Examining Some of The Students' Challenges in Learning Organic Chemistry

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ABSTRACT: Organic chemistry is considered a difficult subject which discourages learners and is associated with poor performance. Our research aims to examine some of the challenges that students face in learning organic chemistry topics related to acid/base and resonance structures theories. For this purpose, organic chemistry exams were analyzed in regards to these troublesome topics. A questionnaire was administered to further understand some of the challenges students face when enrolled in organic chemistry. Our data show that students face several challenges learning these topics and that there is a need to change the way these topics are addressed in instruction.

Keywords: chemical education research, challenges, acidity/basicity and resonance

INTRODUCTION

Chemistry is the branch of science that deals with the identification and transformation of the substances of which matter is composed, whereas organic chemistry focuses on carbon based compounds. Organic Chemistry involves the study of structures, reactions, and properties of organic compounds. The organic compounds in the human body include proteins, carbohydrates, and other macromolecules that are essential in maintaining life. Organic chemistry teaches students the chemical composition of organic compounds, their reactions, and much more [1]. It involves more than memorizing relevant information, but instead the development of conceptual understanding of the structures and reactions. These include resonance structures, the reactions that take place, the acidity/basicity of compounds, and the identification of compounds using spectroscopic methods, to name a few. Knowledge in organic chemistry allows students to pursue careers as chemists, physicians, pharmacist among other jobs in the medical field.

Organic chemistry courses cover a wide range of topics that require conceptual understanding and knowledge which might be related to students' perception that the course is difficult [2]. Organic chemistry is considered a difficult subject within the branch of chemistry, this causes an obstruction to learners from continuing with studying the subject matter [3]. Both learners and instructors find it very difficult to absorb and explain some of the materials in an educational setting. This has made learning organic chemistry increasingly difficulty over time, and the need to address this problem rests on the shoulders of the learners and their instructors.

Students enroll and start classes with the assumption that they know about the nature of learning and what they intend to achieve, which is based on their prior schooling experience and future academic goals [2]. Since chemistry studying relies on understanding the structure of matter, organic chemistry is particularly challenging for students [4].

Learning organic chemistry requires understanding the connections between microscopic, macroscopic, and symbolic levels of matter which proves to be an obstacle to learning [3]. Organic chemistry learning is vital to those who study science, engineering, and medicine. Chemistry curricula commonly incorporate many abstract concepts, which are essential to further learning in both chemistry and other sciences [4].

Learning organic chemistry requires conceptual understating in addition to memorization and application of some nomenclature, acidity and basicity, resonance, and mechanism rules. Although students might perform well on examinations, evidence based research shows that they possess many misconceptions and do not have well developed conceptual understanding of the subject matter [2]. There seems to be a disconnect between what the instructors teach and what the student learn. In one study, researchers found that an organic chemistry curriculum designed to be used by instructors in classrooms did not support and enhance learners' ability and capacity to understand because the topics were not well arranged in increasing difficulty [5]. This causes students to fear studying organic chemistry which could result in abandoning studying the topic or resulting in poor performance. Prior to the 1960s, organic chemistry teaching emphasized memorization and descriptive chemistry as competencies required for success in organic chemistry courses.

Conceptual understanding and meaningful learning in chemistry relies on the students' abilities to learn, relate, and differentiate between the microscopic, macroscopic, and symbolic levels [6]. Understanding the nature of matter on the three levels plays a determining factor in developing conceptual understanding and succeeding in organic chemistry. Students who struggle with one of the levels are more likely to struggle with understanding the other levels. Organic chemistry is especially challenging to learn because of the conceptual nature and the way the concepts are represented [7]. Organic chemistry teaching needs to place more emphasis on addressing the development of conceptual and less emphasis on preparing students for the next stage of organic chemistry [8]. Organic chemistry instructors and experts appreciate the logic of organic chemistry, whereas, the students and learners do not see the logic of the subject matter and experience challenges in learning. It has also been argued that the learners struggle learning, relating, and differentiating the three levels being taught at once [7]. It seems that instructors highlight the symbolic representational level in their teaching and inadequately emphasize the microscopic and macroscopic levels.

