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ABSTRACT

This paper describes the development of a mobile application (app) created as a learning tool to help organic chemistry students increase their conceptual understanding of a given topic. The learning needs of organic chemistry students studying the unit “functional groups” were first identified, appropriate learning theories were chosen, and then a working prototype of the mobile application “TsoiChem©” was designed and created using Apple’s iOS Software Development Kit. An iterative development process incorporated several learning theories along with the chemistry students’ feedback into the app’s design so as to best leverage the multi-touch feature of the device. This paper also discusses the preliminary data on the effectiveness of the design elements on student perceptions of the app and students’ conceptual understanding. Future directions for the app and this study are also presented.

KEYWORDS
Mobile learning, mobile application, mobile application design, conceptual understanding, Apple iPod Touch, learning theory, learning needs, science education, organic chemistry

1. INTRODUCTION

Organic chemistry is known as a difficult course in post-secondary science courses of study. With its low passing-rate, many researchers have proposed possible interventions to ameliorate this pervasive pattern. Some of the approaches include active learning environments, Web-based pre-class student preparation activities, cooperative learning, poster sessions, and even changing the pacing and delivery of the curriculum (Bradley, Ulrich, Jones, & Jones, 2002; Collard, Girardot, & Deutsch, 2002; Hagen, 2000; Huddle, 2000; Paulson, 1999; Sartoris, 1992). Other researchers have attempted to look at the “root” of the problem and investigate the factors that may contribute to the high number of failures in chemistry (Angel & LaLonde, 1998; Bunce & Hutchinson, 1993; McFate & Olmstead, 1999). Conceptual understanding of core concepts presented in organic chemistry has been cited as perhaps one of the more influential factors contributing to the
disparate patterns of student performance (Szu, Nandagopal, Shavelson, Lopez, Penn, Scharberg, & Hill, 2011).

Seemingly unrelated, the interest in mobile learning, or m-learning, has increased dramatically over the last few years. Lee (2006) and Leung and Chan (2003) note that there are over 10 billion users worldwide and this number continues to grow every year. Technology and learning both have become more individualized and user-centered over the past 30 years (Sharples & Westmancott, 2002). Just as new technologies in the past have garnered excitement and buzz as the new “magic bullet” that will cure all our educational ills, the mobile device is gaining similar interest today. The difference with this new technology, however, is the fact that the mobile device is becoming a part of today’s students’ daily activities and lifestyle. Consumers’ expectations of their mobile devices are changing (Tucker & Winchester, 2009). Termed “cell phone culture” (Katz, 2002), today’s youth interact with the mobile device in more ways than just as a communication tool. Students use their cell phones for tasks such as viewing videos and pictures, accessing the Internet, scheduling, and reading e-mail. With a multimedia tool that is accessed several times a day, it follows that educators are considering the possibility of harnessing this avenue as a way to impact student learning inside and outside the classroom.

In this study, we attempted to merge these two ideas into a project to help students learning in three organic chemistry sections at a local 4-year college. We targeted, as the curricular topic of focus, the skill of identifying functional groups - a fundamental concept that is typically a challenge for organic chemistry students. A mobile application (app) called “TsoiChem©” was designed and developed to help students practice functional group identification and elucidate common misconceptions. Since conceptual understanding was indicated by research as one of the more influential factors of student performance, the design of the app focused on increasing students’ conceptual understanding of functional group identification. Therefore, we used educational learning theories to inform key decisions about the design and layout of TsoiChem© in order to maximize students’ conceptual understanding. The app was then provided to organic chemistry students through the Apple© iPod Touch device and data was gathered on student opinions and performance. This data was then used to inform revisions and changes to the TsoiChem© app. In summary, given the popularity of mobile devices among students today, we wanted to investigate how students would respond to an educational application when played on a touch-screen mobile device if the application was designed with their learning needs in mind and how it might affect their conceptual understanding.

In this paper, we describe the theoretical background behind the project (Section 2) and then detail the design of the mobile app (Section 3). We then provide student feedback on the TsoiChem© app as well as preliminary data on student performance in identifying functional groups before and after playing TsoiChem© (Section 3). Finally, we describe the future directions of this project (Section 4), which include long-term student use of TsoiChem© and porting this learning app to a tablet platform.

2. BACKGROUND
2.1 Mobile Learning

Mobile learning has become an important form of learning and has received a lot of attention in recent years. It has been described as any form of learning that is mediated through the use of a mobile device, with an emphasis on “mediated” (Winters, 2006). The fact that there is a 1:1 ratio of student to computer also allows for a more personalized learning experience (Chan, 2006). Another advantage of using mobile applications in learning is the ability to provide immediate feedback. It has been long accepted (Gilmer, 1979) that immediate feedback helps students self-correct and rectify prior misconceptions. All these advantages may have contributed to the recent increased use of mobile devices for learning.

