Computerized Lexical Analysis of Students' Written Interpretations of Chemical Representations

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Abstract

Constructed response assessments, such as writing, provide insight into student thinking and allow instructors to create learning experiences that foster conceptual change. We investigate how computerized lexical analysis tools can facilitate the use of written assessments in high-enrollment introductory science courses. Specifically, we examine student interpretations of visual representations in chemistry using a combination of lexical and statistical analyses. Using this approach, we identified key ideas in student writing. Students expressed correct ideas that demonstrated their ability to make connections between the structure of molecules and their function. Additionally, groups of responses expressing incorrect or incoherent explanations were also extracted from student writing. Our results support the use lexical analysis coupled with statistical analyses to gain insight into student interpretations of chemical structures, and have the potential to support rapid feedback on formative assessments in high-enrollment introductory courses.

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Representations

Constructed response assessments, for which students have to demonstrate their knowledge in

their own language, are widely viewed as providing greater insight into student thinking than

multiple-choice (MC) assessments (Birenbaum and Tatsuoka 1987). Writing is a commonly used

constructed response assessment and an important science practice. When students write, they

engage in an authentic scientific practice of communicating their ideas. Additionally, writing

extends beyond transmission of ideas. It is intrinsically tied with thinking and provides an

opportunity for refining and restructuring ideas, solving problems and building arguments

(Driver et al. 2000, Rivard and Straw 2000, Norris and Phillips 2003). Furthermore, through

student writing, instructors gain insight to students' thinking and can use this information to

create learning experiences that foster conceptual change (Fellows 1994).

Despite these affordances of writing and other constructed responses assessments, instructors

often decide not to use them because of the effort necessary to assess and give feedback on these

assignments; this is especially true for large enrollment courses. Our research seeks to address

this barrier by developing computerized analytic tools that can assess constructed responses in

science disciplines (Haudek et al, 2012; Prevost et al, 2013).

In this study, we investigate how computerized text analytic tools can be used to analyze

students' written interpretations of visual representations in chemistry. Visual representations,

such as graphs, drawings, symbols and models are important means of communicating scientific

ideas and information (Schönborn and Anderson 2006). Thus, the construction and interpretation of visual representations comprise essential skills that facilitate student learning (Ainsworth et al. 2011). We focus on students' interpretation of chemical structures to explain chemical properties, a key chemistry concept (or big idea; The College Board, 2013). Specifically, we address the following questions: How can lexical analysis tools be used to investigate student understanding on visual representations? What conceptual difficulties harbored by students are uncovered using automated lexical analysis?

Methods

We conducted a study applying text analytic resources we had previously developed to the analysis of written responses to chemistry items administered in the *beSocratic* platform. The *beSocratic* platform is an online, cross-platform, intelligent tutoring system designed for the recognition, evaluation, and analysis of free-form student drawings (Bryfczynski et al. 2012). Students interact with the software to complete activities by drawing - (graphs, models, diagrams), and writing (explanations and arguments). We analyzed the response data from an existing *beSocratic* question on acid base chemistry. Students were given the Lewis structures of two compounds (ammonia and water) and asked to identify and explain which is a stronger acid (Figure 1). This question requires understanding that the chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them (The College Board, 2013).

Based on the Lewis structures of ammonia (NH_3) and water (H_2O) below, which one of them is a stronger acid? Please explain your reasoning.
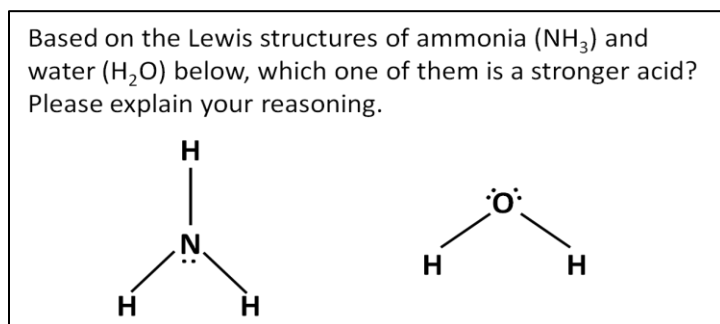
Figure 1. Acid-base chemistry question administered to students via *beSocratic* platform

We collected responses from 246 students in an introductory chemistry course at a large southeastern university. Responses were downloaded from *beSocratic* and uploaded into an analysis stream in IBM SPSS Modeler for lexical and statistical analysis.

