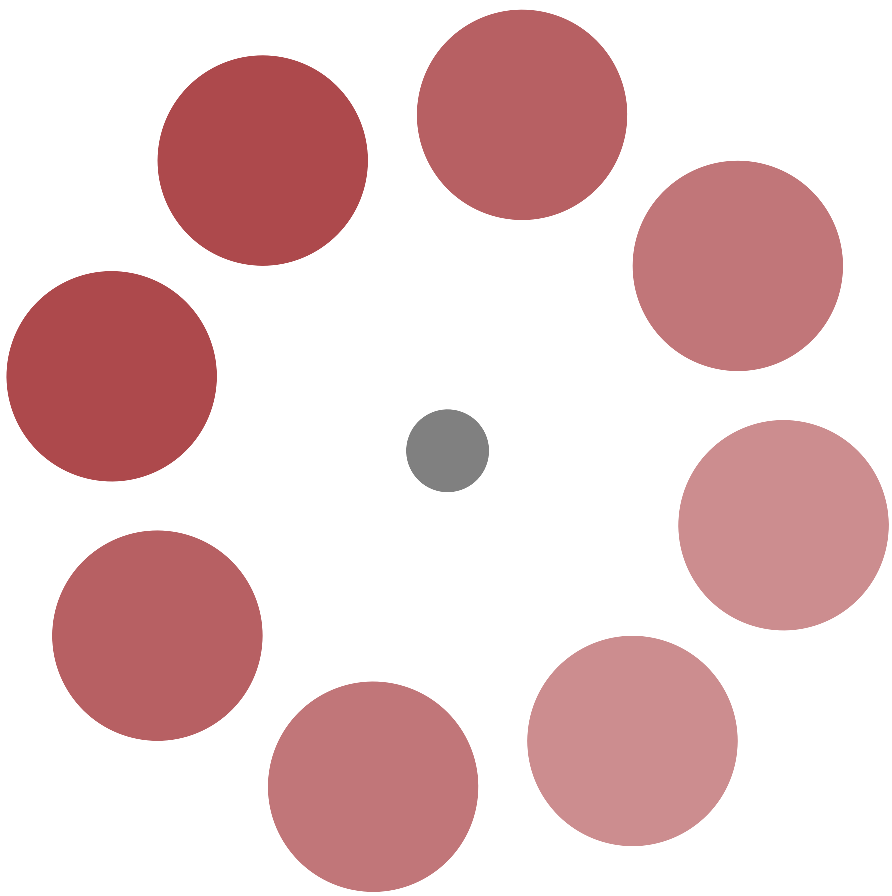
Recollection: Incorporating Smartpen Adaptive Interfaces into Learning Management Systems



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Recollection: Incorporating Smartpen Adaptive Interfaces into Learning Management Systems

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I also thank my family for their unending love and support as I went through this process.

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ABSTRACT

With the constant increase of online learning courses utilizing learning management systems (LMS), the technology has yet to be fully optimized to allow easy navigation of course material for study and practice, which makes the user interface (UI) design cumbersome. These systems assess learning but do little to enhance or improve the process, which forces students to find new and unique ways to utilize the existing software suites.

This research presents a design for a potential adaptive user interface that utilizes smartpens as a means of navigation and enhancement of learning and study practices. Students in online courses often complain about the lack of detailed feedback with regards to how assignment questions are missed. In-person courses allow professors to directly answer student questions in real-time, while LMS-based questions rely on a system of correctness feedback responses (Kehrer et al., 2013). Being preplanned, these responses do not offer reactive feedback that students can receive in-person.

The mnemonic device of physically writing out one's handwritten lecture notes and study guides is a lost practice in online course management systems. Utilizing smartpen optical character recognition and laser tracking allows for the design of a user interface that reincorporates these helpful practices into daily study tasks. Pairing these features with machine learning enables adaptive interfaces that can assist learning depending on the needs and the skill level of the student. Together, these technological affordances and comparative case studies of existing smartpens inform the design of an innovative UI that pushes LMS into a user-friendly, user-adaptive future.

KEY TERMS

Learning Management Systems:

Abbreviated LMS, an educational software tool designed to provide a comprehensive, seamless, and safe virtual environment in which learning can take place (Danver, 2016).

Learning Management Ecosystem:

An 'ecosystem' that includes not just the UI, but also incorporates a smart pen (this idea of an 'ecosystem' = multiple components)

User Interface:

Abbreviated UI, how the user and a computer system interact utilizing input devices, display devices, and software.

Adaptive User Interface:

How UI responds to the student learning level by adapting assignments, providing feedback, offering aid when they get 'stuck', helping them remember lecture discussions and how lectures connect to homework, studying, etc.

Machine Learning:

Abbreviated ML, programming computers to use example data or past experience to solve a given problem (Alpaydin, 2004).

Different Student Learning Levels:

Students who are doing poorly vs doing 'OK' vs doing well; also, different levels of 'familiarity with online classes'

Optical Character Recognition:

Abbreviated OCR, the process of scanning and recognizing static images of text characters (Tiwari et al., 2019).

Mnemonic:

A memory aid, intended to assist the memory.

Reinforcement Learning:

Algorithm attaches rewards and punishments for answers to enforce results using conditioning much like training a dog. A machine sees a negative score as detrimental and over time can perfect its process to get the highest possible score (Pabianczyk, 2017).

RESEARCH QUESTIONS

How can the design of an **adaptive user interface** for a learning management ecosystem **support student learning** in an online college chemistry course?

Sub Question 1:

How can an adaptive UI ecosystem support students in identifying, locating, and recalling connections/relationships among the courses' different 'learning activities' (e.g., assignments, video lectures, note-taking, studying, exams)?

Sub Question 2:

How can the UI apply machine learning techniques to accommodate students at different learning levels?

Sub Question 3:

How can the features and capabilities of smartpens be incorporated into the UI design/ecosystem to support students in their course learning activities?

"Younger students are most interested in the **interactivity** of the software, while older students place more value in the **video lectures**."

(Brock and Simonds, 2016)

PROBLEM STATEMENT

As the digital space expands further into education, learning management systems (LMS) are currently limiting in terms of adaptability. A typical online course layout incorporates lectures, readings, homework, and examinations. Within current LMS, such as Moodle, interaction with material is rigid and difficult to use for study and practice. Navigation is clunky and countless students complain about the shortcomings of such an integral part of modern college courses. Each student has varying levels of experience using the system which emphasizes these concerns. A novice is more likely to make mistakes or have difficulty navigating in comparison to an experienced user and there are no directives or successful assistive features that remedy this.