The advent of revised school syllabus in the 1960s and 1970s, organic chemistry offering in many countries morphed into what the academic experts would see as a logical order with little or no consideration of the learners. Similarly, early chapters in almost all textbooks for first level higher education courses start with topics like atomic theory, line spectra, Schrödinger equations, orbital, hybridization, bonding, formulae, equations, balancing ionic equations, calculations, and stoichiometry. This is the "grammar and syntax" of chemistry but it is horrifying for the student [9]. Johnstone has made arguments against this logical order, which may well not be psychologically accessible to the learner [10]. Since students lack understating, relating, and differentiating the nature of matter on the three levels, a new paradigm of teaching and learning strategy should be considered [10].

Another hindrance to learning organic chemistry is the working memory space which has a limited capacity. Students have different memory capacities to store information in a given period of time [10]. By nature, humans have limited memory space. When students are faced with learning situations where there is a high demand on the limited memory space, they have difficulty deciphering important information from others. Because learning organic chemistry involves conceptually complex material, we have an obligation to nurture students' ability to organic concepts so that working memory space is not overloaded, for the other important information to be processed and interpreted as noise [11]. Unless this is accomplished, students will rely on rote-learning, which does not transform to conceptual understanding. Instructors need to increase their knowledge about human learning, examine the nature of the discipline of organic chemistry, and make an effort to blend them [2].

Language can be considered to be another contributing factor to impeding the learning of organic chemistry [7]. Some of the language associated problems include unfamiliar, misleading vocabulary, and double or triple negatives [12]. For example, in second language learners, it was found that the usable working memory space dropped by about one unit, which could have been used to deal with language transfer [13]. In the United States, one researcher has noted the challenges students face with learning organic chemistry may not necessarily be related to the subject matter itself but to the way it is presented and discussed [14]. Her findings include the teachers' use of words that were not accessible to their students.

in Scotland, Cassels and Johnstone have argued that non-technical words used in the learning of science were a cause of misunderstanding for students [15]. Some commonly used words in the English language might have a different meaning and use in science. For example, the students assume that the word "volatile" means "unstable", "explosive" or "flammable". It should be noted that scientifically it means "easily vaporized", which was unknown to students. Moreover, an argument was made that learning involves receiving information through learner sensory systems and transforming it to available information in long-term memory [16]. This enables the learner to recognize and organize the incoming information and make sense of it. Cognitive processes may be considered to involve the interaction of the components of memory that include working and long-term memory.

Language plays a significant role in the thinking processes necessary to tackle any task. This is supported by observations made by Cassels and Johnston [17], where they noted that there should be a careful thought about language use. Language use can assist or obstruct interactions with long-term memory and in some cases can lead to information overload in learners.

Organic chemistry has an abundance of abstract concepts and therefore its learning requires intellectual thought and discernment. Concepts such as dissolution, particulate nature of matter, and chemical bonding are essential to learning organic chemistry [18-20]. Therefore, studying students' conceptions of the concepts in organic chemistry has been a research focus for the last several decades [2]. Researchers found that students had difficulties understanding functional groups and their role. As a results, they struggled learning about esterification, condensation, synthesis, and hydrolysis [21].

Motivation is another important factor to consider to ensure learning and success. Instructors note that they face challenges when their students lack the motivation to learn and understand. Students' perceptions about the difficulty of organic chemistry plays a significant role in their ability and willingness to learn it [22]. Students' motivation to learn is intrinsic or extrinsic. Intrinsic motivation refers to learning for one's sake, whereas extrinsic motivation refers to learning for a grade [23]. It is noteworthy that students with different motivational types also have different learning styles [24].