Lexical Analysis

We conducted lexical analysis of student responses using the text analysis node in IBM SPSS Modeler (IBM 2011). The text analysis node extracted and categorized concepts (words and phrases) from student writing. We used a previously created acid-base lexical library; a library is a collection of words and phrases that are relevant to the question and subject matter and that are recognized by text analysis software. After extraction, words and phrases which represent homogenous ideas are grouped into categories. For example, the category *electronegative* in Figure 2 contains the terms *electronegative*, and *electronegativity*. Categories are revised by a researcher with expertise in the subject matter to ensure that only relevant terms are included. Once categories have been finalized, each response can be classified into zero or more categories based on the words and phrases used in that response.

Exploratory Statistical Analysis

The categories were used as variables in a k-means cluster analysis to identify groups of similar responses.   Each response is classified into the cluster for which it is closest to that cluster mean, or centroid. Thus, responses in a given cluster were more similar to each other than to responses in other clusters. *K*-means cluster analysis allows the recombination of cases and *k* user-defined clusters over repeated iterations. Recombinations are iterated until no further change in the clusters occurs. Clusters were formed based on the frequency and association of categories in and among responses. The cluster analysis was iterated for values of k=2 to 5 and clusters were homogeneous in the types of the responses they contained. A content expert in the field examined the predicted clusters to ensure that they were conceptually meaningful and that each lexical category included only one homogeneous idea.

Two cluster analyses were conducted, one for responses in which water was selected as the stronger acid, and other for responses in which ammonia was selected as the stronger acid. For each of the two groups (water and ammonia), a 3-cluster analysis was selected, as little explanatory improvement was made by adding additional clusters.

Results

Lexical analysis identified twenty-six (26) categories within student responses. Figure 2 shows the distribution of responses in lexical analysis categories by the molecule selected as the stronger acid (water or ammonia). The most common lexical analysis categories for responses in which water was identified as the stronger acid were *water*, *more*, *electronegative* and *oxygen*.

The most common lexical analysis categories for responses in which ammonia was identified as the stronger acid were *ammonia*, *more*, *hydrogen* and *water*.
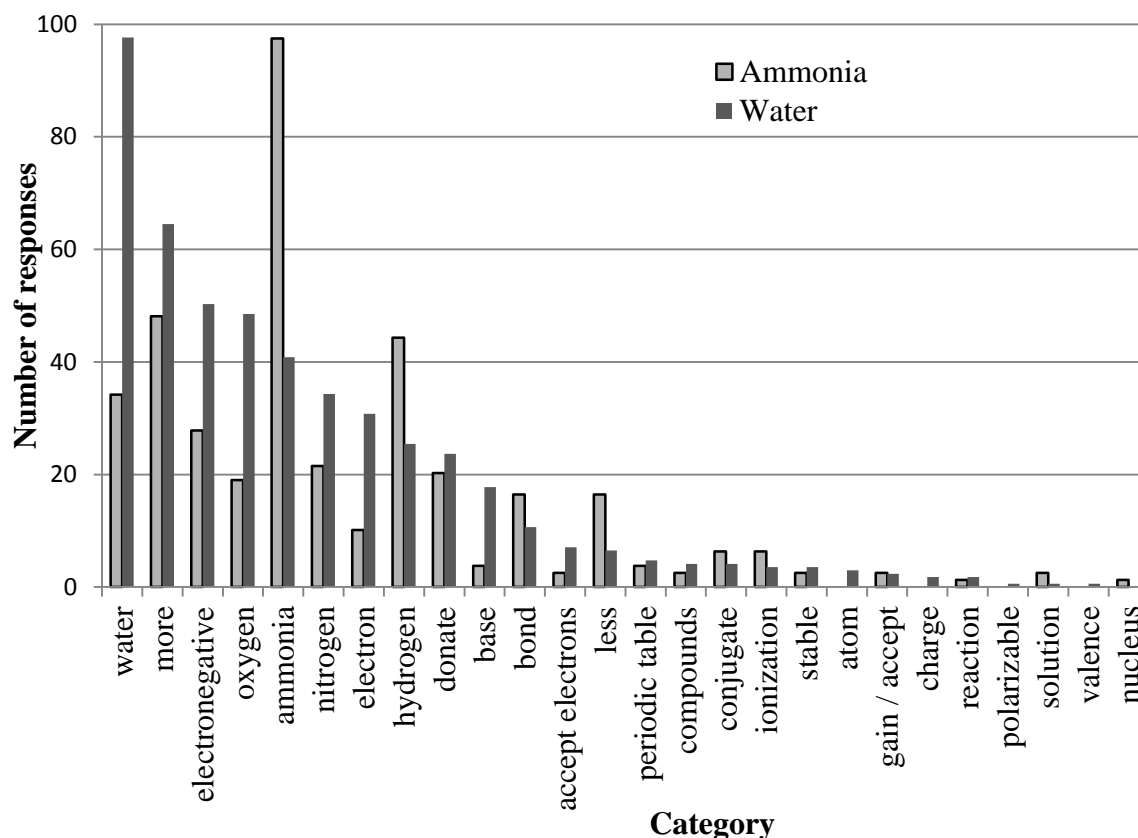
Figure 2. Distribution of lexical analysis categories by student selection (water, n= 169; ammonia, n=77)