In online courses require LMS access and students purchase access to the system alongside the clickers for each class to complete assignments. Students approach homework as if it were a series of mini-quizzes. Quizzes are already present in most courses and homework requires constant practice to aid with memory retention. Homework allows very few responses before locking out edits and programmed answer explanations are generic and only list the correct answer. This makes it exceedingly difficult for students to discover where they made mistakes that lead to a missed problem. Due to this mini-quiz homework style, students often do not receive formal practice, leaving them with holes in the learning process regarding what to practice ensuring understanding and retention of needed knowledge. External help through limited, user-assisted online forums such as Chegg or Khan Academy become the student's best hope for learning the course material.

Note taking currently occurs outside of an LMS and incorporating into the program would benefit retention and ease of access. However, these integrated notes should not take the form of typed notes. Mueller and Oppenheimer did three studies on the benefits of handwritten notes vs typed notes and found that typed notes tend to be verbatim rather than process the information and reframing it in their own words for retention. Students taking longhand notes are more selective with what they record, and this has benefitted them overall (2014). Here enters the smartpen. Mueller and Oppenheimer agree that there is potential for handwritten notes in digital spaces with the integration of smartpens such as Livescribe (2014). Mueller and Oppenheimer found a significant positive interaction between handwritten notes and studying indicating that this tactile approach to learning enhances a student's ability to study and practice (2014). Smartpens can enhance an LMS by bringing back the natural, mnemonic practice of notetaking and handwritten practice.

Smartpens also allow for creative user interfaces using laser tracking and OCR technology to expand how we interact with our LMS tools. Hovering menus and expanding interaction to non-touch enabled devices are easily obtainable using this technology. With smartpens, the learning process can become more streamlined and user-friendly. Students will be connecting the digital and physical world of academia by incorporating physical notetaking, drawing, and practice with the smart pen and connecting it to digital affordances such as video lectures, easy searching, and collaboration.

> "Student learning in these online systems is often **not supported** by **detailed formative feedback**, as options in current LMS are quite limited."
>
> (Hedtrich and Graulich, 2018)

JUSTIFICATION

There are many existing dysfunctions associated with LMS. Professors design recorded lectures to present all the needed material from the perspective of the professor. However, students do not receive detailed formative feedback, as the options in current LMSs are quite limited (Hedtrich and Graulich, 2018). Students utilize internet and library searches for deeper exploration and assistance. Lecture and notes are meant to prepare students for exams, while homework uses a randomized set of questions which may inadvertently not be fully covered in class. Such learning tasks are areas where an interface improvement, influenced by smartpens, can change LMS software for the better, either to allow further practice and experimentation in homework or to learn from lecture content by making notes more directly associated with the material covered in class.

Behind the scenes, machine learning enables pens with OCR to be successfully implemented. Computers gain the ability to learn without explicit programming due to machine learning (Pabianczyk, 2017). Specifically, the reinforcement learning algorithm attaches rewards and punishments for answers to enforce results using conditioning much like training a dog. A machine sees a negative score as detrimental, and over time, can perfect its process to achieve the highest possible score (Pabianczyk, 2017). The reinforcement learning algorithm takes massive amounts of data and time but would be the most effective for LMS integration. Here data is plentiful, and optimization can occur quickly as an LMS has access to thousands of students' data and databases such as ChemDraw (ChemDraw is a drag and drop building block system for chemical compounds and structures).

Smartpen interfaces and activities incorporate a mnemonic process through writing into an LMS which aids with memory retention of learned material. "Although more notes are beneficial, at least to a point, if the notes are taken indiscriminately or by mindlessly transcribing the content, as is more likely the case on a laptop than when notes are taken longhand, the benefit disappears. Indeed, synthesizing and summarizing content rather than verbatim transcription can serve as a desirable difficulty toward improved educational outcomes." (Mueller and Oppenheimer, 2014, p.13). By incorporating smartpens as drawing devices, students can improve memory of chemical structures and equations by creating a visual as a response in homework problems or notes. Students already use a drag and drop program known as ChemDraw to create the structures, but this prevents students from practicing to draw structures themselves. By shifting the problems to the smartpen the encoded memory trace that is rich in contextual information and generates detailed memory (Wammes et al., 2018). To facilitate better learning practices, incorporating mnemonic tools is important for designers to consider when creating a more active interface for an LMS that is more considerate of the user, the student.

ASSUMPTIONS

This study assumes that smartpens have taken the place of clickers as essential online course equipment material. This incorporation requires an intuitive UI, as a pen-based input system will behave differently than one based on a mouse and keyboard. Users do not receive learning-based practice which leaves then frustrated. Based on the speculated progression of smartpen technology indicated by the smart pen comparative analysis (see p.30), future pens will likely follow the development path of the Phree smartpen. These pens have affordances including laser tracking, OCR, haptic feedback, microphones, speakers, and pen caps for stylus use when ink is not needed. Students are willing to accept the pens as valued study and practice tools and encouraged to do so through the implementation of course requirements. Every user does not have the same level of knowledge and this system will adapt from novice to experienced user levels.

LIMITATIONS

While this design solution benefits numerous courses and fields, I limit the scope of this investigation according to the given time constraints. I focused on how this system will change LMS for online college-level chemistry courses due to the versatility of chemistry problems that span mathematical equations, paired with memorization, and theory. Students take assessment in the form of quizzes and tests in these introductory science courses, but in the current online course environment homework also serves as an assessment. Homework that focuses purely on assessment does not leave room for continued practice as the limited problem attempts do not give detailed, reactive feedback (Kehrer et al., 2013). I focused on the development of a system that gives homework as a means of practice and expansive learning. The biggest challenge was defining and creating a user interface that supports this system while promoting future development. Smartpen implementation will occur where all students access and complete course material using additional technology such as a laptop or desktop computer. I limited accessibility research based on time and as such the focus remains on able-bodied students. As future technology, development in LMS software to include smartpens has not yet occurred and evaluation can only occur on the level of user interface visuals and videos.

