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Learning Theory Guided Iterative Development of a Mobile Learning Paradigm Aimed at Enhancing Organic Chemistry Laboratory Instruction at Undergraduate Level

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Learning Theory Guided Iterative Development of a Mobile Learning Paradigm Aimed at Enhancing Organic Chemistry Laboratory Instruction at Undergraduate Level

A Thesis submitted in partial satisfaction of the requirements for the degree of Master of Science

in

Chemistry

by

Song Wang

Committee in charge:

Haim Weizman, Chair
Thomas Bussey
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2017
The Thesis of Song Wang is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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Chair

University of California, San Diego

2017
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ABSTRACT OF THE THESIS

Learning Theory Guided Iterative Development of a Mobile Learning Paradigm Aimed at Enhancing Organic Chemistry Laboratory Instruction at Undergraduate Level

by

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Master of Science in Chemistry

University of California, San Diego, 2017

Haim Weizman, Chair

Helping students achieve meaningful learning effectively in large-enrollment, introductory organic chemistry laboratory course can be a difficult task. Due to the abstract nature of the subject and the limited laboratory time available to students, it can be difficult for some to understand the connection between the observed physical properties and the molecular structures. Since understanding the relationship between structure and properties is imperative for manipulating or purifying compounds in
organic laboratory, a smartphone based learning paradigm, “OChem Lab”, was developed aiming to help students bridge their knowledge. Using organic extraction as an entry point, the application was designed with the theory of retrieval-based learning in mind and incorporated formative feedback after several iterations. It was introduced to students who are enrolled in an introductory organic chemistry laboratory course as an tool to facilitate learning. The goal of the study was not to simply determine the usefulness of a given mobile learning paradigm, but to develop and improve a theoretical framework for designing and implementing mobile learning paradigm for a large-enrollment introductory organic chemistry laboratory course. Student usage and their perception of the application were assessed both quantitatively and qualitatively in order to incorporate student feedback in the iterative development process of the application. This study describes the development and refinement of a theoretical framework for designing and implementing a mobile learning paradigm to supplement an undergraduate organic chemistry instructional laboratory class, as well as the iterative development process of the mobile application under such framework.
CHAPTER ONE: INTRODUCTION

1.1 Challenge in Organic Chemistry Laboratory Instruction

As Novak’s theory of education notes, "meaningful learning underlies the constructive integration of thinking, feeling, and acting, leading to human empowerment of commitment and responsibility" (Bretz, 2001). Facilitating meaningful learning in instructional laboratory classes is instrumental to a chemistry student’s education as these classes both help the student familiarize with various techniques used in chemistry research and further the student’s understanding of how the submicroscopic interactions on molecular level explains the macroscopic observed phenomena. For example, students studying distillation must not only think about how molecular structure influence boiling points, but also conduct experiments which allow them to connect the abstract concepts with concrete observations and their application to daily lives (e.g. how fractional distillation is used in the oil industry). In addition, meaningful learning has often been mentioned in contrast to rote learning; whereas rote learning is considered brittle and transient, meaningful learning is thought to be robust and enduring (Karpicke & Grimaldi, 2012). Engaging in meaningful learning requires active processing, where the learner integrate knowledge and experience to form a clear, deep understanding of content and process (Mayer & Moreno, 2003). If students fully understand a field of knowledge, they will be able to transfer the information from one process and apply it to another and see the relationship between the two(Supasorna, Suits, Jonesb, & Vibuljanc, 2008). Thus, meaningful learning is thought to produce organized, coherent, and integrated mental models that allow people to make inference and apply knowledge (Karpicke & Grimaldi, 2012).
However, facilitating meaningful learning in large-enrollment introductory organic laboratory classes can be challenging. There is considerable intrinsic cognitive load associated with being in a laboratory setting itself. The pure samples of substances, which are already an abstraction from real life material, seem commonplace in the laboratory but are rarely found in a student’s daily venture. Students in a laboratory course are essentially asked to explain a physical experience with an abstract mental model, while both of which seem disconnected from daily life and from each other. In addition to the intrinsic challenge of facilitating meaningful learning in large-enrollment introductory organic chemistry laboratory classes, the resources in these courses are often stretched thin; students only have access to laboratory space for a limited time per week while having to finish work required in the lab manual. As a result, many students report that when under the stress of time constraint, it is difficult for them to think about the underlying chemistry while performing lab work simultaneously. Some report that during the experiment they would follow the lab manual step by step mindlessly and behave more “like a worker trying to get things done”, struggling to actively absorb the chemistry principles behind the experiments.

1.2 Organic Extraction as a Starting Focus

In an undergraduate introductory organic laboratory course, one of the most common activities is liquid-liquid extraction, where students are instructed to complete a series of acid-base extractions to isolate and purify a sample containing a mixture of organic compounds. Organic extraction is one of the most frequently used techniques in organic chemistry laboratory, therefore it is often introduced to students early in their organic laboratory course. Although the technique of acid-base extraction is simple
enough for a novice to master in a short amount of time, the underlying chemistry principles can prove challenging to grasp. Students must construct a complete and accurate mental model at the molecular level of what happens during extraction and properly connect the mental model with experimental observations to fully understand organic extraction. However, the solvents and solutes used in organic extraction are mostly colorless, so the lack of visually observable changes in the process of organic extraction impairs students’ ability to link their mental models with the experimental procedures, causing cognitive dissonance in students as the consistency between theory and observation is not visually pronounced. Thus, confused students often resort to mindlessly following the manual while performing organic extraction in order to finish required lab work in time, resulting in little meaningful learning.

### 1.3 Ripe Environment for Experimenting with Mobile Learning

As an attempt to facilitate more meaningful learning in an introductory organic chemistry instructional laboratory course, a blended learning approach (Güzer & Caner, 2014), where a mobile pedagogy was designed to complement traditional face-to-face laboratory meetings, was explored. The rise in smart phone popularity among college students has offered opportunity for developing both formal and informal learning paradigms. The continually increasing functionality, the convenience size, and the expanding connectivity of smartphones can afford educators to design more complex and personal learning aids for students to carry around with them easily. Due to the advantages of smartphones, research on mobile learning has been gaining popularity in recent years; a past study suggests that an overwhelming 88% of the population were interested in using mobile phones for learning purposes (Alrasheedi & FernandoCapretz,
Although smartphones and other mobile devices are increasingly incorporated into educational settings and educational researchers have been conducting more and more studies on mobile learning, mobile learning paradigms are still underutilized in higher education chemistry instruction. In a recent meta-analysis study, researchers offered a comprehensive analysis of studies on mobile learning from the year 2000 and forward. Out of the 49 articles selected for the analysis, only one article is about chemistry instruction in higher education (Crompton, Burke, Gregory, & Grabe, 2016). The lack of research indicates that there is still much to learn about incorporating mobile learning in higher education chemistry instruction.