The use of laptops and smart phones has become very common on college campuses and some universities have conducted studies on the use of mobile technology for academic purposes. Previous studies (Belanger, 2005; Patten, 2006; Pennington, 2010; Sauder, 2009), discuss the various uses of mobile devices for academic purposes. Our goal in this study was to harness students’ familiarity of the mobile device in delivering a learning tool that could enhance the learning of organic chemistry students by increasing conceptual understanding. Because of the visual nature of the subject, a handheld device that supports multimedia functions would be an ideal tool with which to provide students with additional practice opportunities, personal feedback, and individualized instruction aimed at correcting common misconceptions and therefore increasing conceptual understanding.

Past studies have emphasized that mobile learning should be used in addition to an existing learning environment. Learning is not an activity whereby information is merely absorbed by the user as the device delivers the content. Indeed, as the learner interacts with all modes of information (textbook, lecture, online discussions, etc.), it is thought that the synthesis of the information as the learner evaluates, understands, and applies the new content is what makes up the learning experience. Therefore, mobile devices should be investigated as a promising platform on which students can access information, but also perhaps obtain assistance in synthesizing all the sources of content.

The challenge, then, is “…adapting and appropriating the technology for learning in a way consistent with learning goals and principles” (Hoppe, 2004). The device should support the objectives of the course and be user-friendly enough so that the learner engages with the content being supported by the device. As well, the mobile content must be developed in such a way as to appeal to a wide audience, a large range of abilities, and varied levels of technological know-how. So, in the end, when mobile devices are used, they really should be used as enhancements and supplements to the main lesson, and not the only way that the lesson is delivered. Therefore, mobile applications have focused on short, defined goals or tasks so as to be more effective in capturing the interest of users and to simplify the mobile device-user interaction. In our case, the TsoiChem© app focused on the sole concept of identifying functional groups in organic chemistry and did not include extraneous curricular concepts such as reactivity of functional groups, for example.

2.2 Student Learning Needs in Organic Chemistry
Organic chemistry students usually struggle with the content for a variety of reasons, but the main causes are: the large amount of material covered, the way in which the content builds on itself throughout the course (therefore a weak understanding of core concepts can spell failure for later topics in the class), and the subject’s visual nature and requirement for various learning skills (visual, logical and mechanical).

One of the common areas of difficulty for our students is functional groups. Functional groups are specific groupings of atoms that react in particular ways. In organic chemistry, it is important for students to be able to recognize these groupings in order to correctly predict how a molecule will react in a certain set of conditions. In the last three academic years, we have assessed student performance on this concept and it has averaged 64%, which indicates that students are not fully mastering this core concept of the course.

Molecules can be represented in a variety of formats (condensed, line-bond formula, Kékule, etc.) so the memorization of functional groups has proven somewhat difficult for organic students over the years. Typical textbooks offer students a summative chart of all the functional group categories encountered throughout the course and instructors usually require students to memorize the “chart” (McMurry, 2007; Smith, 2011). Practice problems most commonly entail requiring students to find the functional group in a given molecule and naming its category.

The problem with the above learning method is that students are confused when they are presented with a functional group represented in a different format than the format given in the memorized textbook chart. They are asked to make that “leap” in comprehension and figure out how the functional groups can appear in alternative formats. For example, the aldehyde functional group includes a carbon atom that is doubly bonded to an oxygen atom. Students typically see it in the textbook chart in the “line-bond format” as:

\[
\begin{align*}
\text{R} & \quad \text{C} \\
& \quad \text{H}
\end{align*}
\]

However, on a practice problem, students somehow are required to also recognize that the figure shown below also represents the aldehyde functional group:

\[
\text{RCHO}
\]

At first glance, these two structures seem to have different functional groups, but in fact they both contain the aldehyde functional group. It is assumed in the latter case that students realize there is still a double bond between the carbon and oxygen atoms, even though apparently a hydrogen atom (H) is written in between the C and the O. This “condensed” format of drawing the molecule therefore may lead students to develop the misunderstanding that in an aldehyde functional group, the carbon atom is actually bonded to the hydrogen—seemingly a logical conclusion based on how the molecule is presented in this case. It is no wonder that the conceptual understanding of functional groups has been an area of low achievement for our students.