LITERATURE REVIEW

Learning Management Systems

Professors use LMS in online courses as a means of course management where they can track and post grades, lectures, homework, examinations, and more. Partly due to its origins as management software, assignments such as homework too often focus on providing a grade than assisting with the learning process which defeats its purpose. Students often no longer receive textbooks to use in online courses, which prevents additional practice from text (Muzyka, 2015). When answering questions, current LMS use a remarkably simple input response design where professors must be specific about what answers are acceptable to the assignment. Even incorrect answers need an accurate explanation of why a problem was missed. Homework has the potential to guide students to the correct answer through practice. With little instruction into how these complex systems work, teachers and students rarely utilize LMS to its full potential (Debattista, 2018). Younger students are most interested in the interactivity of the software, while older students place more value in the video lectures (Brock and Simonds, 2016). Classes are exceptionally large which causes many professors to only interact with students when students initiate the contact due to the difficulty of establishing interaction between themselves and students (Scheg & Ruefman, 2016). Large enrollments make one-on-one interactions exceedingly difficult and time-consuming, so most interaction occurs when students request help over email (Scheg & Ruefman, 2016). Due to these limitations, students often lack formative feedback. This feedback weakness leaves room for expansion (Hedtrich & Graulich, 2018). In physical class sessions, one of the best ways to assess feedback is through quizzing a student on learned material from lectures and base lessons on what most students miss (Muzyka, 2015). However, in online sessions, professors record lectures ahead of time and practice must occur elsewhere. A common myth associated with LMS is that online courses only use technology or that online learning is inferior to physical classrooms, which is simply not true (Borges and Fores, 2015).

Online Community/Collaboration

Online community and collaboration are important in online courses. Small groups have helped with class academic performance and bring back some of the missing interpersonal interaction (Akcaoglu, 2016). Bringing instances of self-directed collaboration into the online experience can help to replace the areas of one-on-one interactions between the professor and student that are missing.

Smart Pens

Smartpens are note-taking tools where anyone can digitize their notes to store, edit or distribute. This digital media can enhance practice by connecting the tactile and digital experience (Siddiqui and Muntjir, 2017). There are many devices available but emerging smartpens no longer require the limitation of specialized paper or clunky clip-on scanners. Scholars are already speculating how these pens can use machine learning to become more accurate by learning from users. One area of concern is how mistakes could be identified and patterns of similar mistakes could be isolated and remedied (Jain et al., 2017). Optical character recognition has proven to be a powerful tool and has high accuracy when interpreting what a smartpen is drawing or interacting with (Tiwari et al., 2019). Currently, we interact with LMS using a keyboard and mouse, but a smartpen could enhance this interaction making it more natural. Olabisi and David agree, stating “the purpose of education and learning is often defeated when gadgets developed to assist in the process of learning is not user-friendly or ends up becoming a distraction in the classroom due to its size. A smart pen does not create distraction due to its portability, that is user-friendly and above all its affordable nature” (2013, p. 1).

Mnemonic Learning

A mnemonic is any device that aids in memory retention and retrieval. Handwritten notes have proven to be a mnemonic process and only expand when integrated with other facets of an LMS such as lecture videos and practice (Mueller and Oppenheimer, 2014). Mnemonic learning is important in that it connects multiple sensations into study and practice to improve learning retention. Metsamuuronen and Rasanen argue that “Effective teachers use mnemonic tools or mnemonic triggers to improve the students' retention of the study material” (2018, p.1). This mnemonic feature connects through physical notetaking, but also through the drawing aspect of chemistry courses. Research proves that drawing physical representations of material helps with learning retention across all ages (Wammes et al., 2018). Connecting a smart pen with an LMS allows users to connect the iconic quote, “a picture is worth a thousand words” into one system by expanding notetaking as an interface that bridges the physical and digital classroom. Enhancing notes and practice with drawing gives a boost to performance thanks to the mnemonic practice (Fernandes et al., 2018).

PRECEDENTS

Online Course

To further deepen my understanding of how educators use LMS, and in what capacity, I first completed a graduate-level education course on online teaching and education systems. I obtained detailed insight into the history (as far as progression) of LMS-based systems and was able to research ways to improve collaboration and effectiveness. As the only designer taking the course, I was able to bring a unique perspective to the group regarding the user interface and system design. During the many collaborative assignments aimed to assemble students from various fields. I gathered insights from my peers covering interpersonal communication and history courses.