1.4 Research Objectives of This Study

This design-based research study details the iterative development process of a mobile learning paradigm aimed at improving large-enrollment undergraduate introductory organic chemistry laboratory and the evolution of its guiding design principles. The goal of the study is not to merely evaluate the effectiveness of a certain learning paradigm, but to iteratively develop a mobile learning paradigm that incorporates a set of design principles that can be improved based on students’ needs and feedback. The novel mobile learning paradigm will be tuned through the design-based research and possibly lead to general design principles that other educators can use for developing similar interventions.
CHAPTER TWO: REVIEW OF LITERATURE

2.1 The Chemistry Triangle

The notion proposed by Johnstone that there are three levels of chemical knowledge, macroscopic, submicroscopic, and symbolic, has been highly influential and productive in the field of chemical education. Johnstone argued that the nature of chemistry “exists in three forms which can be thought of as corners of a triangle” where “no one form is superior to another, but each one complements another”. He also suggested that “These forms of the subject are (a) the macro and tangible: what can be seen, touched and smelt; (b) the submicro: atoms, molecules, ions and structures; and (c) the representational: symbols, formulae, equations, molarity, mathematical manipulation and graphs” (Figure 1) (Johnstone, 2000). The chemistry triangle theory has important educational implications: the nature of chemistry as a subject is complex because it involves two distinct levels of formal concepts that need to be related to each other and to observed phenomena, and it is communicated not only through technical vocabulary but also in terms of a whole range of other symbolic forms of representation (Taber, 2013).
Figure 1: The Chemistry Triangle. Understanding chemistry involves not only the ability to explain a set of macroscopic concepts with submicroscopic concepts using specialized technical vocabulary and other formal symbolic representations, but also the ability to connect both levels of conceptualization with experiential chemical phenomena. (Taber, 2013)

In the context of organic laboratory instruction, in order to achieve meaningful learning, the learner must not only be able to explain macroscopic physical properties of organic substances in terms of the submicroscopic properties of their molecular structures using symbolic representation (i.e. structural formula), but also be able to connect the explanation to observations made in lab. The novice student, however, will struggle to
cope with learning activities which flits back and forth between the observed phenomena and the formal conceptual categories at the macroscopic level, and the formal theoretical models at the submicroscopic level, especially when drawing upon technical vocabulary, various formulae, equations and other formalisms (Taber, 2013). For example, for a learner to fully understand the process of organic extraction, the learner must not only be able to explain a compound’s polarity in terms of functional groups in its molecular structure, but also be able to connect this explanation with experience of tracking a target molecule when performing extraction in the lab (i.e. observation of different solubility). However, moving between the two levels of understanding and connecting them with experimental procedure and observation can be challenging for novice students, since they have trouble visualizing or imagining what is happening at the molecular level when they conduct each extraction step (Supasorna, Suits, Jonesb, & Vibuljanc, 2008). The lack of conceptual understanding can be detrimental to a chemistry student’s development, as it has been cited as perhaps one of the more influential factors contributing to the disparate patterns of student performance (Szu, et al., 2011).

### 2.2 Mobile Learning

Traditional chemistry lectures have limited ability to facilitate understanding at molecular level. Computer-based technology can help students develop their understanding more readily because these multimedia visualization tools can provide links to the concepts at the submicroscopic level (Russell, et al., 1997). For example, computer simulations can illustrate chemical processes with molecular features that cannot be observed in a hands-on activity (Woodfield, et al., 2004). Simulated experiments where processes are modeled at the molecular level can help students
understand chemistry concepts better while improving their ability to construct dynamic mental models, develop conceptual understanding about particulate phenomena, and develop their own scientific creativity (Supasorna, Suits, Jonesb, & Vibuljanc, 2008). As computing technology advanced in the past two decades, the computing power of mobile communication devices has been increasing rapidly while the price of those devices has been declining steadily. As a result of the exponential growth in the development of mobile computing, computing power that was once associated with desktop computers can now be realized on smartphones that fits the user’s pocket. As students and teachers are already spending a lot of time on smartphones, mobile applications can now serve as powerful and convenient educational tools on mobile platform, transforming the landscape of chemical education with interactive touch screen display (Huang, 2015). With a multimedia tool that is accessible anywhere, anytime, it follows that educators are considering the possibility of harnessing this avenue to impact student learning inside and outside the classroom (Dekhane & Tsoi, 2012). Mobile learning is characterized by learner’s mobility, the possibility of having localized data and information, the large amount of data that can be collected during a learning session, the affordance provided by the technologies, and the social dynamic that characterize the context in which learning takes place (Fulantelli, Taibi, & Arrigo, 2015). The interactive display of a touch screen smartphone can allow us to simulate the events in the laboratory while reduce the extraneous tasks associated with working in a real laboratory under time constraint; in addition, the ability to display both a simulation of the real world and the submicroscopic representation of the molecules can potentially help students bridge the different levels of understanding.
In the context of utilizing functions unique to smartphone technology, educational applications can be broadly divided into two categories: “replicant” type applications, which seek to replicate learning activities that can and do take place in other domains, and “extender” type applications, which, in contrast, seek to enhance or supplement the existing learning experience in ways only possible through mobile application technology (McLain, 2014). For example, flashcard applications are typical “replicant” type applications, since these applications are designed only to replicate the existing learning experience offered by paper flashcards, while “extender” type applications such as experiment simulations that utilize features unique to smartphone technology such as the interactive display to show chemical reactions on both macroscale and molecular level are designed to enhance the existing learning activity of conducting experiment by providing visualization on molecular level. Although the design of “replicant” type applications can be as effective in helping students satisfy learning needs as the learning activities they replicate, the design of “extender” type applications holds more research value as they aim not to replicate existing learning activities but to innovate and potentially transform the existing learning experience to facilitate more meaningful learning. Past studies have also emphasized that mobile applications should focus on short, defined goals or tasks to be more effective at capturing the interest of the users, and they should be used as an enhancement to current learning environment instead of the only way that the lesson is delivered (Dekhane & Tsoi, 2012).

2.3 Learning Theories

Mobile learning paradigms as supplemental learning activities offer students the advantage of being able to engage in learning at their own preferred time without location
constraints (Seery & O’Connor, 2015). In addition to the pedagogical basis, effective mobile learning paradigm design should also take the research in cognitive science into consideration. For decades, researchers in cognitive psychology have made arguments on both logical and empirical grounds that people do not reproduce past experience verbatim at the time of retrieval, and that attempting retrieval early in the process of learning, even before a person would be able to successfully recall desired knowledge, will help the learner encode knowledge during studying by helping them create a search set into which new knowledge can be incorporated (Karpicke & Grimaldi, 2012). Additionally, the theory of immediate feedback is also appropriate for the context of mobile learning as smartphones can provide feedback more readily than in-class quizzes which could take days before feedback is provided. The theory notes that feedback allows the learner to deconstruct and reform a new perception based on the feedback received, and the sooner the feedback is provided to the learner, the less permanently a misconception is rooted in knowledge; when feedback is received days or even weeks later, it is more difficult for the learner to modify or replace the already established erroneous idea (Dekhane & Tsoi, 2012). In addition, cognitive load theory must also be taken into consideration when introducing learning theories into mobile learning instructional design. Cognitive load theory provides a basis for how learners receive and process new information, and purports that during any given learning event, there is a maximum capacity that learners can process, i.e. working memory capacity, which is governed by three types of load: the intrinsic load, which is associated with the difficulty of the learning material; the extraneous load, which is associated with the effort to extract information from the learning material; and finally the germane load, which is associated with the effort to
process new information and integrate it into long-term memory (Seery & O’Connor, 2015). Therefore, effective mobile learning paradigm design should utilize the advantages afforded by smartphone technology to manage the intrinsic and extraneous load in order to maximize working memory capacity available for the germane load in order to help facilitate meaningful learning. The theory of “scaffolding learning”, one states that people learn new material best when sufficient support is provided when first introduced to the new material (Wood, Bruner, & Ross, 1976), can be applied to manage the intrinsic cognitive load along with the theory of retrieval learning and immediate feedback.

2.4 Mobile Application Usability Engineering

Since mobile applications are often used when learner was also performing additional tasks such as walking, reducing the extraneous cognitive load through usability engineering is also instrumental to maximizing learning. The PACMAD (People At the Center of Mobile Application Development) usability model was proposed by Harrison et al. to address the limitations of current usability models when applied to mobile technology. The PACMAD usability model identifies three factors that affect the overall usability of a mobile application: user, task, and context, as well as seven attributes that reflect the usability of a mobile application: effectiveness, efficiency, satisfaction, learnability, memorability, errors, and cognitive load (Harrison, Flood, & Duce, 2013). Broadly speaking, mobile application design with high usability should enable users to accomplish their goal in the environment for which the mobile application is designed while also remaining easy and pleasant to use even after a period have passed. In the context of supplementing organic chemistry instructional laboratory course, to help
students achieve meaningful learning, mobile applications should be designed to utilize the interactive display to help students link their molecular mental models with observed laboratory phenomena through proper visualization of both the molecular representation and the observed phenomena while remaining intuitive and pleasant to use. Previous studies on mobile learning have focused predominantly on effectiveness rather than design, which failed to recognize technology as a process rather than an artifact, resulting in little systematic advice for the practitioner; a new approach to mobile learning research, one that is grounded in the design of the technology and directed by values and principles, must be pursued (Amiel & Reeves, 2008).