METHODS

Our research aims to examine some of the challenges that students face in learning organic chemistry topics related to acid/base theories and resonance structures. Participants of this study were City College of New York, science, engineering, and pre-health field students who were enrolled in the first-semester of organic chemistry. The participants were recruited from two organic chemistry classes consisting of about 200 students. In order to properly examine the challenges that students face in learning organic chemistry, data were collected in several ways. Data collection was broken down into a Likert-type questionnaire, a short answer questionnaire, student interviews, and examining old examinations. Organic chemistry exams containing problems that asked the students to draw resonance structures of the given structure and to arrange given compounds in order of increasing acidity/basicity were examined. The surveys were anonymous and the interviewees picked at random.

After examining about 200 organic chemistry tests, data showed that students had difficulties with resonance and acid/bases theories. Several Likert-type and open-ended questions were devised with intent of helping us better understand some of the challenges they face learning organic chemistry.

TABLE 1. Survey questions on students' performance and knowledge in resonance and acid/bases. Questions 1, 3, 4, 6, 7, and 9-11 are Likert-type questions. Questions 2, 5, 8, and 12 are open-ended questions.

1.	At first, I struggled with resonance structures
2.	Can you list some of the challenges you faced while learning resonance structures?
3.	By the end of the course, I understood resonance structures
4.	A different teaching style would have helped me understand resonance structures better
5.	Can you give an example of a teaching style that would have helped you understand resonance structures better?
6.	Now, I can draw correct resonance structures in less time and with less effort than at the beginning of the course
7.	At first, I struggled with acid/base organic molecule questions
8.	Can you list some of the problems you faced in understanding acidity/basicity?
9.	My understanding of acid/base properties improved throughout the semester
10.	I am confident I now understand acidity/basicity of organic molecules
11.	A different teaching style would have been better for me to understand acidity/basicity of organic molecules
12.	Can you give an example of a teaching style that would have been more helpful for you to understand how to arrange organic molecules in increasing acidity/basicity?

The Likert-type section included eight questions that were scaled between strongly disagree and strongly agree. The Likert-type section was scored on a five-point scale ranging from (1) Strongly Disagree, (2) Disagree, (3) Neutral, (4) Agree, and (5) Strongly agree. The questions are listed in Table 1. Questions 1-6 contain open-ended and Likert-type questions related to resonance. Questions 7-12 are related to acidity/basicity theory of organic molecules. For the open-ended questions, students were asked to list some problems that would help us identify challenges that students face in learning about resonance and acid/base theories and how we can help them overcome these obstacles.

RESULT AND DISCUSSION

Drawing Resonance Structures

Some common challenges found in the problem that asked the students to draw resonance structures involved movement of electrons, arrow drawings, usage and placement of charge, number of resonance structures to draw, following octet rule, and the stability and contribution to the hybrid of each structure. This shows that the students did not possess a developed conceptual understanding of resonance theory and that they face several challenges learning it.

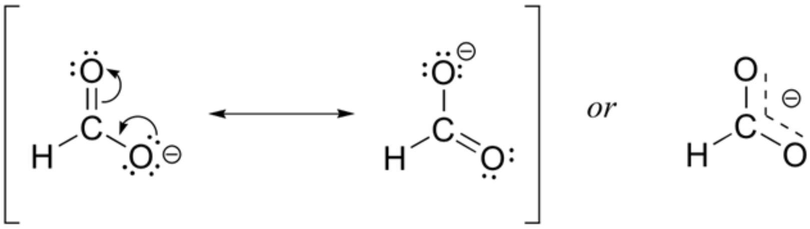

FIGURE 1. Resonance of a carboxylic anion is shown above.