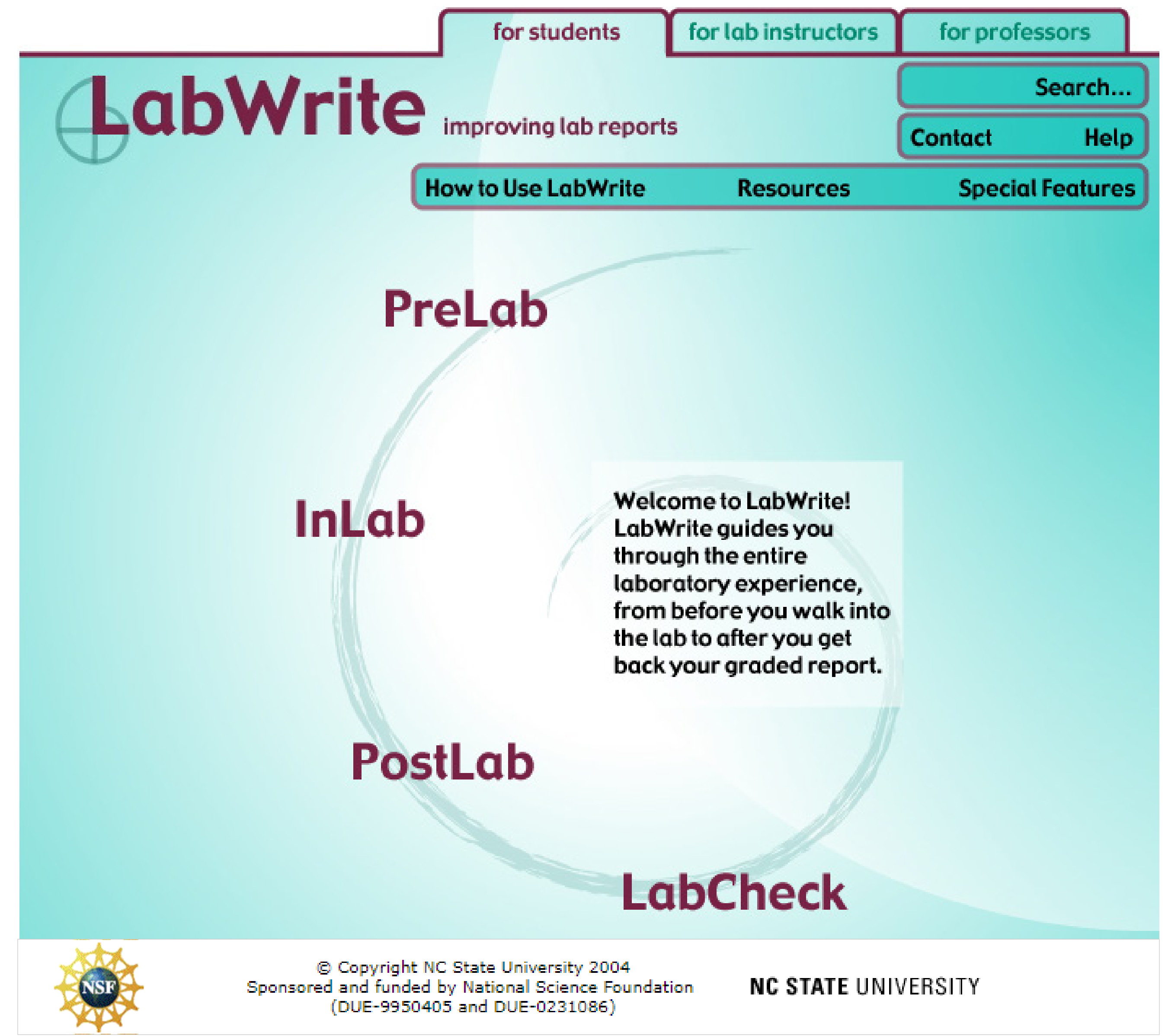
In an online interpersonal communication course, Moodle was the LMS of choice. Moodle is an open source LMS and is well known for its ability to set up blog style discussion posts. Typical content for this course included weekly readings and discussion boards, quizzes, three large essays, and exams. After assigning readings, the professor started the discussion board for the week which increased student morale and led to richer posts since the students knew the professor was also posting and reading each comment. The five-minute edit access limitation in Moodle proved to be problematic if students wished to update responses or essays that they submitted before the due date. A second complaint stated that test subjects were not overly clear in these courses. Many courses give a test outline or an understanding from completing homework, but in this case, that was not possible, and tests came from readings. This criterion was known ahead of time, and reading clearly was stressed, but areas of student focus became evident in the discussion posts. This instance highlights a case where the lack of a lecture-discussion to cover any feedback led to missed material.

In an online history course, WordPress is a common choice. This type of class contained weekly lectures recorded for online use that followed professor notes. Downloading notes helped to establish an informal study guide. Assigned readings inform quizzes and the only exam, the final exam, was created from the quizzes themselves. The notes served to assist with the quizzes, but some information came from the readings, rather than the notes. Multiple choices were used for every question, which removed the answer accuracy/clarity problems that come with fill in the blank style questions, but exam takers can see a repeat of the inconsistency of the notes to provide a flawless study guide, much like the interpersonal communication course. The teacher was available during office hours, but there was a lack of student/teacher interaction throughout the class. The only potential improvements would involve more professor participation in the course or the addition of worksheets that prepare students for the quizzes since there was no homework to check to understand (and arguably no tests). At its core, WordPress is simply a website or blog generator. The professor used the tool effectively to present and receive information, but there will always be caveats with unspecialized software.

LabWrite

LabWrite was a 2004 National Science Foundation grant project created at North Carolina State University in Raleigh, NC (Figure 0). Researchers discovered that chemistry courses have more failures, withdrawals, and repeats than any other course on campus. Due to this problem, researchers attempted to find a way to improve these results. The result of the project was a website known as Labwrite.

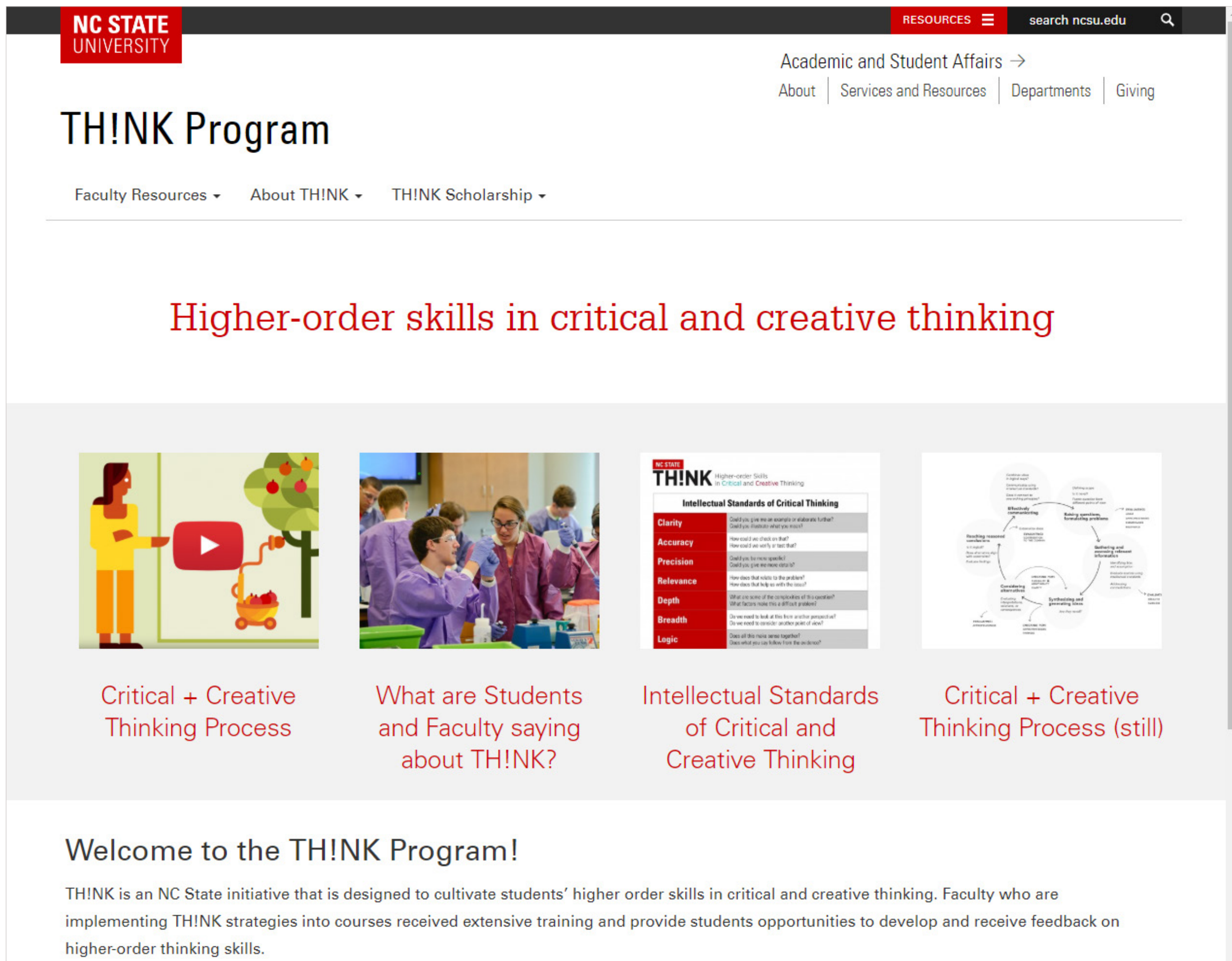
The website gives a step by step guide to laboratory component course requirements and indicates what is appropriate to write about in reports. Students receive checklists and resources to self-check their work. While this precedent focused on laboratory courses data that led to its creation emphasized the importance of narrowing my topic within the chemistry field.