Another area of potential misconception is that of the rest of the molecule to which the functional group is connected. Often, the functional group chart in textbooks represents the
rest of the molecule with the letter “R” or a wavy line. Then, when students are presented with a functional group attached to various molecules, they are unable to recognize the type of functional group. For example, the alcohol functional group is usually shown as

\[ \text{ROH} \quad \text{or} \quad \begin{array}{c} \text{OH} \\ \end{array} \]

in textbooks, where the oxygen atom “O” is bonded to a hydrogen atom “H”. However, students see a molecule with an alcohol such as:

![Alcohol molecule](image)

and confuse it with the benzene functional group, which is shown as:

![Benzene structure](image)

It appears that both structures have a ring structure to them. However, the first example is an alcohol and the ring is only part of the “rest” of the molecule. In the second example, the ring actually makes up the functional group benzene. Thus, the “rest” of the molecule can add confusion to the identification of functional groups when it approximates other structures that are to be memorized.

Finally, students struggle with identifying all the parts of a functional group and understanding which parts are included. A prime example is that of the ketone functional group, which is simply a carbon atom with a double bond to an oxygen atom, as shown below:

![Ketone structure](image)

Many times we have found that on assessments, students do not recognize the carboxylic acid functional group. This is because it too includes a carbon with a double bond to an oxygen; however, it also includes a second oxygen atom—but it is bonded to a hydrogen.

![Carboxylic acid structure](image)

So, when presented with a carboxylic acid, students mistakenly identify it as two functional groups: a ketone with an alcohol (-OH) attached to it. The correct answer is that the two parts together make up one functional group – the carboxylic acid.

In summary, the student learning needs in organic chemistry within the topic of functional groups are centered on several aspects: the variability in formats, the “rest” of the molecule, and functional groups with multiple parts. These common misconception areas have not been adequately addressed for our students with paper-and-pen practice problems from a textbook. Given past research that indicates that using a touch-screen mobile device for memorization purposes seems to be just as effective as using a pen-and-paper worksheet (Tsoi, in press), as well as the shallow learning curve of mobile devices
with today’s students, we propose that students’ conceptual understanding of functional groups can be enhanced with a mobile application.

2.3 Learning Theories Incorporated

Traditional organic chemistry courses rely on textbooks and out-of-class problem solving to introduce and convey the content. With the advent of the Internet, there has been an increase in websites that offer other alternatives to mastering the material, with videos, simulations, and alternate models of visualizing the molecules. However, few of these modes of learning incorporate the Theory of Multiple Intelligences (Gardner, 1983), which states that there is not one way to measure intelligence and that humans learn through a variety of methods based on their strongest modes of intelligence. Educators utilize this theory in designing curriculum in schools today, hoping to capture the greatest number of students’ interest by addressing a wide variety of learning strengths.

Therefore, a mobile application that is able to accommodate the widest variety of learning styles would be the most useful and transferable of all apps currently available to the student. In addition, the level of mastery by each student must also be addressed in an effective application. Just as students learn via different modes of learning, students also learn at different paces depending on a variety of factors, such as intrinsic/extrinsic motivation, as suggested by Bandura (1986), and engagement. So the application must also incorporate the learning theory of “scaffolded learning”, a theory introduced in the late 1950’s by Jerome Bruner (Bruner, 1986). This theory states that people learn new material best when sufficient support is provided when first introduced to the material (Wood, 1976). As familiarity and mastery increases, the support is gradually removed to increase independence and incorporation of the new material into the existing set of content and skills possessed by the student.

These two main theories informed the development of the mobile app TsoiChem© because of the prior research supporting these learning theories and that much of science education is based on these two premises. A secondary theory incorporated was that of immediate feedback (Gilmer, 1979) and misconceptions – the idea that the sooner the feedback is provided to a learner, the less permanent a misconception is rooted into knowledge. This allows the learner to deconstruct and reform a new perception based on the feedback received. When feedback is received days or even weeks later, it is more difficult for the learner to then go back and unroot an erroneous idea, replacing it with a modified version that better approximates the correct way of thinking.

Finally, two other learning theories were considered. The idea that people can be motivated by different factors, intrinsically and extrinsically, was a key factor in how the app “rewarded” users. Bandura postulated that people could change thinking and behavior patterns if motivated to do so. The source of the motivation can come from within (intrinsic) or outside the person (extrinsic). We harnessed these ideas while designing the app. We also looked into learning theories dealing with learners with special needs, especially those with attention or visual processing issues. Minskoff and Allsopp (2002) suggests that by using colors, bold divisions, and clean designs, students are more apt to pay attention and to comprehend given information when the page has “sections” and definite boundaries.

