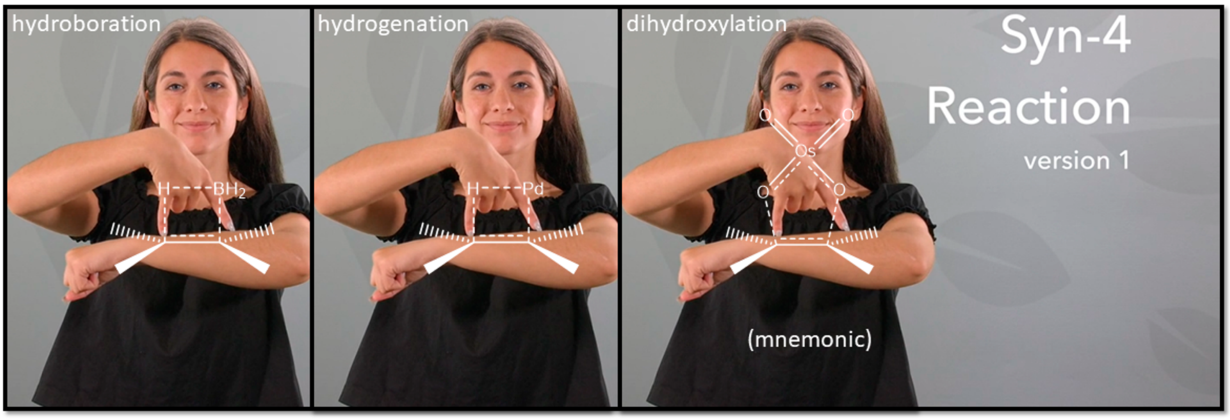

Figure 5. Sample of transition states that can be categorized as a syn-4 addition reaction of an alkene. The transition states for hydroboration, hydrogenation, and dihydroxylaton are shown, respectively.

Propagation of the Organic Chemistry Lexicon via Peer-Led Team Learning (PLTL)

Instituting the newly developed terminology was assisted through the incorporation of peer-led team learning (PLTL). PLTL is an assistive pedagogy whereby students meet with a peer who has already completed the course to practice problems relevant to the materials of the course.[12] A PLTL workshop requires that the students form small groups and work together by communicating their thoughts on solving the problem. The pedagogy is grounded in group work and the premise that students are less fearful of being wrong in front of a peer leader than the instructor. The key to PLTL workshop success is communication. Prior to our organic sign development, the workshops at RIT had D/HH students integrated with their hearing peers. Since PLTL is a pedagogy reliant on small group discussions, D/HH students did not benefit in the same way as their hearing peers from the delivery of these workshops. Once the organic lexicon was created, it made more sense to create separate PLTL workshops for D/HH students. In the midst of the organic chemistry sign development, the first D/HH-only workshops were delivered. However, that first year of D/HH-only workshops was led by a deaf support tutor since there were no existing deaf students from previous years who had used the new signs to act as a peer leader. Once this first cohort completed the organic chemistry course, two of those students willingly served as deaf peer leaders the following year to the subsequent deaf cohort taking organic chemistry. Since the incorporation of the organic signs, organic instruction at RIT has been operating D/HH-only workshops in addition to hearing workshops. The workshop format for D/HH students runs operationally the same as hearing workshops. Deaf workshop leaders have the choice of weekly training with the NTID support tutor assigned to the course or with the instructor alongside hearing students using an interpreter. The PLTL approach in concert with the support tutors and well-trained interpreters serves to preserve and propagate the new organic chemistry lexicon outside of the classroom.

Preservation of the Organic Chemistry Lexicon via ASLcore

Dictionaries are evolving language logs that preserve a foundational consistency. This is no different in American Sign Language (ASL) except that each entry is now added as a video. Prior to the internet, this project would have little hope of extending beyond the walls of our campus. As such, in order to increase accessibility of our signs and prevent reinvention, we sought to have them included in ASLcore,[7] an online repository created by a group at NTID. The group of D/HH chemistry majors and former PLTL leaders involved in sign creation were tasked with capturing the signs in formal video productions. The team also produced video expansions of the signs that explain the meaning of the sign, its mechanistic representation in ASL, and using the signs or classifiers in proper context.