F0: LabWrite user interface. Image is from the launch screen of LabWrite.ncsu.edu

TH!NK Program

TH!NK is an ongoing NCSU program that aims to improve student critical and creative thinking (Figure 1). The program supports course design by redesigning assignments and rubrics to help professors better facilitate the four outcomes below. This was important to consider since my designed solution utilizes a new interface to improve student learning and retention.



F1: TH!NK web structure. Image is from the launch screen of think.dasa.ncsu.edu

The program established four key outcomes:

A: Students will explain the intellectual standards for critical and creative thinking.

B: Students will evaluate the work of others using the intellectual standards for critical and creative thinking.

C: Students will apply critical and creative thinking skills and intellectual standards in the process of solving problems and addressing questions.

D: Students will reflect on their own thinking.

PERSONAS

Novice Student

Jack is a novice student in his mid-twenties. He is returning to education from active deployment and is learning how to use LMS. He is struggling to navigate LMS and relies on tips and guides to navigate him through the process. He is a chemistry major and wishes to get back into an academic mindset as he continues his degree.

Mid-Level Student

Sarah is a mid-level student and has just started college at 19. She is a biochemistry major and has had many online courses. She is an all-around average student and tends to do well and learn at a steady pace.

Advanced Student

Cindy is an advanced student. She is a sophomore who has just turned 20 and is excelling in the LMS based course. She rarely worries about studying the right material and her grades reflect a strong student. She easily navigates the system to perfect her already thorough notes.

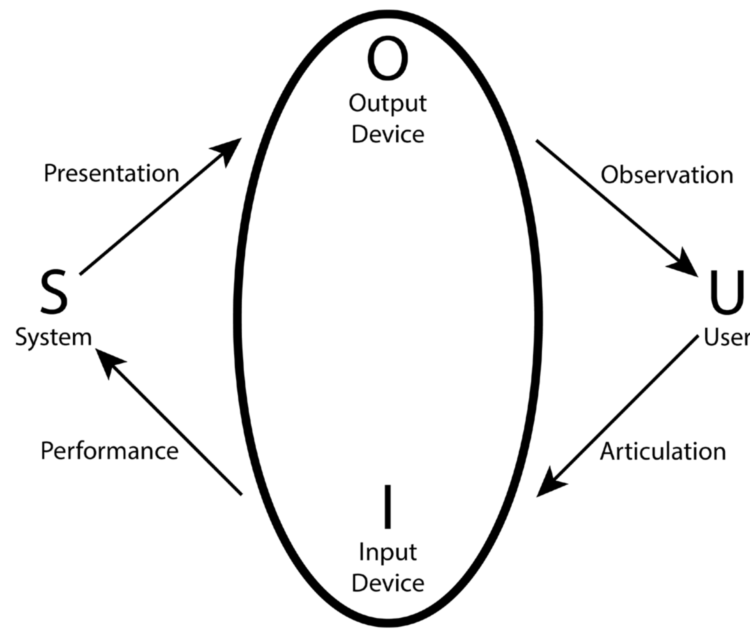
F2: Chart of Personas used to design for users

FRAMEWORKS

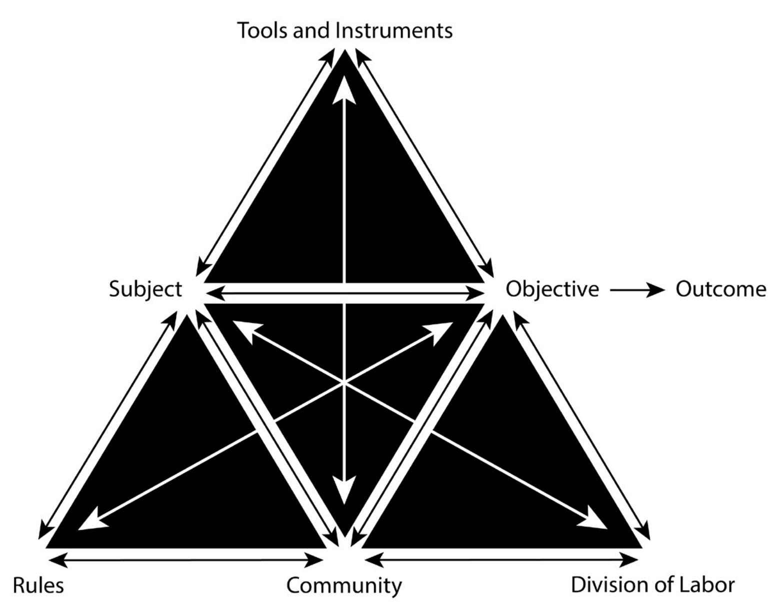
Theoretical Frameworks

Two theoretical frameworks were key to the development of my smartpen interface. The human-computer interaction (HCI) framework (Abowd and Beale, 1991) looks at how the user and system interact through a user interface (Figure 3). By breaking down my UI into the four key sections of the user, input, system, and output it ensures my design considers the user interaction with the system. The user section defines who is interacting with the UI. The input device section, the smartpen, is how the user interacts with the UI. LMS is the system controlled by the UI and what processes the response. The output, the UI displayed on a monitor, is how the system responds to the user input. The HCI framework is most useful when developing the user interface system as it considers both the interaction and response in a continuous four section cycle. As the user interacts with the system the UI should flow smoothly from one task to the next.