3.1 Selecting Appropriate Examples

The goal in creating this mobile application was to transfer the effectiveness of pen and paper practice methods to a portable digital device. Instead of just creating flash cards of functional groups (the traditional and most common method of learning this concept in organic chemistry), this app would provide multiple opportunities for students to learn functional groups in a purposeful way that incorporated several learning theories. By designing the application and selecting examples so as to address the common errors and areas of misconceptions students have in learning this topic, we believe the app was effective in helping students increase their conceptual understanding of functional groups.

As discussed in section 2.2, the first area of concern in the students’ learning was enabling them to recognize functional groups in a variety of formats. Therefore, we created problems that represented all functional groups in a variety of formats. Each functional group was shown in both line-bond format and condensed format, multiple times for both. But we also included several examples where a functional group was nested in a molecule containing several other functional groups. Many times molecules contain several groups and unlike the traditional “memorization chart” in textbooks, test questions commonly require students to find multiple functional groups within a molecular structure. These problems would give students adequate practice in doing so.

Another common area of error was addressed through multiple formatted problems. The app provided a variety of molecules in which a specific functional group was located. The “R”, or rest of the molecule, varied between each problem. In addition, the R in some problems was purposefully chosen to sometimes approximate that of other problems. For example, several problems had ring structures attached in order to show students that a ring does not necessarily equate to the benzene functional group.

3.2 App Design and Features

Another main area of concern was the fact that students struggle with identifying all the parts of a functional group. Especially when the group is presented in condensed format and the bonds are not drawn out, students sometimes miss the idea that there is a double bond or a connection between atoms that is not clearly shown. In order to address this, we harnessed the touch-screen capability of the Apple© iPod Touch. Students are asked to touch each atom and each bond (if shown) that they think are included in the requested functional group. Moreover, the app does not let the student continue to the next step until all the parts of the functional group have been identified and touched (shown by a change in color). Through this haptic action, students would be able to address one of the three areas of common errors: learn exactly what atoms/parts formed the structure of various functional groups. In Figure 1 the corner carbon atom (implied), the double bond and the oxygen each need to be highlighted individually by the user to identify functional group Ketone.
The fact that the app does not allow the student to continue unless all the parts are highlighted is an example of how we incorporated the misconception/feedback theory of learning. We found that students initially got frustrated when the screen did not change after they believed they located all the parts of the functional group. Often, they felt the app was “broken” or not working properly. Only until they happened to discover the missing part or parts and highlighted them did the screen change. Immediately, they were able to determine that their previous understanding of the functional group’s makeup was incorrect. This immediate feedback assisted them in correcting previously held misconceptions and informed them of the correct number of parts of the functional group. With TsoiChem©, students are prevented from repeating an error because the app stays on the same screen until the correct parts are identified, thus stopping the misconception from perpetuating in the learner’s mind.

This application has three modes. Unlike other apps that simply provide “easy”, “medium” or “difficult” levels, we modeled these modes after the theory of scaffolded learning discussed in section 2.3. After launching the application, the user can select from “Practice It”, “Name It” or “Find It” modes.

The purpose of the “Practice It” mode is to help the user identify all the components of a functional group, identify the functional groups in their various forms, and begin to associate the visual representations with the name. In this mode, the user is provided with an example, randomly chosen by the application, and then the user is asked to touch and thus highlight the atoms and bonds that form a functional group. When all the components of a functional group are identified, the name of that functional group is displayed and an audio clip pronounces the category of functional group to the user, providing the most “scaffolding” and relating well to multiple learning styles of users.

The “Name It” mode is designed to help the user self-assess and review the concepts practiced in the “Practice It” mode. The “scaffold” of providing the name for the user is removed in this mode. Hence, in the “Name It” mode the user is once again provided with a randomly chosen example and once again has to highlight atoms and bonds that form the functional group. When all the components are highlighted, the user must select the correct name of the identified functional groups from four name choices, as shown in Figure 2.

It is not expected that the student is able to fully identify the functional group without some guidance at this point. Therefore, it was important to limit the list from which the user could choose so as to not overwhelm. The user gets three chances to correctly specify the name of the identified functional groups. Humor is employed as an extrinsic motivator, as three wrong answers result in the friendly avatar being blown up by the exploding beaker. Studies have shown that humor (Bryant & Zillmann, 1989) can be effective in easing the tension of learning and to help students retain information. Also, motivating the learner to continue playing the app was an important design concept in this mode. Students can feel negatively when corrected and perhaps choose to stop the app due to these negative feelings. In order to mitigate this possibility,
the app turns the consequence of the error onto the hapless avatar and makes it “suffer” the consequences in an exaggerated way. Many students laughed when they saw this unexpected outcome of their error as shown in the Figure 3.