2.5 Design-based Research

Design-based research has been receiving increasing attention from education researchers as a potentially more advantageous research framework. The general framework of design-based research involves addressing complex problems in real contexts in collaboration with practitioners, integrating known and hypothetical design principles with technological advances to render plausible solutions to these complex problems, conducting rigorous and reflective inquiry to test and refine innovative learning environments, and finally producing new design principles (Reeves, 2006).

![Design-based research](image)

Figure 2: Design-based Research (Amiel & Reeves, 2008).
Design-based research provides a cycle that promotes the reflective foundation upon which researches that focus on long-term educational aims can be conducted. It recognizes and incorporates the iterative cycles of technology development into educational research. The goal of design-based research is to build a stronger connection between educational research and real world problems, so an emphasis is placed on an iterative research and development process that does not just evaluate an innovative product or intervention, but systematically attempts to refine the innovation while also producing design principles that can guide similar research and development endeavors (Amiel & Reeves, 2008).
CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Development of Mobile Learning Paradigm

After reviewing relevant literatures on mobile learning and assessing students’ learning needs, a concept for developing a mobile learning paradigm that mixes students’ learning needs with learning theories to enhance student learning outside of classroom in an introductory instructional organic chemistry laboratory class was conceived with a focus on organic extraction as a starting point. Aimed at utilizing the interactive display and Internet connectivity of smartphone technology to enhance current learning activity and help facilitate meaningful learning, the “extender” type mobile application incorporates the principles of retrieval learning while attempting to bridge the different levels of conceptualization. The mobile application was first developed for iOS platform to shorten development time and reduce development cost, as less testing is required for iOS applications since there are less variations in screen sizes and operating systems for iOS devices than Android devices. The mobile application was made available for download first through “Testflight” as a beta testing version, then through Apple App Store as a free application. A server was also constructed to store data on students’ interaction with the application such as student answers and submission times.

3.2 Research Questions

As mentioned before, design-based research is the predominant research framework used since the study sought to address problem in real classroom context in collaboration with instructors and to integrate research based design principles with mobile technology to develop plausible solutions. Since the mobile learning paradigm is
designed for accessing voluntarily outside of classroom, assessing and improving student engagement in the mobile application is also imperative to improving the effectiveness of the pedagogical design, since learning is only possible if students engage in the learning activity. After the development of a prototype, in order to drive the development of the mobile application and its guiding theoretical framework forward democratically with considerations from both published literature and student feedback, the following research questions were proposed:

1. How should the mobile learning paradigm design be improved in order to maximize meaningful learning?

2. How should the mobile learning paradigm design be improved in order to promote student engagement?

The mobile learning paradigm will improve as the guiding theoretical framework evolves with the exploration of these two questions in each cycle of iteration.

3.3 Data Collection Methods

The mobile application was introduced to students enrolled in one quarter Organic Chemistry laboratory course (CHEM 143A) as an optional learning aid for organic extraction. Since the application is only available on iOS platform, students without access to iOS devices are offered with opportunities to use the application on iOS devices provided by the author. Both quantitative and qualitative data were collected during the iterative development process to inform the updates and modifications made to the mobile learning paradigm and the guiding theoretical framework of its design. Student performance data such as students’ answers to the problems and times of submission
were recorded and uploaded to a server, then entered into SPSS software for further analysis. In addition to qualitative data recorded at the server, pre-test and post-test questions were also administered to students to collect quantitative data to assess the impact of the application on student test score. A survey containing 6-point Likert scale questions on student perception of the mobile application was administrated in order to also incorporate quantitative student feedback into the development process. Semi-structured student interviews were also conducted to assess student perception of the mobile application qualitatively. Student interviews were then transcribed to find reoccurring comments and suggestions. Both the survey and the interview protocol are included in the appendix.
CHAPTER FOUR: ITERATIVE DEVELOPMENT PROCESS

4.1 Prototype

4.1.1 OChemLab Prototype Design

Gaining an understanding of the principles behind acid-base extraction of organic compounds, namely the principles of solubility and acid-base chemistry, is essentially the learning need for organic extraction. As an attempt to manage the intrinsic cognitive load to achieve such learning need, the learning need of organic extraction is broken down into the following three levels of learning goals:

Level 1 Learning Goals:
- The student will be able to recall the relative polarity of various solvents.
- The student will be able to recall the general pH range of 10% HCl solution, 10% NaOH solution, and 10% NaHCO₃ solution.
- The student will be able to recall the general pKa of the following functional groups: amine, carboxylic acid, alcohol, aldehyde, phenol, and aromatic rings.

Level 2 Learning Goals:
- The student will be able to identify the following functional groups in the molecular structure of an organic compound: amine, amide, carboxylic acid, alcohol, aldehyde, phenol, and aromatic rings.
- The student will be able to classify an organic compound as polar or nonpolar based on the compound’s molecular structure.

Level 3 Learning Goals:
- Given a simulated aqueous-organic extraction under different pH conditions, the student will be able to apply the knowledge of pKa of different functional groups to determine the protonation state of organic compounds.

- The student will be able to use the principle of solubility to determine the solvent phase in which the majority of an organic compound will reside after extraction with a given solvent system.

The learning goals are introduced through ten problems with immediate feedback and explanation to provide scaffolding and facilitate retrieval learning, so that students can use knowledge gained in previous problems as support for solving new problems and gradually build a complex and nuanced mental model of organic extraction. In each problem, students are asked to retrieve and apply their prior knowledge about organic extraction to solve a new problem within similar contexts; they will be given molecular structures of different organic compounds and a solvent system, and will utilize their knowledge in acid-base chemistry to determine the protonation state of these organic compounds, and the principle of solubility to determine the solvent phase in which the majority of these organic compounds will reside after extraction. Although the learner is engaged in trying to achieve all three levels of learning goals from the beginning, scaffolding still can be realized by gradually introducing the complexity of different functional groups and solvent systems, so that the novice learner would not be overwhelmed by the nuance of the complete mental model for organic extraction, as one would if it were presented together at once. Demonstrated in Figure 3, after students has been gradually introduced to different functional groups and solvent systems, the later problems challenge students by presenting them with molecules with increasingly
complex structure. Students will have to be able to identify relevant functional groups in increasingly complex molecular structure context in addition to applying their knowledge of acid-base extraction to solve the problems.

![Conceptual Complexity](image)

### Figure 3: Two Dimensions of Complexity Involved in the Pedagogical Design.

The learning objectives of the ten problems for gradually introducing complexity are the following:

**Problem 1 Learning Objective:**
- Student will be able to recall the polarity of water and diethylether.
- Student will be able to classify benzene ring structure as non-polar.
- Student will be able to recognize organic salts as polar due to formal charge.

**Problem 2 Learning Objective:**
- Student will be able to recognize that some small organic molecules are polar enough to be water-soluble.
Problem 3 Learning Objective:
- Student will be able to recall the polarity of dichloromethane.
- Student will be able to recognize HCl solution as strongly acidic.
- Student will be able to select the correct protonation state for amine and phenol under acidic condition.

Problem 4 Learning Objective:
- Student will be able to recognize NaHCO₃ solution as weakly basic.
- Student will be able to select the correct protonation state for amine, phenol, and carboxylic acid under weakly basic condition.

Problem 5 Learning Objective:
- Student will be able to recognize NaOH solution as strongly basic.
- Student will be able to select the correct protonation state for amine, phenol, and carboxylic acid under strongly basic condition.

Problem 6 Learning Objective:
- Student will be able to distinguish between amine and amide.
- Student will be able to select the correct protonation state for amide and carboxylic acid under acidic condition.