The activity theory framework (Engestrom, 1999) assists the interface design process by bringing attention to each part of an interface and how these interact within the system (Figure 4). It considers how the tools affect the user, how the user affects those tools, how much passes to the machine, and what rules the tools must follow. From this activity, the theory is most useful as a tool to evaluate effectiveness across the system.



F3: Human computer interaction framework (Abowd & Beale, 1991)

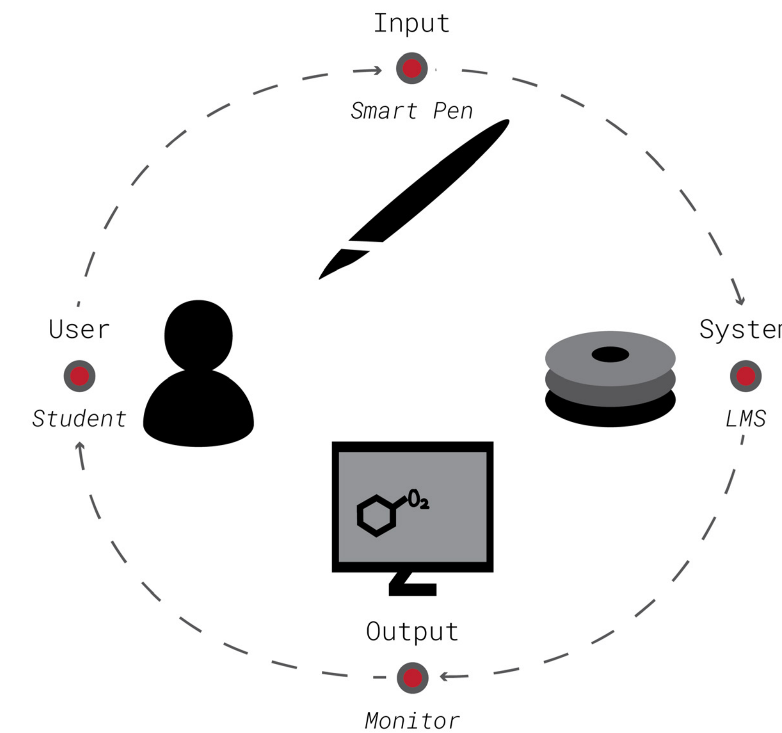


F4: Activity theory framework (Engestrom, 1999)

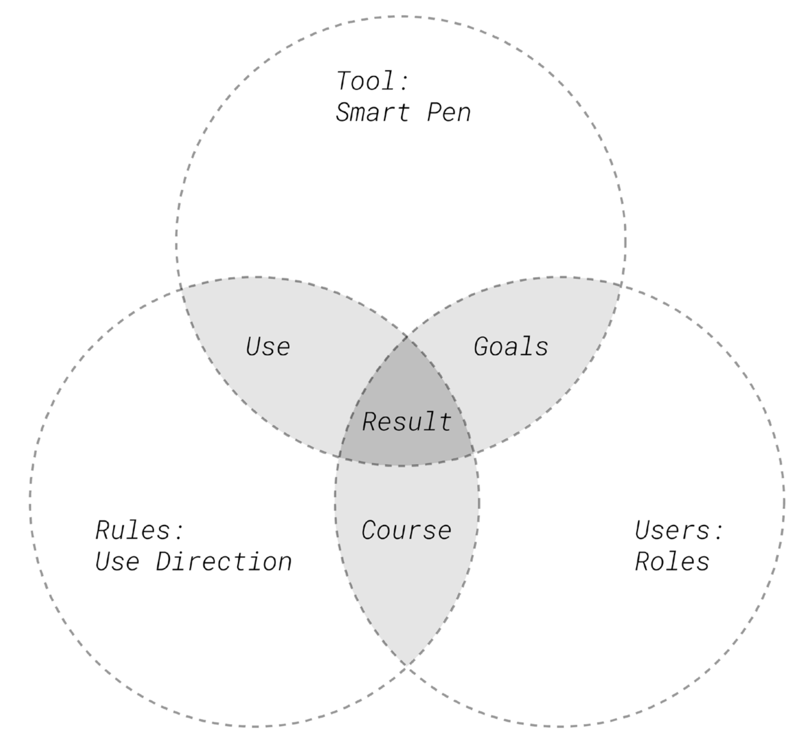
Conceptual Frameworks

The conceptual frameworks informing my research cover two key areas. The first is a cyclic system derivative of the HCI theory (Figure 5). I further specify the four-step cycle to include user (student), input (smart pen), system (LMS), and output (monitor). No matter the task this is the feedback circle of data and emphasizes the smartpen as valuable input to the system.

My second framework is a derivative of activity theory. It restructures the framework into a three-way Venn diagram (Figure 6). The three key system managers become tool, users, and rules. The new framework indicates needs for the interface design and the importance of the users in guiding the system.