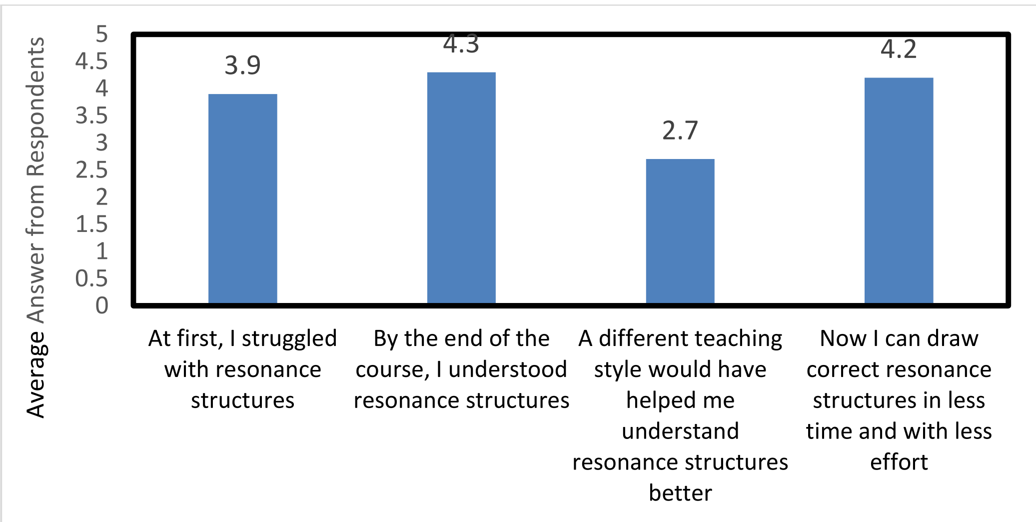

FIGURE 2. Bar graph of the results of questions 1, 3, 4, and 6 from Table 1. The graph shows the average answer from the students.

Figure 2. demonstrates that students believe that they struggle with resonance structures. Furthermore, they also believe that they have learned resonance and have an understanding due to instruction which is made up of a lecture and recitation that mimics peer-led team learning (PLTL) [25]. The fact that students did not score highly on the importance of different teaching style to improve their own learning could be attributed to their lack of exposure to different teaching styles. Most of them, being science and engineering majors, only experience teaching by traditional lecture format with very little exposure to active learning which they do experience in PLTL.

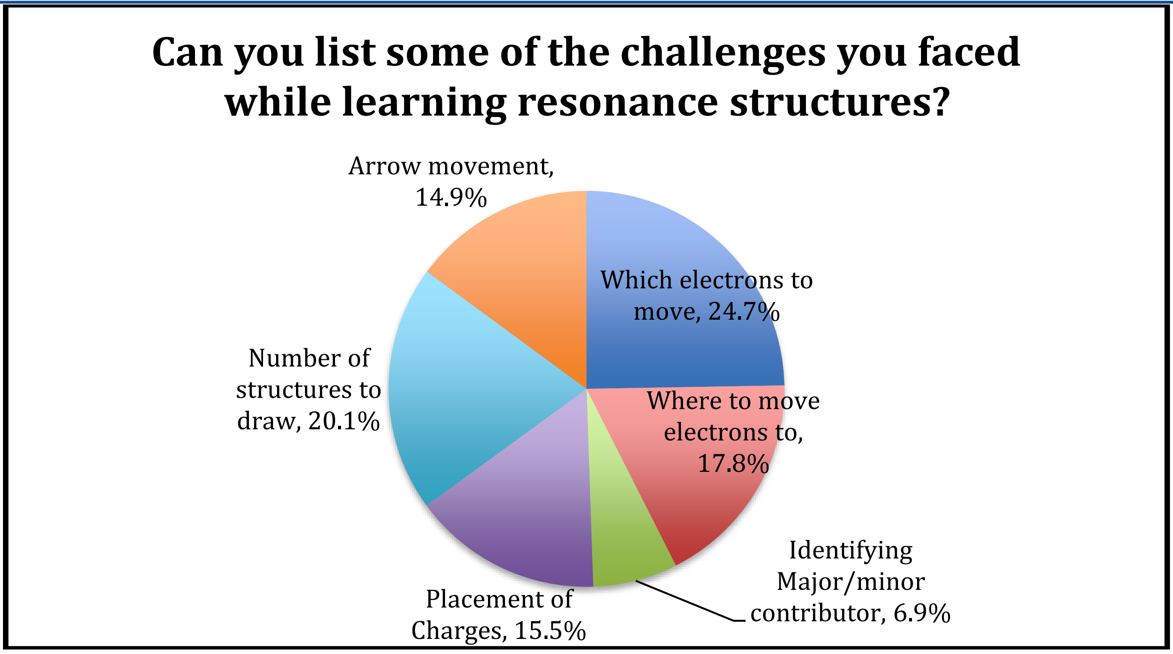

FIGURE 3. Pie chart of the results of question 2 from Table 1. The answers from the surveys were tallied up and converted to percentages.