Of the twenty-six lexical categories, nine categories were significant in determining the results of the cluster analysis. These nine categories are illustrated in the diagrams in Figures 3 and 4. Cluster analysis of responses in which water was correctly chosen as the stronger acid revealed three clusters. Responses in the first cluster compare the electronegativity of the two central atoms, with oxygen having greater electronegativity than nitrogen. This cluster contained about half (46%) of the students that selected water as the correct choice. Responses in the second

cluster talked about the molecule donating hydrogen or protons. The third cluster focused on the

pH of the compound.

We created semantic network web diagrams (see Figure 3) for each cluster that represent the

semantic relationships among student ideas. In Cluster 1, which compares electronegativity, the

categories *nitrogen*, *electronegativity*, *oxygen* and *less* occurred with the highest frequency, and

are represented as having the largest nodes (circles) in the semantic web diagram (Figure 3). The

semantic web diagrams also illustrate the covariances (connections) among categories by the

lines connecting two nodes; the more solid the line, the greater the covariance between

categories in that particular cluster (see Figure 3 legend). For example, there is a stronger

connection in these students' minds between electronegative and oxygen than between

electronegative and nitrogen. Example student responses that were closest to each cluster

centroid -- hence most representative of that cluster -- are shown below each diagram.
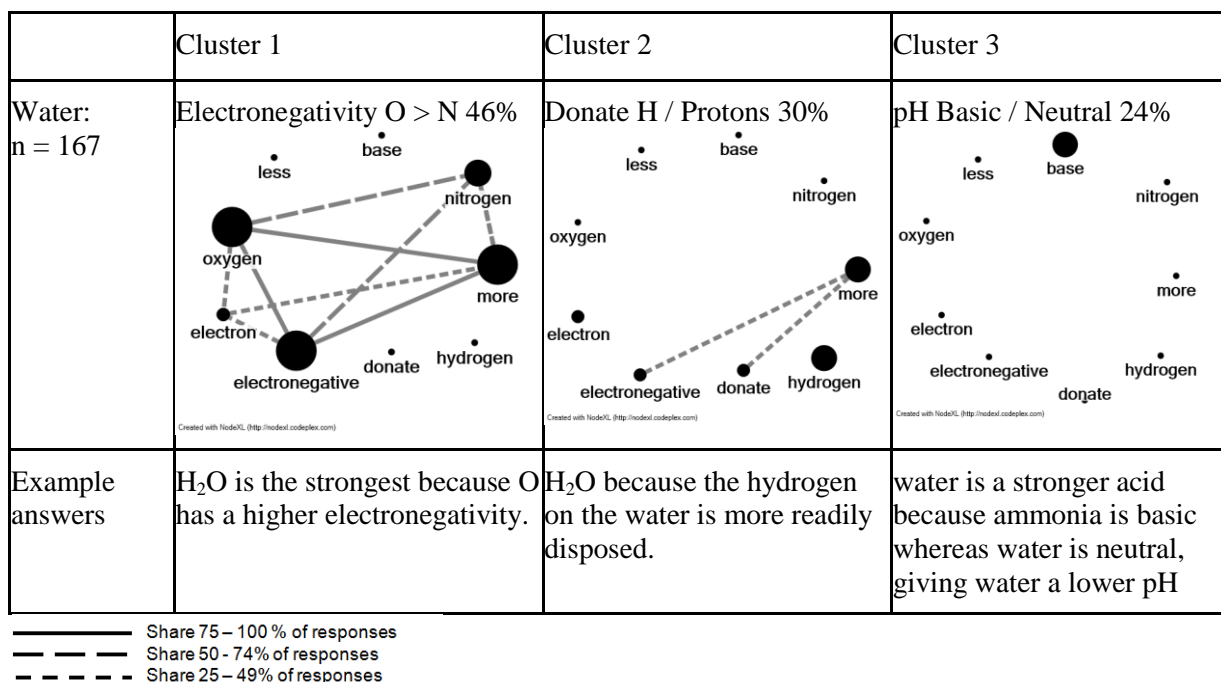
	Cluster 1	Cluster 2	Cluster 3
Water: n = 167	Electronegativity O > N 46% less base nitrogen oxygen more electron donate hydrogen electronegative Created with NodeXL (http://nodexl.codeplex.com)	Donate H / Protons 30% less base nitrogen oxygen more electron electronegative donate hydrogen Created with NodeXL (http://nodexl.codeplex.com)	pH Basic / Neutral 24% less base nitrogen oxygen more electron electronegative hydrogen donate Created with NodeXL (http://nodexl.codeplex.com)