Problem 7 Learning Objective:
- Student will be able to distinguish between phenols and phenols with electron-withdrawing groups on o-/p- position in terms of pKa.
- Student will be able to select the correct protonation state of carboxylic acid and substituted phenols under weakly basic condition.
Problem 8 Learning Objective:
- Student will be able to distinguish between phenols and alcohols.
- Student will be able to select the correct protonation state of alcohols and secondary amine under strongly basic condition.
- Student will be given slightly more complex molecular structures and will be able to recognize functional groups in the more complex structural context.

Problem 9 Learning Objective:
- Student will be able to recognize that stereochemistry can affect a molecule’s solubility in water.
- Students will be given more complex molecular structures, and will be able to recognize chemically identical functional groups.

Problem 10 Learning Objective:
- Student will be able to distinguish between phenol substituted with electron-withdrawing groups and phenol substituted with electron-donating groups.
- Students will be given even more complex molecular structures that features more than one type of functional group.

The user interface design of the mobile application needs to be taken into consideration along with the pedagogical design to maximize meaningful learning, as effective user interface design can reduce the associated extraneous cognitive load, freeing up more working memory capacity for learning. Traditionally, organic extraction problems are presented in the form of a flowchart, as shown in Figure 4, which only
emphasize on the submicroscopic level conceptualization of the organic extraction process without considering what students would observe during the experiment.

**Figure 4: Organic Extraction Flowchart Question Format.** A typical organic extraction flowchart question requires the learner to determine the solvent phase in which the majority of each compound in a set of compounds would reside after extraction is conducted with given solvent condition, as well as determine the protonation state of each compound.

In addition to the visualization being isolated on submicroscopic level, the design of flowchart problems also involves considerable extraneous cognitive load as students must draw the molecular structures repeatedly. The feedback provided to students after they have completed such learning activity is also suboptimal, as it is often either delayed or standardized, leaving students more susceptible to misconception. Hence, when
designing the user interface of an “extender” type mobile application to enhance the existing learning activity using features unique to mobile learning, emphasis was placed on three aspects: connecting the submicroscopic conceptualization with experimental observation, reducing extraneous cognitive load associated with drawing molecular structures repeatedly, and providing students with immediate, personal feedback. Shown in Figure 5, as an attempt to help students bridge their submicroscopic conceptual understanding and observation made in lab, the mobile application presents a diagram of a separatory funnel with two solvent phases labeled, along with the molecular structure of organic compounds. By presenting a visual simulation of the experiential perception of organic extraction along with the submicroscopic visualization, the mobile application provides students with scaffolding for mapping the empirical evidence that they obtained in the laboratory onto the theoretical knowledge they obtained in books.

Although the display size of smartphone is limited, the interactivity afforded by the touch screen allows the user to solicit immediate visual feedback on the display with a simple touch. The extraneous cognitive load associated with drawing molecular structure repeatedly when changing protonation state or choosing solvent phase is reduced by the interactive display of smartphones. Students can simply tap on the separatory funnel to choose solvent phase, and tap on the molecular structure to cycle through different possible protonation states of the molecule, instead of drawing the molecular structure of the organic compound repeatedly on paper, which impose unnecessary extraneous cognitive load. Reducing the extraneous cognitive load can also potentially allow students to engage in the learning activity more casually using fragmented time periods that are not long enough for formal learning, and achieve greater
learning gain over time. Animation was also implemented to increase the interactivity of the application: colored pin pops out from the separatory funnel when students choose solvent phase, and the background color of the molecular structure intensify when students change the protonation state. Such visual cues can potentially keep students more engaged and reduce confusion while using the application.

**Figure 5: OChemLab Prototype Design Feature: Funnel Diagram.** The user interface design of the mobile application features a diagram of separatory funnel as visual representation of laboratory observation, while displaying the molecular structure of organic compounds. Students will tap on the diagram to choose the solvent phase and tap on the molecular structure to cycle through the molecule’s different protonation states.

Although the small display size of smartphones limits the number of molecular structures that can be presented along with a diagram of the separatory funnel, the interactive nature of the touch screen allows the interface design to present one structure
at a time while only showing other molecular structures to the students when they interact with the application through tapping or swiping.

Since a past study has suggested that using colors, bold divisions, and clean design can make students more apt to pay attention and to comprehend given information (Minskoff & Allsopp, 2002), the background of the molecular structures is color-coded and a pin with corresponding color will indicate the solvent phase selection students made for the molecule, as shown in Figure 6. Students are presented with one molecular structure for choosing protonation state and solvent phase, and other molecules in the same problem can be viewed by swiping left or right on the molecular structure. After choosing the solvent phase and protonation state for all four organic compounds, students will submit their answers to the server. Student answers and times of submission are both recorded at the server so that the instructors and the researchers can analyze student engagement and performance in the mobile application with ease.
Figure 6: OChemLab Prototype Design Feature: Colored Pins. Colored pins are used to present the student’s choices of solvent phase for all four compounds altogether on the diagram, where the students can tap on the pin in addition to swiping to show the corresponding molecular structure at the bottom. Students must choose the solvent phases and protonation states for all four organic compounds presented in the problem before being able to submit answers to the server. Round dots are placed at the bottom of the screen to indicate that there are multiple compounds in the problem.

Students will receive immediate feedback (Figure 7) on their responses upon submission, as well as the correct answer and explanation (Figure 8) are provided to students before they move on to the next problem. Upon finishing all problems, students are offered an opportunity to clear all their answers and attempt all the problems for a second time.
Figure 7: OChemLab Prototype Design Feature: Immediate Feedback. Immediate feedback is provided to students once they submit their answers to the server. Red and green colors are chosen to further amplify visual stimulation of the feedback. Students tap on the “Continue” button to proceed to viewing the correct answer and explanations.
Figure 8: OChemLab Prototype Design Feature: Explanation. Correct answer and detailed explanation are provided following immediate feedback to further help eliminate misconception. The explanations are color-coded with the same color as the pin and the background of their corresponding molecule. Students can view the explanation by either tapping on the “See Explanation” button or swipe to the molecule of interest and tap on its molecular structure.

Overall, the design of the mobile application is mindful of the relevant learning theories as well as the strengths and weaknesses of smartphone technology. It attempts to address the pedagogical deficiency of traditional learning activities by utilizing the interactive display of smartphones to help students connect their conceptualization of organic extraction on different levels, while taking the limited screen size into consideration.

4.1.2 OChemLab Prototype Student Feedback

The prototype was made available to students enrolled in CHEM 143A at UC San
Diego during summer session 1 of 2015 academic year as an optional learning aid for organic extraction. Qualitative data collected at the server, along with data collected through administering a survey featuring 6-point Likert scale questions, was analyzed to assess student engagement and perception of the application (results summarized in Table 1). Out of the total sample of 42 students, 20 used the application to study. Server recorded a total number of 680 submissions from students, which means on average each student has attempted all ten problems 3.4 times, indicating additional problems should be added to the application to provide the extra practice students want. Student engagement data recorded at the server also exhibits great variation between individual students: data showed that nine students attempted all ten problems more than three times while two students stopped after attempting only the first few problems. One student attempted all problems five times, starting with only getting three questions correct and only stopped after getting all ten questions correct. When asked to rate the perceived usefulness and the perceived ease of use in the survey, students rated positively in terms of both; when asked if they will be willing to recommend the mobile application to others, 19 out of 20 students responded with a positive answer.

**Table 1: Summary of OChemLab Prototype Student Rating.** Average student rating for the application assessed with a 6-point scale, with 1 being lowest and 6 being highest.