Figure 3 shows a visual depiction with percentages of challenges that students identified in learning about resonance structures and theory. The pie chart is arranged from most challenging to least according to students includes: identifying which electrons to move, the number of structures to draw, where to move the electrons to, placement of charges, arrow movement, and the ability to identify major/minor contributor to the hybrid.

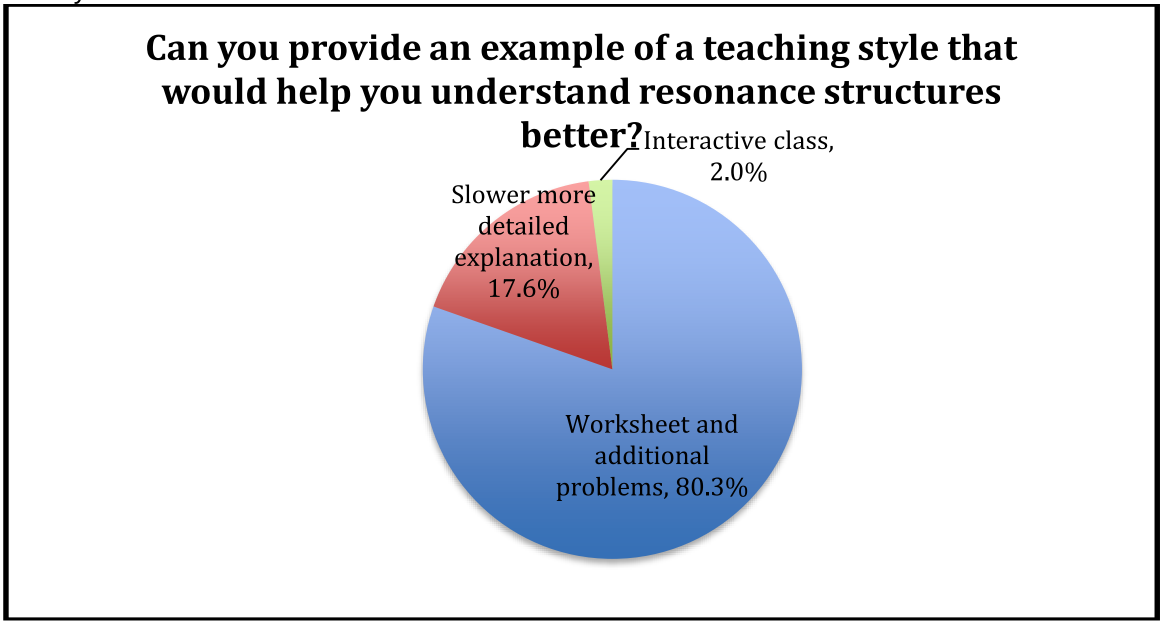

FIGURE 4. Pie chart of the results of question 5 from Table 1.

Figure 4 shows the students lack of knowledge or exposure to active learning and student centered classrooms. Students overwhelmingly think that worksheets and additional problems as well as lower more detailed explanation, are types of teaching styles. Only 2 percent mention active learning and interactive classroom. This could be due to the fact that most institutions still teach organic chemistry courses based on passive lecture format with very little involvement of the students in the learning process.