Example answers	H_2O is the strongest because O has a higher electronegativity.	H_2O because the hydrogen on the water is more readily disposed.	water is a stronger acid because ammonia is basic whereas water is neutral, giving water a lower pH

———— Share 75 – 100 % of responses
— — — Share 50 - 74% of responses
- - - - - Share 25 – 49% of responses

Figure 3. Results of cluster analysis for responses selecting "water" as the stronger acid

Responses with ammonia as the selected answer were also grouped into three clusters (Figure 4). The first cluster contained responses that compared the electronegativity of the central atoms and indicated, incorrectly, that oxygen was less electronegative than nitrogen. The second cluster contained responses that described stronger acids as donating hydrogen or having more hydrogen atoms to donate. Finally, the ammonia responses contained a miscellaneous cluster which contained a variety of incorrect or incomplete ideas. This miscellaneous cluster contained about half of the students that chose ammonia, suggesting that many students do not have a common, coherent explanation for their incorrect choice. As shown in Figure 4, the miscellaneous cluster has very low category frequencies, as shown by the small sized nodes, indicating that the responses in this cluster express few chemically relevant ideas. Additionally, the covariances among the categories in this cluster are low, so there are weak or no connections among the nodes in the diagrams.
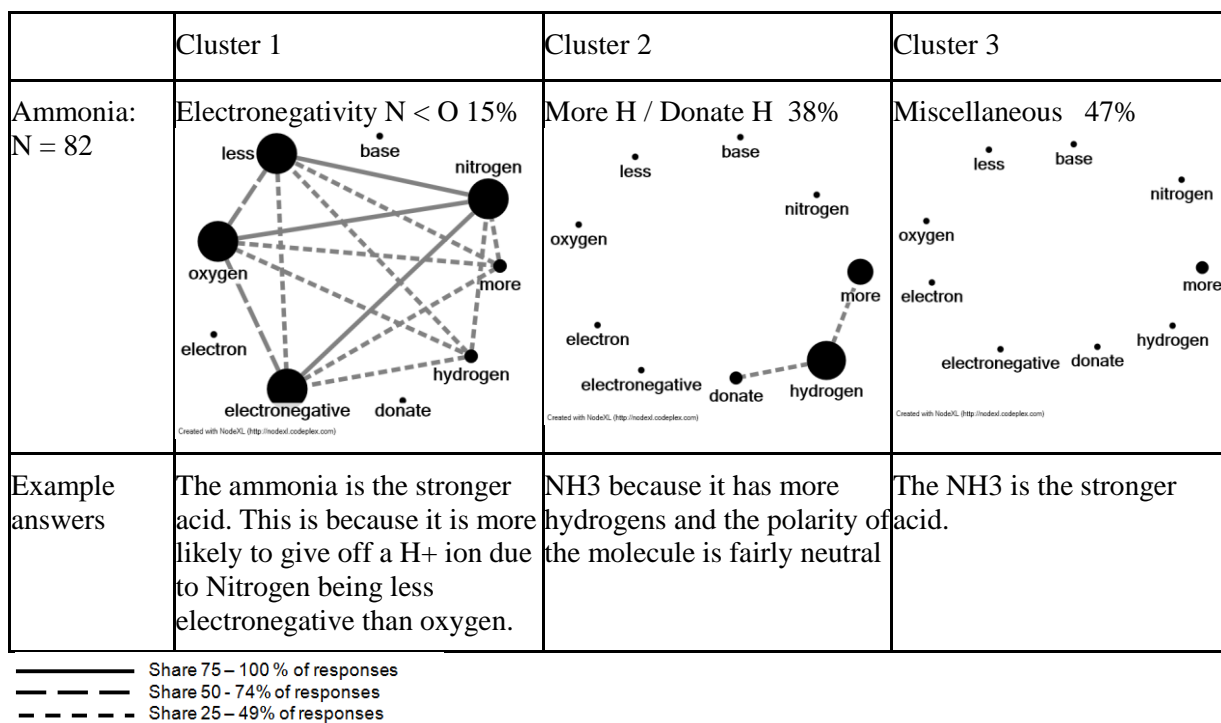
	Cluster 1	Cluster 2	Cluster 3
Ammonia: N = 82	Electronegativity N < O 15%	More H / Donate H 38%	Miscellaneous 47%
Example answers	The ammonia is the stronger acid. This is because it is more likely to give off a H+ ion due to Nitrogen being less electronegative than oxygen.	NH3 because it has more hydrogens and the polarity of the molecule is fairly neutral	The NH3 is the stronger acid.