<table>
<thead>
<tr>
<th>Perceived Helpfulness</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Solubility</td>
<td>4.8</td>
</tr>
<tr>
<td>Acid/Base chemistry</td>
<td>4.8</td>
</tr>
<tr>
<td>Acid-base extraction</td>
<td>4.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Perceived Ease of Use</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Choose Solvent Phase</td>
<td>4.8</td>
</tr>
<tr>
<td>Change Protonation State</td>
<td>4.4</td>
</tr>
<tr>
<td>View Explanation</td>
<td>5.2</td>
</tr>
<tr>
<td>Review Previous Question</td>
<td>4.6</td>
</tr>
</tbody>
</table>
The survey included a question assessing the reasons for students to not use the application to study. As shown in Figure 9, 45% of students who were not able to use the mobile application cited lack of access to iOS devices as the major reason. However, given the time and resource constraints when developing the prototype, choosing the iOS platform over the android platform is an appropriate compromise; as only 22.5% of the total sample population reported the lack of access to iOS devices, making the application available only on iOS platform could still theoretically reach much of the student body, while focusing time and resource on the further improvement of the pedagogical design of the mobile application.

![Reason For Not Using App](image)

**Figure 9: Distribution of Reason for Not Using Application Prototype.** Nine students cited lack of access to iPhone, making it the leading reason for student to not use the application. Four students cited technical difficulty, four cited lack of time, and two students reported that they did not use the application because they did not think it would be helpful.

An open-ended question asking for additional comments and suggestions was also included at the end of the survey. Although students rated their perceived ease of use of the application positively, since the mobile applications was introduced to the students by
demonstration in lecture, some students who missed the demonstration in lecture reported confusion when using the mobile application for the first time, and had to go through a period of trial and error to familiarize with the application, suggesting the need to include instructions in the application.

4.2 OChemLab v1.0

4.2.1 OChemLab v1.0 Design Updates

To meet the students’ need for more practice problems, the problem pool was expanded to 40 problems because the average number of questions answered per student during prototype testing being 34. With the additional problems, more structural complexity was introduced gradually to provide students with enough scaffolding. The 40 problems were arranged into four levels in terms of structural complexity. To reduce the extraneous cognitive load associated with the learnability issue of the application, an instruction featuring both text and animation, as shown in Figure 10, was added to the application. The animation and the text are presented together since a past study has suggested that learners benefit more from an illustration when it is coordinated with written text than when it is followed by written text (Mayer, Steinhoff, Bower, & Mars, 1995). The instruction is presented to students before they can attempt the first problem, and they are required to read through all the instructions and tap on the “Got it” button before moving on to attempt problems.
4.2.2 OChemLab v1.0 Student Feedback

OChemLab v1.0 mobile application was able to pass the screening process of Apple’s App Store and was published on the App Store, available to be downloaded for free. A more robust server was constructed with the ability to record the time of submission along with student answers, provided a pattern of student engagement with the application. OChemLab v1.0 was introduced to students enrolled in CHEM 143A in winter, spring, and summer of 2016. In addition to the survey, student interviews were also conducted where student volunteers were asked a series of questions to assess their perception of the application qualitatively and ask for more extensive suggestions. With a larger sample at hand, pre and post quizzes on organic extraction were also administered to students during winter as an attempt to gauge the effectiveness of the mobile application through correlation analysis. Survey on the accessibility of the mobile application produced consistent results with prototype test, with 50% of the student body using the application and 22% of the student body citing lack of access to iOS device as
the reason for not using the application. However, due to the constraints of time and resources, the more rational focus appears to be trying to improve the design of the application to engage the 28% of student body who have access to iOS device but did not use the application.

**Figure 11: OChemLab v1.0 Feedback: Number of Problems.** The total number of problems answered is shown in relation to the number of days left before the final exam. The application was introduced to students later in winter after pre-quiz assessment, when students have already conducted the organic extraction experiment. Summer version of the course is significantly more compact than the regular version.
Figure 12: OChemLab v1.0 Feedback: Number of Users. The number of daily active users is shown in relation to the number of days left before the final exam. An active user is defined as someone who has at least submitted an answer to one problem on that day.

As shown in Figure 11, the peaking of student engagement right before an exam suggests that most students perceived the mobile application as a useful tool to prepare for an upcoming test. When the mobile application was introduced before students started conducting the experiment of organic extraction, initial student engagement fared better than when it was introduced after the experiment; Figure 12 also shows that although the technique of organic extraction was used multiple times in later experiments that addressed more complex topics, a lot of students waited until near the final exam to use the mobile learning paradigm rather than engaging in the mobile learning paradigm regularly, suggesting that the mobile application’s perceived relevancy to immediate test performance improvement also has an impact on student engagement. Student engagement in the summer was also considerably better than that in a normal academic quarter, possibly because the compact schedule of summer sessions kept students’
attention focused better than the schedule of a normal academic quarter where students have many other classes and responsibilities. The difference in student engagement in the same pedagogical design context suggests that the implementation of the mobile learning paradigm is also paramount to the success of creating a blended learning environment utilizing mobile technology.

In addition to the student engagement data recorded at the server, a survey was administered to assess student perception of the usability of the application. Students are asked to rate how much they agree with each of the statements presented in the survey on a 6-point Likert scale, with 1 being “strongly disagree” and 6 being “strongly agree”. Some items are negatively coded in order to control the noise in the data.

Table 2: Summary of OChemLab v1.0 Student Rating

<table>
<thead>
<tr>
<th>Statement</th>
<th>Average Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generally speaking, I enjoy learning extraction using the mobile app.</td>
<td>5.0</td>
</tr>
<tr>
<td>I am always on my phone while commuting to school.</td>
<td>3.8</td>
</tr>
<tr>
<td>I prefer the mobile app to traditional homework.</td>
<td>4.4</td>
</tr>
<tr>
<td>I use the app to study while commuting to school.</td>
<td>3.0</td>
</tr>
<tr>
<td>I am distracted by other apps on my phone while studying with the app.</td>
<td>2.9</td>
</tr>
<tr>
<td>I am confused while reading the instructions.</td>
<td>2.8</td>
</tr>
<tr>
<td>I find the user interface intuitive and easy to use.</td>
<td>4.6</td>
</tr>
<tr>
<td>After reading the instructions, I am still confused about using the app.</td>
<td>2.0</td>
</tr>
<tr>
<td>Learning how to use the app took me quite some time.</td>
<td>2.4</td>
</tr>
<tr>
<td>I can easily navigate through the app after reading the instructions.</td>
<td>4.6</td>
</tr>
<tr>
<td>I need to read the instructions again every time I use the app.</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Table 2: Summary of OChemLab v1.0 Student Rating, continued

<table>
<thead>
<tr>
<th>Statement</th>
<th>Average Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even if I don’t use the app for a week, I would remember how to use it.</td>
<td>5.3</td>
</tr>
<tr>
<td>I understand the principles behind solubility better.</td>
<td>5.1</td>
</tr>
<tr>
<td>I understand acid-base chemistry better.</td>
<td>5.0</td>
</tr>
<tr>
<td>I find it easier to come up with an extraction scheme in lab.</td>
<td>4.1</td>
</tr>
<tr>
<td>I still have trouble keeping track of my compound during an extraction.</td>
<td>2.8</td>
</tr>
</tbody>
</table>

The average scores of survey statements are shown in Table 2 above: students rated highly of their perceived effectiveness, satisfaction, and memorability with respect to the mobile application’s design. However, comments and suggestions for the mobile application collected in class suggested that the learnability issue of the mobile application persists even with the addition of instructions. Students reported that when they were presented the instructions as they logged into the mobile application for the first time, they habitually swiped through the instructions and tapped on “Got it” without reading. Since the application did not include clear indications to where to find the instructions after the initial presentation, many students reported that they were left confused about how to change the protonation state of the compounds. Although some students eventually figured out how to change the protonation state through trial and error, others remained confused as they failed to notice the difference in protonation states when comparing their submitted answer to the correct answer. Such confusion caused great frustration to students, as they perceived their answer as consistent with the correct answer, and concluded that the mobile application must be broken.

As an attempt to assess the impact of the mobile application on student test scores,
a quiz containing an organic extraction flowchart question with four organic compounds was administered to students both before the organic extraction experiment was conducted and during the final exam. With a larger sample at hand, an independent T-test was run to compare the post-quiz scores of those who used the mobile application to study with the scores of those who did not. The p-value of Levene’s test is greater than 0.05 (p=.229), suggesting no significant difference between the score of students who used the app and those who did not.