Acidity/Basicity Theory

On the organic chemistry tests that we examined, students were asked to arrange certain ions and anions of compounds in order of increasing acidity and basicity. It was evident that students struggle with acid/base theory understanding. Acidity/basicity theory does not have a simple clear explanation. Acidity of a molecule depends on the type of atom attached to hydrogen to be donated, the presence of resonance structures which can be stabilize the resulting anion, the inductive effect, and the orbitals of the atom attached to hydrogen to be donated. Furthermore, the charge on the molecule also plays a role in acidity/basicity. Theses make learning and developing conceptual understanding of acidity/basicity theory a challenging one.

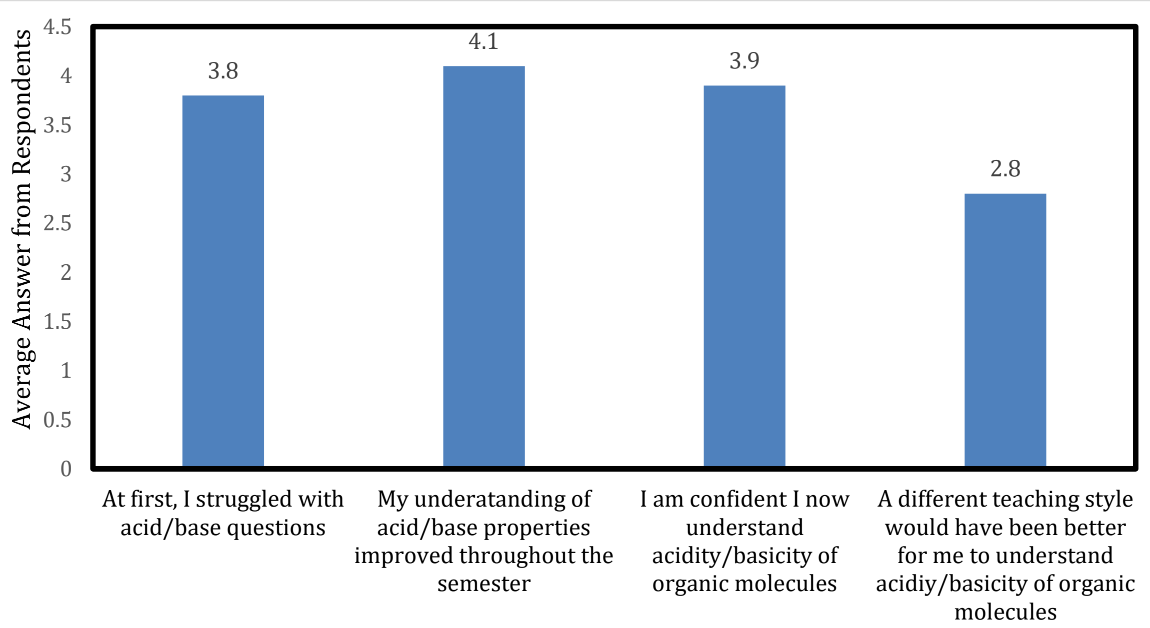

FIGURE 5. Bar graph of the results of questions 7, 9, 10, and 11 from Table 1.

Figure 5 shows a graph with averages of answers from respondents of challenges that students identified in learning about acid/base theories. The results are similar to those obtained for resonance structures where they believe that they struggle with acid/base theory, and have learned it, now having a better understanding as result of instruction. Students did not score highly on the importance of different teaching style to improve their own learning.