The third and final mode, the “Find It” mode is the least scaffolded form of practice; there is no guidance as to the association between functional group and name. Several structures are shown on the screen. The user is asked to locate those that contain a given functional group and “drag” those examples into a “beaker”, as shown in 4. The beaker displays a counter that updates as the examples are dropped in it. Once all the examples have been correctly identified the user can move to the next functional group. As in the other modes, the examples in this mode are also randomly chosen and multiple formats of each functional group are displayed to address the main areas of error for students. If incorrect examples are dropped in the bin, they “snap back” to their original position—just enough feedback to show the user that the choice was incorrect, but not so negatively as to impact user motivation to try again. If any of the examples are placed anywhere else on the screen they also snap back to their original position. In this mode, the user must be able to accomplish the three goals of functional group recognition: identify ALL parts of a functional group, identify the functional group in a variety of forms, and associate the functional group with its correct name—all with no “scaffolding” or guidance from the app.

A scoring feature was added into the design during the second version of this app. This was also to increase student motivation through an extrinsic source—a score. Common in video games, the score sometimes motivates users to continue using the game. The score was also an area of feedback for the software development students and the instructors: because wrong answers deducted points from the total score, a user’s score could be deduced as a general approximation of mastery. One of our future directions is to analyze students’ scores on the TsoiChem© app and perhaps examine any possible connections to the students’ scores on the class exam on functional groups.

The application also provides audio feedback for all the examples in all the modes, along with visual feedback. The three modes are brightly colored with different color schemes to help the user differentiate between the decreasing stages of scaffolding provided. The screen “real-estate” was partitioned purposefully so as to maximize the screen space, allowing the structures and text to be as clear as possible, and to clearly partition sections of the screen. This was designed with the learners with special needs in mind; fewer distractions may mean that a learner will more likely engage with the app and be able to complete it successfully.

The TsoiChem© application includes an interactive tutorial. After reading or listening to directions for using the app, the user can choose to try an example. The example is similar to what they may see in the other modes. The difference is that in the interactive tutorial mode the individual components keep flashing one at a time and the user is directed to tap
and highlight it. Once the user highlights the component the next component starts flashing and directs user to tap, so on and so forth. The user can practice this multiple times. These aspects were added to decrease frustration and to provide users with tools to self-help as they encountered misconceptions or errors in their thinking but were unable to adequately discover the correct answer. By allowing the user several ways to get “unstuck”, we hoped to decrease frustration and increase motivation to continue playing TsoiChem©.

In summary, the design of the app was purposeful and mindful. We strived to incorporate as much learning theory as possible in order to best address the learning needs of organic chemistry students in understanding functional groups. As well, our past experience with the common areas of trouble for these students helped inform the design of the app and helped us create unique methods for targeting these trouble spots. We then looked to the usability testing phase of the software development cycle and general student performance on a pre- and post-quiz to determine what effect these interventions had on student opinions about the app and student performance on the identification of functional groups.

3.3 Implementation

The students enrolled in Software Development II course developed this application. The initial details of this project are discussed in Dekhane and Tsoi (2010). The iOS SDK was used to create this application. The user interface was designed using Interface Builder. Xcode was used as the development environment. This environment allows the user to test the application on an iPhone simulator. The application was also later tested on Apple iPod Touch devices. Xcode also supports software configuration management. A central Subversion repository was created on Assembla© (Assembla, 2011) and configured in Xcode for controlling the source code. Information on the technical details about the platform used by the students and the software tools mentioned in this section can be found on Apple’s website (“iOS Development Center,” 2011). The website also provides guidelines on creating a user interface (“iOS Developer Library,” 2011), preparing your app for submission to app store, and the approval process.

The images for this application were created using the software GIMP© (GIMP, 2011) and the audio feedback clips were created using the program Audacity© (Audacity, 2011).

3.4 Usability Testing

Testing the TsoiChem© product on actual devices was important in this case, to get an authentic touch screen experience. To be able to test the application on devices, we took advantage of Apple’s University Program, which allows up to 200 devices to be used for testing.