Correlation analysis was also performed to assess students’ learning gains in the mobile application, and it was found that the correction rate of a student’s answers had a significant positive correlation to the total number of questions answered: r(55)=.491, p<.001, suggesting that students gained a better understanding of the presented material as they were interacting more with the mobile application. As shown in Table 3, when controlling for students’ scores in their pre-quiz, their post-quiz score is positively correlated to their correction rate in the mobile application: r(55)=.312, p<.05, indicating better performance in the application is related to better performance in exam. However, since the learning material was delivered to students through different means, it is premature to make conclusion on the effectiveness of the mobile application based solely on the correlation (or the lack of correlation) between student performance data in the application and their test score.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Number of Questions</th>
<th>Post-quiz Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correction Rate</td>
<td>.491***</td>
<td>.312*</td>
</tr>
</tbody>
</table>

Note: Controlled for pre-quiz scores. * p<.05. *** p<.001.
To scientifically assess the impact of the mobile application, first the projected student growth must be constructed with consideration of a multitude of factors such as the student’s academic, social, and economic background, and then compared to the actual student growth that is affected by the mobile learning intervention. Although such rigorous approach to research can produce more scientifically definitive results, such analysis is, however, method-driven rather than result-driven, and treats the learning paradigm as an artifact, producing little practical results on how to improve the design of the learning paradigm. Consistent with past studies, evaluation of effectiveness of the application yielded little advice for directions to improve the learning paradigm, since the focus of such analysis is often the application of a certain statistical maneuver rather than the accomplishment of a certain goal; thus, research in learning media should move to more fruitful directions such as investigating essential characteristics of instructional media in order to improve their quality, researching on learner attributions and beliefs, and assessing the entertainment value of different media (Clark, 1983). In contrast to the lack of practical results from attempts to assess the effectiveness through statistical analysis of quantitative data, qualitative data obtained through student interviews yielded a concrete and practical direction to further improve the pedagogical design of the mobile application: students need to be informed why their answers are wrong in order to identify misconceptions before eliminating them. Hence, the focus of evaluation of later iterations of the mobile application shifted more towards collecting qualitative feedback through student interview to generate more concrete guidelines on how to improve the mobile application.

4.3 OChemLab v1.1
4.3.1 OChemLab v1.1 Design Updates

In order to manage the cognitive load imposed by students’ inability to differentiate their erroneous answer from the correct answer, the theory of formative feedback is incorporated in the application design to help facilitate learning. Feedback is particularly important for students enrolled in introductory organic chemistry instructional laboratory class because during this first organic chemistry laboratory class that they take, they are still coming to terms with the changes of environment, expectations, and teaching approaches. The efficacy of diagnostic feedback with post-test intervention has been established in chemical education research, while the challenge being engaging students with individual feedback and enable them to respond to it, especially in large enrollment courses (Lawrie, et al., 2013). However, immediate, personalized diagnostic feedback can be realized through smartphone technology. Shown in Figure 13, personalized, diagnostic feedback is provided to students as responses to students’ submissions of their answers, attempting to help direct students’ attention to their misconceptions. Since learners benefit more when illustrations and written texts are coordinated, the diagnostic feedback messages are displayed side by side with students’ submitted answers.
In order to further the availability of personalized formative feedback, an online discussion forum, as shown in Figure 14, was also developed and implemented in the application. Students can post questions that can be seen by all users of the application, including the instructor, and can answer questions posted by others as well. In addition to being another means to provide students with feedback to maximize learning outcome, the online discussion forum was also implemented partially as an attempt to promote student engagement, as the discussion forum provides students with a convenient online space to provide feedback to each other.
Figure 14: OChemLab v1.1 Design Update: Online Discussion. Online discussion forum is placed at the first tab of the mobile application to be more visible to students. Students can post questions anonymously.

4.3.2 OChemLab v1.1 Student Feedback

OChemLab v1.1 update patch was approved by Apple’s app store and the updated version of the application was introduced to students enrolled in CHEM 143A in fall of 2016 and winter of 2017.

The class structure for CHEM 143A during fall quarter 2016 had minor changes, as the new instructor administered a midterm exam in addition to the final exam. As shown in Figure 15, the pattern of student engagement in the mobile learning paradigm was greatly impacted by the change in course structure. The spikes in student engagement right before exams indicate that students realized the potential learning gain associated
with the mobile application, but were reluctant to engage in the mobile learning activity on a regular basis.

![FA16 Student Engagement](image)

**Figure 15: OChemLab v1.1 Feedback: Number of Problems.** The number of problems answered both in daily and total are shown with respect to the number of days left before the final exam. Student engagement peaked right before exams, with moderate engagement observed when conducting the organic extraction experiment, and no engagement observed between the midterm exam and the final exam.

The original class structure of CHEM 143A returned during winter quarter of 2017, and the server was further developed to also track the number of student who opened the application but did not submit answer to any of the problems. With the addition of the online discussion forum, it is possible that some students would engage in the application for the discussion forum only. As shown in Figure 16, although the number of daily active users began to diminish after the experiment of organic extraction similarly to previous iterations, student engagement during the static period of time was shown to have increased comparing to previous iterations. The moderate number of daily
users observed throughout the quarter suggests that students would engage in the application in ways other than attempting problems, such as viewing explanations of previously answered questions and engaging in discussion with other students on the online forum. It is also interesting to note that there were 17 new users who registered within 24 hours of the final exam, indicating that some students only perceive the mobile application as a test-preparing tool. The differences and similarities in student engagement pattern show that student engagement in the mobile learning paradigm can be stimulated both by grade related assessment imposed by instructor and by updates to pedagogical design. Although grade-related assessment imposed by instructor could promote student engagement in the short term, it also hinders regular student engagement right after the assessment, whereas updates to pedagogical design can promote regular student engagement.

Figure 16: OChemLab v1.1 Feedback: Number of Users. The numbers of daily all users, daily active users and daily new users are shown in relation to date.
The instructor’s collaboration with the researcher during the implementation of the mobile learning paradigm was also found to have significant impact on student engagement. As shown in Figure 17, during WI16, SU16, and WI17, where the instructor was working in closer collaboration with the researcher and mentioned the mobile application in lecture more frequently, student engagement also fared better both in terms of the portion of the total student body using the mobile application and in terms of the average number of problems attempted per student. Such observation is consistent with the idea that student engagement in the mobile application is greatly impacted by the perceived relevance of the mobile application to their current coursework.

![Student Usage Comparison](image)

**Figure 17: Student Usage Compared Across Academic Quarters.** Student usage is compared across different academic quarter where different instructors emphasized on the mobile application differently.

In addition to the quantitative data on student engagement in the mobile application, a survey containing 6-point Likert scale questions was also administered to
assess student perception of the new iteration of the mobile application quantitatively, where student perception was assessed through students’ reported level of agreement to a series of statement, with 1 being “strongly disagree” and 6 being “strongly agree”. Results are summarized in Table 4 below.