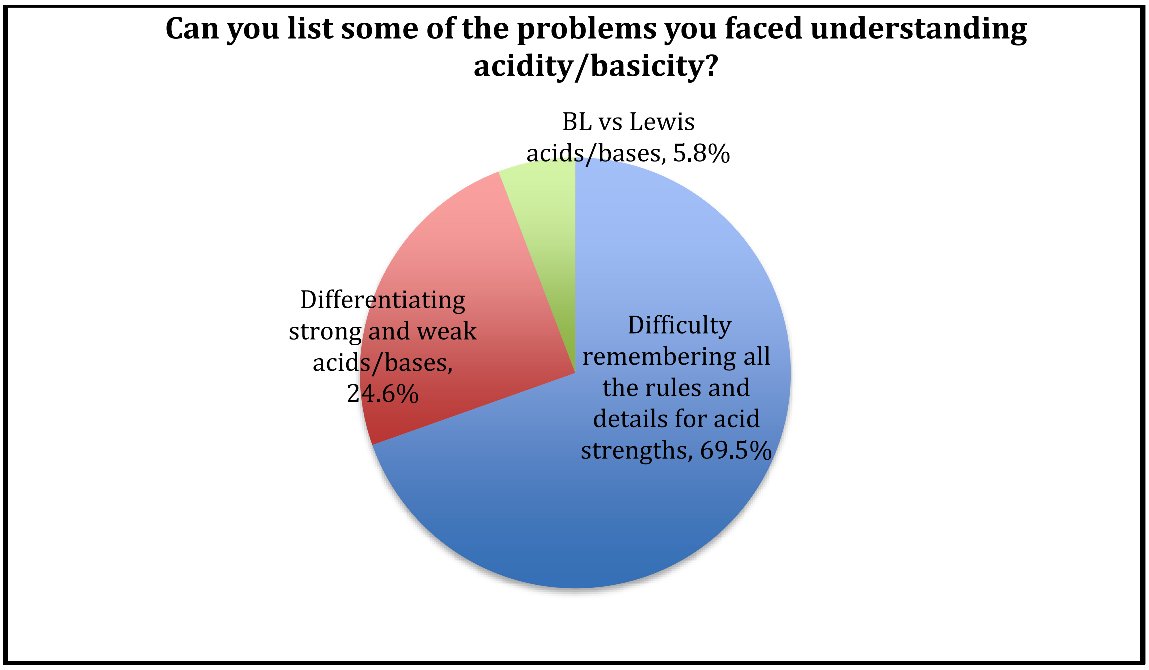

FIGURE 6. Pie chart of the results of question 8 from Table 1.

Figure 6 shows that students' difficulties in learning acidity/basicity theory are largely related to the difficulty remembering all the rules and details for acid/base strengths. This clearly shows that rote-learning and memorization do not serve the students' needs in learning organic chemistry. The students struggle lies in differentiating strong and weak acids and bases from one another. Finally, students find it difficult to learn Lewis acid/base theory after they spend general chemistry learning Brønsted-Lowery acid/base theory.

Based on the results, there seems to be many challenges facing students in learning resonance structures and acidity/basicity theories. With respect to resonance structures, students struggle with the movement of electrons, arrow drawings, usage and placement of charge, number of resonance structures to draw, following octet rule, and the stability and contribution to the hybrid of each structure. Students have difficulties developing conceptual understanding and solving problems related to acidity/basicity theories. Our data show that students had difficulties remembering all the rules and details for acid/base strengths, differentiating strong and weak acids and bases from one another, and learning Lewis acid/base theory as a separate theory from Brønsted-Lowery acid/base theory.

Acid-Base reactions are also important not only in organic chemistry but in all of chemistry. It's significant to understand how acids and bases differ and what pKa range each falls in because this allows you to understand and accomplish much more. Developing conceptual understanding of basic concepts is crucial to learning and understanding more complex organic reaction [26].

Based on our data, a significant number of students struggled with identifying which electrons to move (24.7%), where to move them to (17.8%), and arrow movement (15.9%) in drawing resonance structures. This might have to do with the fact that most textbooks present resonance structures in the first or second chapter and introduces electron pushing in subsequent chapters, usually the third or after. It is noteworthy, that the drawing of arrows to depict movement of electrons is a new and unfamiliar topic for students to learn. According to Bhattacharyya and Bodner, electron-pushing curved arrows used in mechanisms held no physical meaning for the graduate students [27]. Students do not understand that the function of the arrows is not to force a solution out of a problem, in which students most likely propose nonsensical steps to form unlikely intermediates, but to serve as the explanation to the "how" and "why" of a reaction while correlating the arrows they draw with fundamental principles of chemistry [27].