Interpreter Training

With the repository of organic ASLcore videos available, it became much easier to train interpreters assigned to the organic chemistry course. Working with the instructor, the interpreter could use ASLcore to study new terminology signs in anticipation of the next lecture. The hearing instructor for the course worked closely with the interpreters and often used the signs themselves during the class lecture. Advocating for consistency of interpreter assignments has been a huge benefit. It is important to note that having a designated interpreter assigned to the organic chemistry course was a critical component to the success of our study.

■ RESULTS

Longitudinal studies on the effects from the design, implementation, and propagation of the new organic chemistry lexicon, deaf-only PLTL workshops, and a designated interpreter were evaluated. The study considered the trending data prior to 2014 for D/HH students in the organic course and recognized that 2014 was representative of D/HH students taking organic chemistry for the 5 years prior to 2014. However, this study only reports 2014 onward for comparison since the home institution switched from quarters to semesters in 2013 and the same instructor taught the organic sequence in those years. As such summative grade reports are consistent given the stability of these variables. Table 1 outlines the time frame for sign creation, sign expansion adoption, the implementation of deaf-only PLTL workshops, and the first year a veteran organic chemistry interpreter was assigned. It is important to note that only D/HH students who solely rely on the interpreter for communication were included in the study.

Table 1. Table Defines the Timeline Terms of Pre, Mid, and Post Relative to the Incorporation of Each Component to the Study

Cohort (Ay year, D/HH Students)	Signs/Classifiers	Expansions	PLTL Workshops	Interpreter Consistency
Pre (2014, *n* = 4)				
Mid (2015, *n* = 3)	×		×[a]	
Post (2016−2019, *n* = 18)	×	×	×	×

[a] Denotes the fact that this PLTL cohort was led by a tutor/content instructor and not a peer leader.

The challenges facing the D/HH students in the first semester organic chemistry course were evident given that the precohort D/HH students taking organic chemistry would earn a final grade average almost 20 points below their hearing peers (Figure 6). The hope was that our efforts would allow the D/HH students who relied solely on the interpreter during the lectures to meet the cumulative final grade average of their hearing peers in the course. Using the class averages for first semester organic chemistry in a sequence taught by the same instructor, using the same interpreter and support tutor at RIT, the performance of hearing and D/HH students was tracked (Figure 6). It was quite exciting to see that the midcohort of D/HH students, who were the pioneers using the new organic terminology, comprised the first class to meet the average of their hearing peers. Two D/HH students from the midcohort became the first peer leaders for PLTL workshops the following year. Once all elements of our project were in place, it was observed that the postcohort (2016−2019) has consistently performed above the average of their hearing peers.

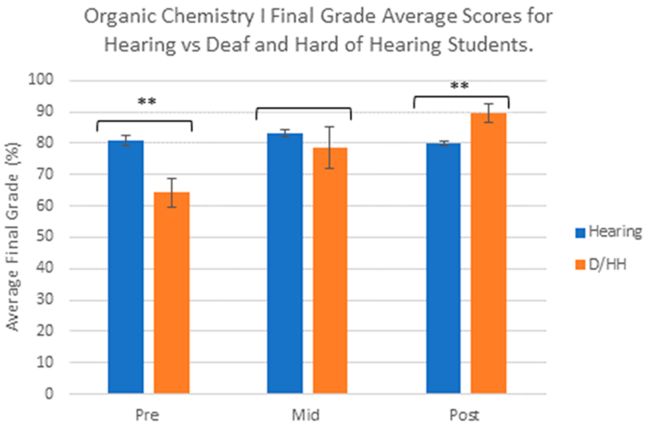

Figure 6. Final grade averages (%) by academic cohort in the first semester of organic chemistry for hearing students and D/HH students requiring an interpreter in the same course. *P*-Values are denoted using *<0.05, **<0.01, ***<0.005.