We conducted usability testing of the TsoiChem© application with several class sections of organic chemistry students over the course of three semesters. The students were given the device and left to explore the application individually, while the student software developers noted their own observations of how the app was used. These chemistry participants were also given pre- and post- surveys to complete to add to the data collected.
Pilot Study Results from Spring 2010

During the first semester of usability testing (Spring 2010), a pilot study with 12 participants was conducted. The average participant was 21 years of age. The other demographics were: 80% of the participants were female and 20% male, 80% of our participants expressed that they preferred interactive games as a way of learning, 60% had regular access to smart phones and 50% had access to either an iPhone or iPod Touch device. The main feedback that we received from this first round of usability testing indicated that the application was lacking proper instructions on its usage; several participants suggested that the app could benefit from either a tutorial or a help section. Many of our users did not know what to do with the examples. They did not realize that as the examples got bigger, they could zoom in and scroll and as the examples got more complex, they had to identify all the functional groups before moving on to the next example. However, all the participants expressed that the application was a great tool for studying functional groups and would be more useful with an introductory tutorial. Hence, a static tutorial was included in the next version of the app, which was then enhanced by adding an interactive component in the third version of the app. These developments were previously described in detail in section 3.2.

We also gathered feedback about the effectiveness of this application as a learning tool at our institution’s annual research exposition in Spring 2010 as part of our pilot study. These 30 participants, with a wide range of chemistry backgrounds, were given the devices and encouraged to explore the TsoiChem© application and then given a survey to complete. The results of this survey were similar to the usability testing survey results from the original 12 pilot students. The expo participants had positive feelings towards smart phones and believed that the touch-screen feature of the TsoiChem© application was extremely useful for practicing functional groups. Several suggested adding a tutorial, adding more examples and sound and including other chemistry areas to this application. As a result of this round of feedback, Help and Hint buttons were added, a tutorial for each mode was added and audio feedback was added to the application.

The positive results of the pilot study indicated that the basic idea behind the app was well received by our target audience. The pilot study also pointed out some important concerns that were then addressed in Fall 2010 and Spring 2011.

Usability Testing Results: Fall 2010-Spring 2011

A more detailed study was conducted in Fall 2010 and Spring 2011. The usability testing was conducted at the end of each semester. In the pre-survey, students were asked questions about their previous mobile device experience, their awareness of the TsoiChem© app and their confidence in identifying functional groups. The results are tabulated below.

Table 1 Pre-Survey Statistics

<table>
<thead>
<tr>
<th>Term</th>
<th>Number of Participants</th>
<th>Used an iPhone/iPod Touch before</th>
<th>Aware of TsoiChem© app</th>
<th>Methods of studying: Flashcards</th>
<th>Methods of studying: Textbook</th>
<th>Used educational software before</th>
</tr>
</thead>
</table>
More than half had previous experience with an Apple mobile device and were aware of TsoiChem©. When asked about methods of studying, the top two results for both semesters were flashcards and textbook. Previous use of educational software differed between the two semesters, however. But both groups, on average, agreed that educational software was helpful.

In the pre-survey we asked students to rate their familiarity with Apple iPhone/iPod Touch on a scale of 1-4, 1 being least familiar and 4 being most familiar. We also asked the students to rate their confidence in identifying functional groups on a scale of 1-5, 1 being least confident and 5 being most. The results of the pre-survey are shown below in Figure 5.

![Usability Testing Pre Survey](image)

**Figure 5 Familiarity and Confidence**

In the post survey, we asked the organic chemistry students to rate statements about the different features of the mobile application on a scale of 1-5, 1 being strongly disagree and 5 being strongly agree with the given statement. On average, the app was perceived as user-friendly and was not impacted by the differences in student familiarity with Apple iPhones prior to using the app.

<table>
<thead>
<tr>
<th>Term</th>
<th>Familiarity with iPhone/iPod Touch rating</th>
<th>Ease of use</th>
<th>Didn’t have to use tutorial</th>
<th>Zoomed in</th>
<th>Scrolled</th>
<th>Will use this app</th>
<th>Will recommend this app to others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2010</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>3.88</td>
<td>4.12</td>
<td>4.12</td>
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<td>4.10</td>
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</table>
The students’ confidence in identifying functional groups before using the app also did not affect their perception of the app’s usefulness, as shown by the high average rating on this domain.

Table 3 Effect of confidence in identifying functional groups on usefulness of the app

<table>
<thead>
<tr>
<th>Term</th>
<th>Confidence in identifying functional groups rating</th>
<th>Highlighting individual components helped in learning</th>
<th>Various game modes helped identify functional groups in different forms</th>
<th>Will use this app</th>
<th>Will recommend this app to others</th>
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<td>4</td>
<td>4.33</td>
<td>4.67</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>-</td>
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</tbody>
</table>

Figure 6 below shows the average rating of students for some of the questions on a scale of 1-5, 1 being strongly disagree and 5 being strongly agree with the given statement.
The student response to the usability testing was positive in both the semesters and even better in Spring 2011. The average ratings for questions, “Will you use the app for studying?” and “Will you recommend the app to others?” were very high. Average ratings for other questions related to ease of use and usefulness of various features were also high.