Table 4: Summary of OChemLab v1.1 Student Rating

<table>
<thead>
<tr>
<th>Statement</th>
<th>Average Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generally speaking, I enjoy learning extraction using the mobile app.</td>
<td>4.5</td>
</tr>
<tr>
<td>I prefer the mobile app to paper homework.</td>
<td>4.2</td>
</tr>
<tr>
<td>I am distracted by other apps on my phone while studying with the app.</td>
<td>3.0</td>
</tr>
<tr>
<td>I find the instructions clear and helpful.</td>
<td>4.1</td>
</tr>
<tr>
<td>I find the user interface intuitive and easy to use.</td>
<td>4.3</td>
</tr>
<tr>
<td>I can easily navigate through the app after reading the instructions.</td>
<td>4.5</td>
</tr>
<tr>
<td>I need to read the instructions again every time.</td>
<td>2.3</td>
</tr>
<tr>
<td>I practiced the problems multiple times.</td>
<td>3.8</td>
</tr>
<tr>
<td>I understand the principles behind solubility better.</td>
<td>4.8</td>
</tr>
<tr>
<td>I understand acid-base chemistry better.</td>
<td>4.7</td>
</tr>
<tr>
<td>I still have trouble keeping track of my compound during an extraction.</td>
<td>3.1</td>
</tr>
</tbody>
</table>

In the survey, correlation analysis was performed on students’ perception rather than on test scores, since the latter provides little practical insights for improving the application design. As shown in Table 5 below, correlation analysis on survey response suggests a significant negative correlation between students’ self-reported level of distraction while using the application correlates and their perceived enjoyment both in general: \( r(94) = -0.283, p < 0.01 \); and compared to doing traditional homework: \( r(97) = -0.265, p < 0.01 \). The significant negative correlation between students’ reported level of distraction
and perceived enjoyment of the application suggests that student engagement in the mobile application could be promoted by introducing gaming elements into the design of the mobile learning paradigm to make it more fun for students.

Table 5: Summary of OChemLab v1.1 Correlation Analysis

<table>
<thead>
<tr>
<th>Scale</th>
<th>General Enjoyment</th>
<th>Compared Enjoyment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distraction</td>
<td>-.283**</td>
<td>-.265**</td>
</tr>
</tbody>
</table>

Note: ** p<.01

Since qualitative data collected during the last iteration through student interviews was proven to be more valuable than quantitative analysis on the effectiveness of the mobile application in terms of producing practical results on how to further improve the design of the mobile application to maximize learning and promote student engagement, data collection method for this iteration shifted towards more student interviews. In addition to quantitative data collected through survey and at the server, one-on-one interviews were conducted to collect more extensive qualitative data. Total of 14 interviews were conducted, including one teaching assistant who had to give a lecture on organic extraction in class, and 13 students. Student interviews were then transcribed and analyzed; some representative student quotes are included below:

Yeah, I was literally waiting for my food and I was playing with it. And the feedback was really good. I think it’s great. And you don't really even notice that you are learning because it's just so accessible. --- Student A

I think this is more helpful [than traditional homework] because you actually got to see it, like what you were doing and where it was going to go. I think that's a lot more helpful especially because with the homework, they are more just basic questions in the back of the book if you look at them. But this one you actually really had to think about why and then if you got it wrong, even if you got it right, it gives you an explanation, which I think is really helpful. --- Student B
It looks really aesthetically appealing. I think it's pretty useful in regards to the explanations to the solvents and what not. Like I said, being very aesthetically appealing is one of the higher things that I value in apps, because if something is just not good to look at and [I just don’t want to use it]. --- Student C

I wish you could just do it again after every single problem, because it's kind of demoralizing like they are all red and I want to do this again and make it green. --- Student D

I think [the application] helps visualizing it more and keeps the solvents in consideration. Because on paper you are seeing the structure of the molecule but you are not considering the solvent as much; and it's helpful with the lab report as well, so it's not just helpful with the lab itself. --- Student E

In order to present qualitative data assessed by student interview in a more succinct fashion, common praises and critics of the mobile application are summarized in Table 6 below.

<table>
<thead>
<tr>
<th>Praise</th>
<th>Critic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helps with conceptual understanding</td>
<td>Lack of content other than extraction</td>
</tr>
<tr>
<td>Interactive and more efficient than traditional homework</td>
<td>Instruction was skipped habitually; would prefer interactive tutorial.</td>
</tr>
<tr>
<td>Accessibility promotes learning using fragmented pieces of time</td>
<td>Cannot redo question immediately after submission.</td>
</tr>
<tr>
<td>Instant, diagnostic feedback promotes more meaningful learning</td>
<td>Need conceptual overview before the problems</td>
</tr>
<tr>
<td>Aesthetically pleasing</td>
<td>Need Anonymous posting in discussion forum</td>
</tr>
</tbody>
</table>

Students generally spoke highly of the pedagogical design, and yearned for more content designed in similar fashion, which suggest a real student need for mobile learning paradigms that are designed to closely supplement their coursework. Although the
introduction of formative feedback was well-received by students, it did not, however, fully address the issue that some students would experience confusion when skipping through the instruction without reading. While most students reported having no trouble figuring out the actions required to change protonation state and to choose solvent phase through trial and error, they expressed the desire for an interactive instruction where they are guided through all the actions required to interact with the mobile application.

Students also cited lack of anonymity when answering posted questions as one of the reasons why they hesitate to engage in discussion on the online forum, since they do not want to appear foolish in public or take responsibility for providing a wrong answer to the question. Although many students have expressed a desire for a conceptual overview before the problems, implementing such feature could cause some students resort to memorizing the overview instead of engaging in retrieval learning by attempting the problems. Students are required to finish all 40 problems before they can clear their answers and attempt the questions again; such mechanic was implemented with the intention of forcing students to engage in the later, more complex problems and prevent students repeatedly attempt a single problem to memorize the answer without much learning. However, during interview, many students expressed the need to reattempt questions right after reading the provided explanation in order to submit the correct answer and gain a sense of progress. Although forcing students to proceed onto new problems could possibly help facilitate more meaningful learning by promoting students to apply the information gained in the explanation of the previous problem to solving the new problem, the frustration caused by such design could have detrimental effects on student engagement. As shown in Figure 18, the number of attempts decreases rapidly in
the first ten problems, suggesting that some students could be frustrated by submitting the wrong answer for several times without a chance of attempting the problems again.

![Figure 18: Student Usage Compared Across Versions.](image)

Student feedback suggests that newly implemented design features are well received and should be kept in the mobile application; in addition, further scaffolding on how to use the mobile application needs to be included, as the current instruction cannot effectively inform students. A tutorial level, where students are presented with only one molecule, and are guided step by step to change the compound’s protonation state and choose its solvent phase, is proposed as an improved format for instruction. Students should also be allowed to reattempt each problem individually so that the perception of increased competence gained through getting a previously wronged question right can help create a state of intrinsic motivation (Deci, Vallerand, Pelletier, & Ryan, 1991).
CHAPTER FIVE: DISCUSSION

5.1 Summary of Results

From the iterative development process of the mobile application that incorporates both learning theories from published literature and student feedback assessed through survey and interview, it was found that in the context of promoting meaningful learning in large enrollment introductory organic chemistry instructional laboratory course with a blended learning approach incorporating mobile technology, the mobile learning paradigm should be designed to utilize the smartphone’s interactivity and accessibility to help students make connections between different levels of conceptual understanding, and incorporate learning theories such as retrieval learning and formative feedback. In addition, the extraneous cognitive load associated with learning how to use the mobile application also needs to be reduced by effective mobile application usability engineering; an interactive tutorial is required to successfully relay instruction to students, as students would skip through text- and animation-based instruction habitually. With the mobile learning paradigm, the laboratory extends to the virtual space, and in turn the virtual space informs the laboratory, thus creating a blended learning cycle. The mobile learning paradigm should also be implemented with emphasis from the course instructor in order to boost student engagement of the learning paradigm. Grade-related assessment in class has been found to stimulate student engagement in the short term, but dampers regular engagement right after the assessment, which can only be stimulated again by another grade assessment, suggesting that students tend to view the problem-based mobile learning paradigm as a test preparation tool. Implementing more generalized functions such as discussion forums, on the other hand, could help promote regular
student engagement. Such findings are consistent with a past study by Güzer and Caner, who argue that teachers using blended learning environments should encourage students for more participation in the environment and should find ways of creating social interaction through collaboration (Güzer & Caner, 2014).