Our results show that 15.5% of the students who participated in our study, found it challenging knowing where to place the charges on the molecule. Formal charge is usually introduced and taught in the same chapter as the resonance structures. Providing students with the time needed to learn and apply formal charge calculation rules would be beneficial to learning about drawing resonance structures. Lastly, our data indicates that 6.9% of participants faced challenges in determining major and minor contributor to the hybrid. This could also be attributed to the number of rules students have to learn and apply to reach the correct conclusion.

With respect to acidity/basicity theory, our data show that students have difficulty remembering the rules for acid strengths (69.5%), differentiating among strong and weak acids and bases (24.6%), and understanding the difference between a Brønsted-Lowry and Lewis acids and bases (5.8%). Although students are introduced to acidity/basicity in general chemistry, it is usually taught for inorganic acids and bases. Whereas, organic acids and bases follow different rules from binary and oxyacids.

The challenges students face in learning about resonance and acid/base theories could be related to the language barrier to learning [17], the lack of personal relevance of the material to their daily lives [28], memory overload where the important information to be processed is interpreted as noise [11], design of the curriculum content of organic chemistry textbooks that are determined by the need for teaching instructors instead of the need of the learner [8], the absence of the development in the learner of simple but meaningful concept maps [29], and the abundance of misconceptions that the students held [2].

Interestingly, when the question of which teaching techniques will best help students understand these topics better, only 2% were interested in an interactive class with both the teacher and among their peers. Students believe that additional problems and worksheets, along with slower more detailed explanation is expected to help them learn. This could be attributed to the fact that most of our students experience lecture authoritarian style method of teaching. Active learning and constructivist teaching methods should be employed more frequently in instruction at the college level especially in the sciences.

Many students come to a class with misconceptions, confused ideas or even a complete lack of background knowledge. Classroom instruction need to address these issues. There is evidence that pre-laboratory and pre-lecture experiences can be effective in increasing conceptual understanding [30-31]. The instructor should work on the development of links between "islands" of knowledge so the learner can benefit by making a coherent whole of key ideas, which nurtures the development of simple but meaningful concept maps [30].

Instructors should take into account the way the learner gains knowledge and modify their teaching in a way that is consistent with patterns of human learning. In particular, the limitations of working memory space have been shown to be important [32]. Their model of learning has been found to be extremely useful in predicting ways by which learning can be made more effective.

Motivation and attitudes should be considered during instruction because they are important aspects for a successful learning outcome. Improving the organic chemistry curriculum and instruction can positively influence attitudes towards the subject matter [33]. Instructor improvement is beyond the scope of this paper. However, making the curriculum more relevant to the learner influences their learning and attitudes [34]. We are not suggesting to water-down the topics or avoid challenging one because this will lead to a perceived reduction of the importance of organic chemistry.

CONCLUSION

The challenges that students face in learning resonance and acidity/basicity theories are reflected in the written answers that the students provided on the assessment tool. This shows that the students did not possess a well-developed conceptual understanding of resonance and acidity/basicity theories and that they face several challenges learning these topics. Our data also show that rote-learning and memorization do not serve the students' needs in learning organic chemistry challenging topics, and that teaching organic chemistry courses based on passive lecture format with very little involvement of the students in the learning process is not beneficial to our students' population.

Our results indicate that there is a need for change in the way resonance and acidity/basicity theories should be addressed in instruction. Based on the data presented here, organic chemistry topics especially the resonance and acidity/basicity theories should be presented with an inquiry-based approach, and students should be more involved as part of the learning process and given ample opportunities to construct their own knowledge. Students in organic chemistry classrooms can benefit by making the course less lecture-based heavy. Active learning and constructivist teaching methods should be employed more frequently in instruction at the college level especially in the sciences. By exposing students to different learning styles and environments, the student might be better able to develop conceptual understanding about resonance and acidity/basicity theories. Ensuring that students learn and develop conceptual understanding of resonance and acidity/basicity theories would provide them with the tools needed to learn and excel when studying organic reactions and mechanisms and increase their chances of successful completion of the course.

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