The standard deviation of the same data is as shown in Figure 7. The bars representing standard deviation in Spring 2011 are lower than those in Fall 2010 on all survey questions except for one. This indicates that the variability of student responses was lower in the more recent data collection. The feedback gathered from usability testing in Fall 2010 was used to enhance the app; thus the lower standard deviation in Spring 2011 may indicate that users perceived the design changes favorably. This is corroborated by the results of the t-test analysis of the average usability scores in both semesters.

The overall average usability of the app on a scale of 0-2 in Fall 2010 was 1.52, while in Spring 2011 it was 1.9, once again indicating that the enhancements to the app were well received by the students in Spring 2011.
The post surveys also included open-ended questions. Some themes emerged from these responses. The following two tables summarize the strengths and weaknesses cited:

### Table 4 Strengths of the App

<table>
<thead>
<tr>
<th>Strengths Cited by Users</th>
<th>Design Aspect Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Usability</strong></td>
<td></td>
</tr>
<tr>
<td>• interactive</td>
<td>o  haptic learning</td>
</tr>
<tr>
<td>• easy</td>
<td>o  multiple intelligences</td>
</tr>
<tr>
<td>• touch and drag</td>
<td>o  scaffolded learning</td>
</tr>
<tr>
<td>• audio feedback</td>
<td></td>
</tr>
<tr>
<td>• animations</td>
<td></td>
</tr>
<tr>
<td>• variety of modes</td>
<td></td>
</tr>
<tr>
<td><strong>Pedagogical</strong></td>
<td></td>
</tr>
<tr>
<td>• different ways of learning</td>
<td>o  multiple intelligences</td>
</tr>
<tr>
<td>• helpful tutorials</td>
<td>o  decrease user frustration</td>
</tr>
<tr>
<td>• ability to break molecules into functional groups</td>
<td>o  student misconception</td>
</tr>
<tr>
<td>• varying complexities</td>
<td>o  scaffolded learning</td>
</tr>
<tr>
<td>• name matching</td>
<td>o  immediate feedback and misconceptions</td>
</tr>
<tr>
<td>• immediate feedback</td>
<td>o  multiple examples</td>
</tr>
<tr>
<td>• repetition</td>
<td></td>
</tr>
<tr>
<td>• having to touch every part of the functional groups</td>
<td></td>
</tr>
<tr>
<td>• helpful hints</td>
<td></td>
</tr>
</tbody>
</table>
Table 5 Weaknesses of the App

<table>
<thead>
<tr>
<th></th>
<th>Weaknesses Cited by Users</th>
<th>Design Aspects Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability</td>
<td>• hard to highlight in some examples</td>
<td>o Technical - Programming needs to expand touchable area</td>
</tr>
<tr>
<td></td>
<td>• annoying sound after using for some time</td>
<td>o Multiple Intelligences</td>
</tr>
<tr>
<td></td>
<td>• unclear instructions in “Find It” mode regarding use</td>
<td>o Scaffolded Learning – more instruction in Find It mode</td>
</tr>
<tr>
<td>Pedagogical</td>
<td>• repetition</td>
<td>o Multiple examples / motivation – need more variety in examples</td>
</tr>
<tr>
<td></td>
<td>• endless testing</td>
<td>o Motivation – need more areas of motivation to prevent feeling of “endless”</td>
</tr>
<tr>
<td></td>
<td>• complex molecules were difficult and too large in size</td>
<td>o Multiple examples – more variation in difficulty / easiness</td>
</tr>
</tbody>
</table>

Following were the most recommended changes:
• More examples in the Find It mode
• More functional groups
• App for “synthesis”, “nomenclature” and “reactions”
• Android and BlackBerry versions
• More assistance
• Difficulty levels

It is interesting to note in these results that repetition emerged as a strength as well as weakness. This was due to the fact that the Practice It and Name It modes had more examples in the beginning, while Find It mode had fewer examples, but randomized grouping of examples in an endless loop. While the students appreciated many pedagogical advantages of this app, they also pointed out some glaring issues related to difficulty in selecting molecules by touching the screen without zooming in on big examples and lack of instruction in the app. Students also complained about the sound when they had already gone through a few examples and didn’t need the instructions. As we observed the chemistry students during usability testing we realized that some of them did not try the tutorial at all, while some looked at just one tutorial instead of all three and hence had a problem in the third mode. Based on this feedback we altered the design of the app to make the tutorial button more distinct and changed the tutorial from static to interactive. Based on student feedback sound was also added to the app along with the ability to turn it ON or OFF.