F5: Human computer interaction conceptual framework



F6: Activity theory conceptual framework

MINI STUDIES

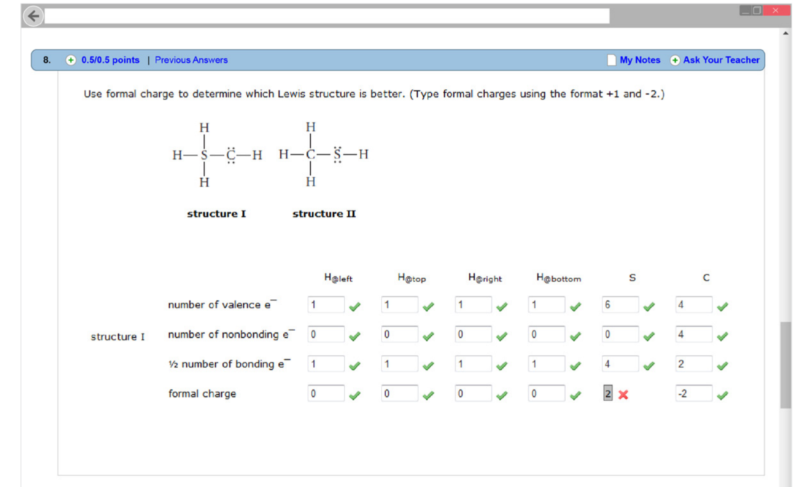
LMS System and Capability Study

Process

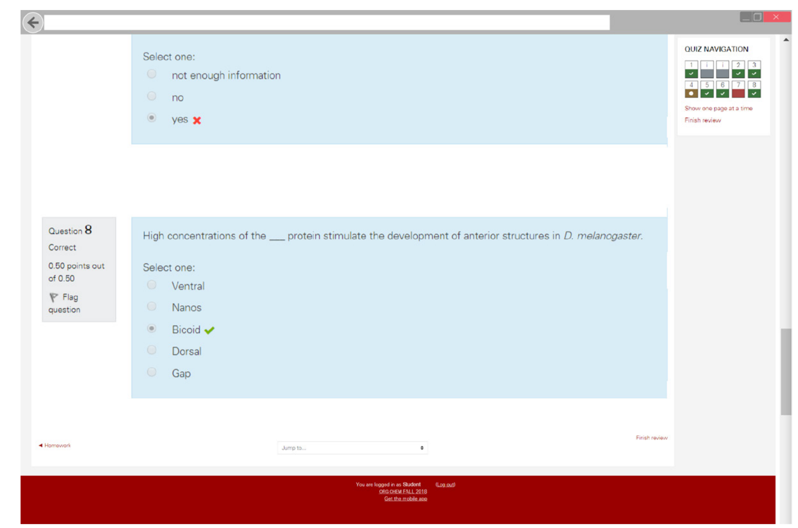
My earliest studies focused on analyzing and breaking down the current UI present in Moodle and WebAssign. I started the process by conducting informal interviews with students who have recently taken a college chemistry course. From the responses, I recognized homework feedback as an area of concern for chemistry students. Students wished to have detailed information describing missed problems to improve and direct study and in an LMS feedback is generic and preplanned. Keeping this in mind I collected data and many screen-captures from Moodle and WebAssign. I then explored what type of data is inserted and how feedback should be received. These studies started by cataloging existing LMS UI present in Moodle and WebAssign. Specifically, I focused on answer delivery and feedback. After this examination, I moved into ways to enhance the existing process by adding prompted suggestions within the LMS for review.

Reflection

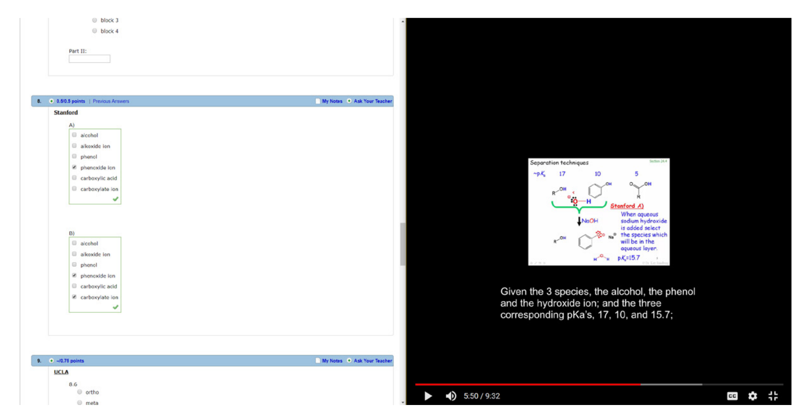
Upon completion of this study, I was able to confirm the students' concerns and recognize the lack of study assistance in the LMS environment. WebAssign (Figure 7) and Moodle (Figure 8) both give assignments with a similar delivery. Typical answers are either multiple choice or fill in the blank. Correct answers are indicated with a green check and incorrect answers with a red “x.” If an incorrect answer is given on any assignment, an untailored explanation is given to indicate why or where the mistake has been made in order to streamline the experience for professors. This was the case even if it was a homework assignment whose purpose should be enforcing the study process. Simply enhancing question feedback with machine learning saves time and ensures more detailed responses. I also noticed that with little instruction given into how these complex systems work, teachers and students rarely utilize LMS to its full potential. Some teachers are also incorporating external assets into the LMS (Figure 9). Note-taking process is not present within modern LMS and there is truly little crossover between the different tools in an LMS leading to a very inefficient UI system. These capability studies were helpful to establish the detailed comparison needed for my designs to progress.