The cause of this increase in overall final grade average for first semester organic chemistry was investigated more closely. Most striking was the comparison of the exam 4 scores in that semester. This exam was singled out because it is traditionally the lowest scoring exam for both hearing and D/HH students due to the content demands of many electron pushing mechanisms (alkene and alkyne chemistry), spatially reliant problems, and student fatigue due to its proximity to the winter break. Given our unique way of categorizing the transition state mechanisms for the sake of sign expansions, a performance advantage was observed to the greatest effect (Figure 7).

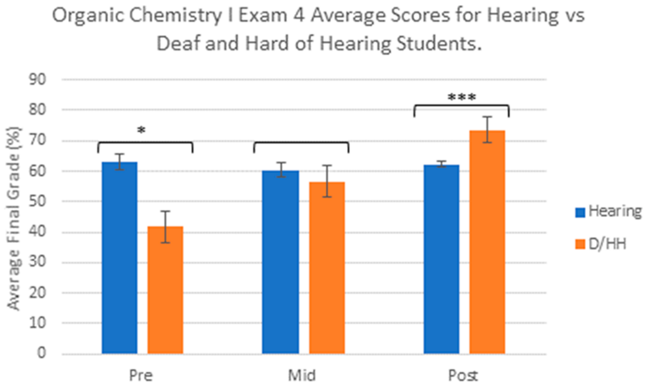

Figure 7. Averages (%) by academic cohort for exam 4 given at the end of the first semester of organic chemistry for hearing students and D/HH students requiring an interpreter in the same course. *P*-Values are denoted using *<0.05, **<0.01, ***<0.005.

Despite seeing a statistically significant difference between the postcohort when compared with their hearing peers for both exam 4 and overall final course grade, we recognized the fact that the number of D/HH students taking organic chemistry in a given year is low relative to hearing students. Thus, we investigated the effect sizes between D/HH student cohorts (Table 2). Since the effect size values in each comparison group were >0.8, it was concluded that the performance improvements by the D/HH students when measured on their own were indeed significant.

Table 2. Effect Sizes for Only D/HH Student Cohorts for Precohort vs Midcohort and for Precohort vs Postcohort for Both the Exam 4 and Final Grade Course Averages

	Effect Size	
	Pre vs Mild	Pre vs Post
Exam 4	1.25	1.72
Final grade	1.18	1.54

One hypothesis for the improved D/HH student performance we observed is rooted in the ease of identifying transition state trends. When these reactions are introduced verbally and on paper, hearing students need to see through seemingly unrelated verbiage and electron pushing formalism to connect the common mechanistic steps. A D/HH student will receive a common sign for each related reaction, directly making the mechanistic connection between them. This data suggests that the use of the developed organic chemistry sign language lexicon utilized via the interpreter and the support tutor for the courses is helping D/HH students achieve greater success in the organic chemistry coursework.

CONCLUSIONS

Through the intentional collaboration between a hearing organic professor, D/HH students, staff support, and interpreters, a standardization of an organic chemistry sign language lexicon within the Deaf community at RIT was established. As a result of this collaboration, a remarkable increase in D/HH student performance in the first semester of the organic chemistry course was observed. The greatest contribution to this overall improved course performance by D/HH students was largely due to their above average scores on the fourth exam which included content on alkene and alkyne mechanisms. Of note, adoption of the signs and deaf-only PLTL did not produce the greatest effects when compared to holistic implementation including sign expansions, true peer leaders, and discipline-trained interpreters.

FUTURE WORK

Encouraged by our preliminary data, we believe that this fundamental shift in the way organic chemistry is presented to D/HH students will inspire other hearing faculty to work in coordination with their D/HH students, interpreters, and support staff so as to foster similar performance outcomes for D/HH students in the STEM fields beyond organic chemistry. Prompted by this work, we are curious to discover whether similar performance gains are observed for hearing students who adopt some signs and expansions. Potentially, these gains may inform education practices for auditory learners in a variety of STEM fields. Our process for development and propagation of the lexicon also has the potential to transform the way in which other STEM terminology is developed for use in the Deaf community.

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Notes

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