Summary of Usability Testing Results
The results presented in section 3.4 indicate that irrespective of students’ background, their familiarity with touch screen devices or their confidence in identifying functional
groups they perceived this app as user-friendly, useful for their learning of functional groups and worth recommending to other students.

The usability testing was very important in identifying the problem areas of the app. While overall the students responded very favorably to the app and reported that the touch screen experience was useful to their learning, they did report some issues related to having difficulty in selecting the molecules and pointed out the lack of instruction. These issues were addressed in the later versions of the app by introducing interactive tutorials and helpful hints. They also did not favor the endless testing in the Find It mode, which was modified in the later version. Hence, the Spring 2011 results were better than the Fall 2010 results. The overall usability of the app also improved significantly in Spring 2011.

3.5 Evaluation of TsoiChem© on Conceptual Understanding

Finally, we conducted preliminary work on testing the effectiveness of Tsoi Chem© on users’ understanding and identification of functional groups. We chose 20 structures that provided a good representation of all the functional groups in different formats and printed them onto a paper-based quiz with instructions to circle and then name all functional groups present. Then students currently enrolled in Organic Chemistry were asked to voluntarily participate in the study by taking the quiz before and after playing the TsoiChem© app on the Apple© iPod Touch device. We were able to collect data from 55 students; the quizzes were then scored based on a point system. The students received 2 points for a functional group if it was circled and named correctly, 1 point if it was only circled (or circled but named incorrectly), and 0 points if it was neither circled nor named correctly. Then we ran a t-test analysis on the pre- and post-quiz scores and determined that they differed significantly (p<0.00001). These results indicate that our testing of the app’s effectiveness has high internal validity. The app’s long-term effects need to be evaluated. Hence, our future directions includes examining the retention of the functional group identification skills over time and looking at which functional groups pose more problems than others as students use the TsoiChem© app to learn this concept.

4. CONCLUSION AND FUTURE DIRECTION

The popularity, portability, ease of use and the advanced multi-touch features of mobile devices can be leveraged to create an engaging mobile application, as was shown in our design of TsoiChem©. The incorporation of educational learning theories into that design seems to have had a positive impact on users’ attitudes towards using the app and their perception of its usefulness. TsoiChem©’s user-friendliness improved as subsequent design changes incorporated user feedback gathered over three semesters. This result was not affected by users’ prior confidence in identifying functional groups or prior familiarity with the device. As well, free-response statements pointed to the numerous design aspects that we purposefully placed in TsoiChem©, signifying further that the incorporation of learning theories and consideration of student learning needs were well-met. The weaknesses of the app pointed to further design changes centering on those same aspects; this means that we indeed did address the major areas of need for students. Preliminary
pre- and post-quiz data indicates that for short-term learning, the app does significantly increase students’ content understanding of functional group identification.

At the same time it is important to discuss that the constantly changing features of the iOS platform can be a challenge for developers. During two semesters, the Mac OS, which was used for development, was updated once, the Apple iPhone OS and the SDK were updated multiple times, and the University Program license agreement was updated multiple times and required administrative approval from our institution. These updates can cause some delays and compatibility issues, such as having to update all the testing devices with the latest OS. These frustrations had an impact on the software development students and their workflow.

When this project was conceived, Apple’s iPhone and iPod Touch were the only touch screen devices. The availability of Android phones has expanded the market and hence opportunities for the development and dissemination of such applications are plenty. The entry of Apple’s iPad in the mobile device market is also a possible future development. With its bigger screen, the iPad provides an excellent platform to create innovative games and apps that make use of its larger landscape to continue increasing student content understanding. Advancements in mobile technology can benefit our students and change the way they learn, especially when learning needs and learning theories come together and are thoughtfully integrated together during the software development cycle of mobile applications. We look forward to exploring these new areas while continuing to upgrade and improve upon the TsoiChem© mobile application for student use.

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BIOGRAPHY

Sonal Dekhane, Ph.D. is an Assistant Professor of Information Technology at Georgia Gwinnett College. Dr. Dekhane’s interests lie in the areas of data mining, software engineering, mobile application development and software engineering education research. Her research has been presented at various national and international conferences including International Conference on Data Mining, International Conference on Frontiers in Education: Computer Science and Computer Engineering and IADIS International Conference on Mobile Learning. She is involved in curriculum development and program assessment initiatives at GGC and her work with the co-author recently garnered the Technology Association of Georgia’s Excalibur Award for 2011.

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REFERENCES


Pennington, R., Pursell, D., Sloop, J. (2010). Engaging science students with wireless technology and applications by re-visiting the Thayer Method of teaching and learning.