———— Share 75 – 100 % of responses
— — — Share 50 - 74% of responses
– – – – Share 25 – 49% of responses

Figure 4. Results of cluster analysis for responses selecting "ammonia" as the stronger acid

Applications for science teaching and learning

Coupling lexical analysis and cluster analysis identified key ideas, both correct and incorrect, in student writing. Particularly, this approach was able uncover whether students arrived at the correct answer (water is the stronger acid) using the appropriate chemistry concepts. The analysis illustrated that some students who identified water as the stronger acid are correctly interpreting the structural interpretation and relating structure to properties. For example, some students applied the concept of a Bronsted-Lowry acid - the ability to of the acid to donate protons. Our analysis also revealed that some students who also arrived at the correct answer (water is the stronger acid) did not relate structure and function of acids but rather recalled properties they had memorized, for example 'ammonia is a base'. Lexical analysis also revealed several incorrect ideas held by students including the idea that having more hydrogen atoms in a molecule makes that molecule a stronger acid.

Prior work using lexical analysis to examine student writing about chemistry, has shown that students present similar ideas in written responses and in interviews (Haudek et al, 2012). As a next step in this analysis, we will use a similar interview methodology to compare student written and verbal interpretations of chemical representations.

Using the lexical and statistical approach presented in this paper, we can provide instructors with feedback on ideas students are able to correctly apply to this question and the concepts with which they continue to struggle. Additionally, we can quickly analyze new student responses to this question using the lexical and statistical models created in this study. In previous work in

introductory biology (Prevost et al, 2013), we have demonstrated how these models can be used to provide instructors with feedback for Just-in-Time Teaching (Novak, 1999).

One limitation of this analysis is the clustering of several incorrect ideas, each of which occurred in just a few responses, into one cluster (Miscellaneous cluster 3, Figure 4). However, to address this issue, when reporting this analysis to instructors, we will create a detailed report format that allows them examine such a cluster in more detail. Such a report will include several examples of the incorrect ideas used infrequently by students.

In this study we focused on the analysis of student written interpretation of visual representations. In future studies, we will compare ideas revealed in student responses to questions with and without visual representations. As both construction and interpretation of visual representations are important skills for student learning (Ainsworth 2011), future work will also examine how we can apply lexical analysis to assess students' writing as they construct, as well as interpret, visual representations.

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