Although mobile learning paradigms should be designed to be accessed outside of classroom in order to fully take advantage of the accessibility afforded by smartphone technology, student engagement in mobile learning paradigm designed to supplement their course work is influenced greatly by extrinsic motivations such as grade related assessments. Thus, design-based research aimed to develop mobile learning paradigm in blended learning context would require close collaboration among researchers and instructors in order to yield more fruitful results that can further improve the pedagogical design, since student engagement in the mobile learning activity outside of classroom is greatly affected by the instructors’ practice. Without such collaboration, feedback from student would be less extensive due to low level of engagement and impairs researchers’ ability to modify design principles to satisfy student needs.

5.2 Limitations

Due to constraints of time and resource, the Android version of the mobile application was never developed. Although the primary focus of the study is to improve the design of the mobile application, and students are offered with opportunities to use the mobile application on provided iOS devices, the lack of Android version poses potential education equity issue as the location and time constrain of making an appointment to test the mobile application limit those students’ accessibility to the mobile application. However, since the learning material was delivered in more ways than just
the mobile application, students without iOS device can still consume the same learning material on other platforms.

Although the design-based study is fruitful in improving a mobile learning paradigm democratically by incorporating learning theories and student feedback, the results from the study are very context specific and may not have broad application. Also, development of blended learning environment that incorporates design-based research takes long periods of time, because theories and interventions tend to be continuously developed and refined through an iterative design process that involves analysis, design, implementation, evaluation, and finally redesign; and each step requires considerable efforts. Hence, the development of a full curriculum that attempts a blended learning approach with mobile technology would still require considerable amount of time and resource.

5.3 Directions for Future Studies

A lot of improvements can be made to the current version of the mobile application to incorporate received student feedback. More gaming features, such as unlocking harder levels upon completing easier ones, could be implemented in the mobile application as means to give students a perception of increasing competence, therefore promote self-determination and create a state of intrinsic motivation, which is found to have a positive relationship with learning achievement (Su & Cheng, 2015). In order to facilitate deeper meaningful learning, the pedagogical design should also help student situate their chemical knowledge in the context of human development, expanding the “chemistry triangle” to “chemistry tetrahedral” (Mahaffy, 2015). In the context of OChemLab v1.1, additional problems that connect the concept of solubility to drug
molecules permeating cell membrane and thus the development of medicine could be included in order to help students see the social and cultural value of their knowledge. Since the server and mobile application infrastructure was built to allow easy expansion of content, as students yearn for similar practices for other concepts covered in the class, mobile learning activities for other topics covered in the course such as thin layer chromatography could be developed under the same theoretical framework in the future to satisfy student learning needs.

Moreover, the visualization afforded by the mobile learning paradigm was found to have the effect of helping non-native speakers of English mitigate language difficulty, suggested by an international student during the interview. Such comment provided a unique perspective: when the interactive display of smartphones is coupled with information accessibility afforded by their connectivity to Internet, the combination have the potential to facilitate learning using only the universal language of chemistry, i.e. molecular structure and other internationally adopted formal symbolism, and bypass the constraints of different spoken languages to help promote chemical education on an international scale in the increasingly globalized world. Future studies could attempt to design mobile learning interventions featuring only simulated experiments with visual, symbolic feedbacks rather than text feedbacks in order to supplement the learning need of a wider audience.

The accessibility of mobile platform also presents unique opportunity to promote science literacy in the general public. Although Massive Open Online Courses (MOOCs) can provide the general public quality learning materials, the time commitment required for engaging in these materials is considerably large and may not suit the need of people
with casual scientific curiosities. Mobile technology has the potential to promote learning in fragmented periods of time during the day and deliver bite-sized scientific knowledge to learners for easier consumption, so that people with busy lifestyles can engage in science learning without committing hours of their time at a time. In addition, the gaming features of mobile learning paradigm have the potential to create intrinsic motivation for people to acquire more scientific knowledge without external stress such as exams. With anti-science rhetoric gaining support from government authorities, science educators should recognize that their responsibility is not only to their students but also to the broader general public and strategically improve and implement educational technology to battle against ignorance.
Appendix A. Sample student survey.

General Instruction

This survey contains several scales designed to measure your opinions and behavior regarding the mobile application tested. Please answer the questions as honestly as possible, in a way that shows how you really are, not how you would like to be or how you think you should be. Don’t spend too much time thinking about your answers. The first answer that pops into your head is what is needed. After the first question, you will be asked to rate how much you agree with the following statements on a six-point scale.

Have you used the mobile app (OChem Lab) this quarter? (circle one) YES  NO
*Please circle the reason stopping you from using the app if your answer is NO.
  a. I did not know the app exists.
  b. I did not have access to an iOS device.
  c. I did not think the app would be useful.
  d. I had trouble downloading/ signing up for the app.
  e. The app is too confusing to use.
  f. Other (Please specify)____________
*Please DO NOT rate the following statements if your answer is NO.

  Generally speaking, I enjoy learning extraction using the mobile app.
  I prefer the mobile app to paper homework.
  I am often distracted by other apps on my phone while studying with the app.
  I could not find instruction on how to use the app.
  I find the user interface intuitive and easy to use.
  I can easily navigate through the app after reading the instructions.
  I need to read the instructions again every time.
After using the app:

  I understand the principles behind solubility better.
  I understand acid-base chemistry better.
  I still have trouble keeping track where my compound is during an extraction.
Appendix B. Sample student interview protocol.

Ochem Lab Interview Protocol WI17

Project title: The Design and Evaluation of a Mobile Learning Paradigm Aimed at Improving Organic Chemistry Laboratory Instruction at Undergraduate Level

Time of Interview:

Place:

Interviewer:

Interviewee:

Academic background of Interviewee:

Questions:

1. What is your overall impression of the mobile application in terms of usefulness? (Help understanding the concept/bridge the gap between knowledge and observation)

2. How would you compare the mobile application to traditional homework?

3. How do you think the mobile application impact your studying habit?

4. What do you think about the difficulty of using the application and learning how to use the application?

5. What kind of improvements/changes would you like to see?
Development Chronology

Nov. 2014 to Dec. 2014 – Initial phase consisted of brainstorming ideas and seeking developers to work on the project. A simple web page demo of the mobile application was developed after finding a developer for the mobile app. Registered a website for the application: ochemlab.com

Jan. 2015 to Mar. 2015 – With learning objectives in mind, 10 problems were designed covering several concepts in organic extraction with increasing difficulty.

Apr. 2015 to Jun. 2015 – A beta version of the application was developed for iOS devices. Online assessing tools to collect data on students’ performance in the mobile app were developed. All student performance data would be stored in server.

Jul. 2015 to Aug. 2015 – Beta testing of the mobile application was administrated using testflight. Students responded to the application positively. A great number of students commented that they would like to have more questions available to them. Students who did not have access to iOS devices were also eager to see an android version of the mobile application.

Aug. 2015 to Dec. 2015 – Expanded the question pool from 10 questions to 40 questions. A detailed explanation was also provided for each new question. However, the beta version of the application could not be used anymore due to a major system update for iOS devices. Other technical difficulties such as termination of subscribed services from provider had also stalled the development of the mobile application.

Jan. 2016 – OChemLab v1.0 was approved by Apple’s App Store and made available to students to download for free.

Apr. 2016 – Student usage data collection for WI16 was finished.

Jun. 2016 – Data had shown a lack of enthusiasm from a lot of students while a few students would use the mobile application extensively. Several new functions were proposed in order to address the lack of student engagement

Jul. 2016 – More student data were collected during summer session.

Aug. 2016 – Data analysis showed that students seemed to be using the application more rigorously during summer sessions than during normal quarters. It also became obvious that some students did not read the instruction before using the application and were have trouble identifying the reason why their answers were wrong.

Sept. 2016 – OChemLab v1.1 made available with the following changes:
- Audio feedback is implemented for changing protonation state.
- After submitting their answer, the students will not only be told if their answer is correct, but will also be told what is wrong with their answer (protonation state or extraction layer).
- A forum system was also implemented for students to discuss course related material.

Oct. 2016 to Apr. 2017 – Student feedback on OChemLab v1.1 was collected and analyzed.
References


Taber, K. S. (2013). Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice, 14*, 156-168.