F7: WebAssign homework interface



F8: Moodle homework interface



F9: External asset integration with WebAssign

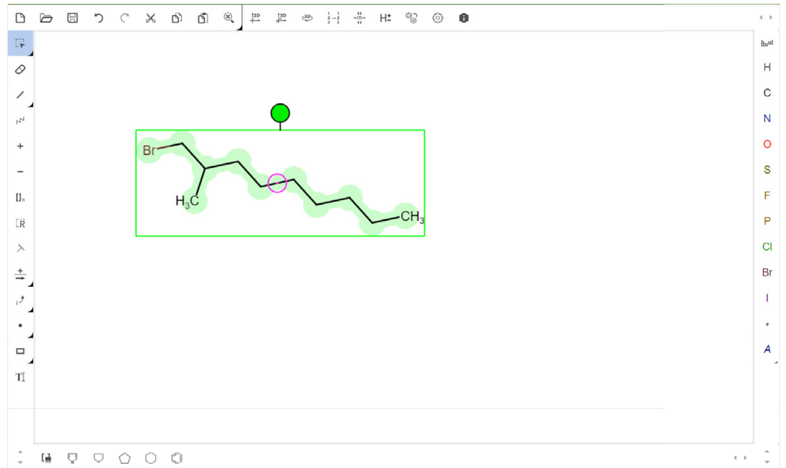
Smart Pens & Assignment Feedback

Process

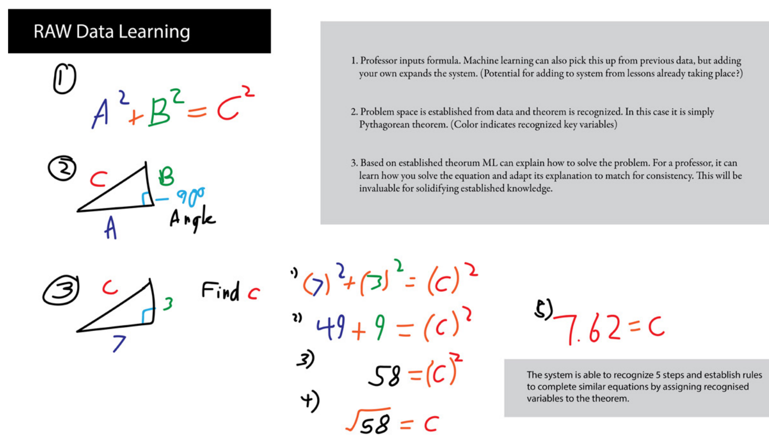
After the early studies focused on improving the feedback system, I started looking for ways to evolve the LMS experience. At North Carolina State University chemistry students taking in-person courses are required to purchase clickers, a device that records responses for attendance and class discussion. They also use an external integrated program known as ChemDraw which allows them to drag and drop parts to create chemical structures and models (Figure 10). This new data encouraged me to look for a binding factor that could help mesh the different program capabilities within an LMS and potentially take the place of clickers. I settled on smartpens and began studies and research into how this modern device could enhance answer input, note taking, and feedback.

Reflection

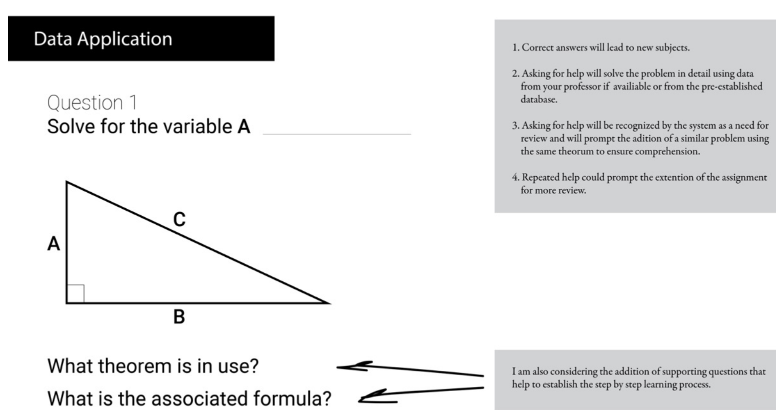
A smartpen has the potential to add additional information to class notes when viewed through an LMS software equipped with machine learning capabilities. In courses such as Organic Chemistry, handwritten notes include drawing organic compounds and structures. Incorporating handwritten notes into the LMS generated new possibilities (Figures 11-17). Next, I developed ideas for how to make notes smarter or more helpful for studying students. It was important to consider connections between note-taking, lecture, and drawing/modeling. I looked at existing pen gestures and what common gestures to implement into the program to ease interface interaction (Figures 18-20).



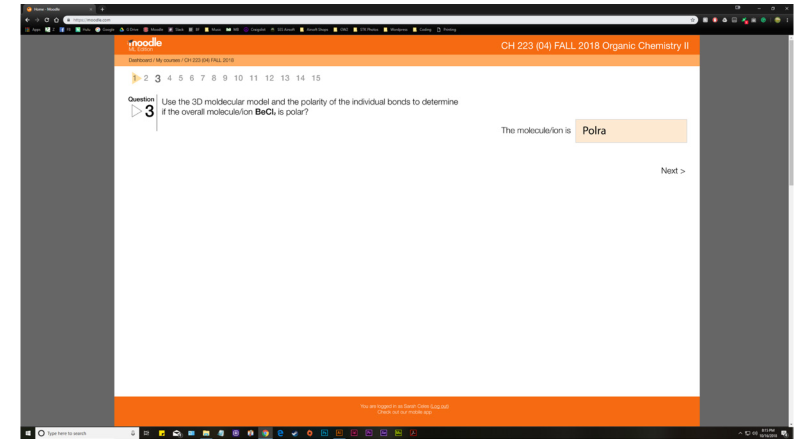
F10: ChemDraw drag and drop chemistry structure builder



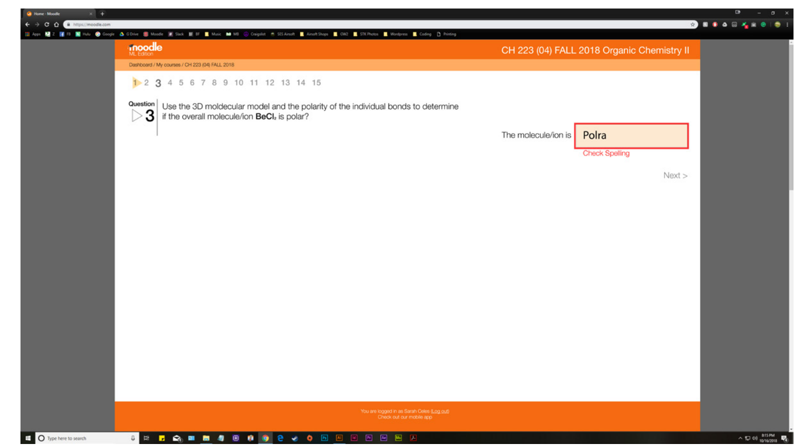
F11: RAW data learning



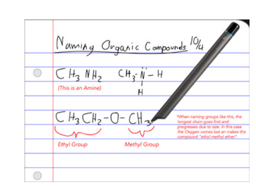
F12: Data application



F13: Answer feedback test 1-1, web-based

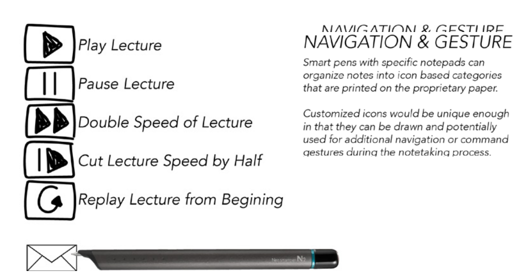


F14: Answer feedback test 1-2, web-based

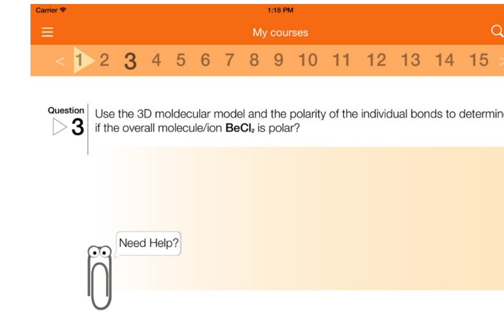


F18: Smartpen integration test 1-1

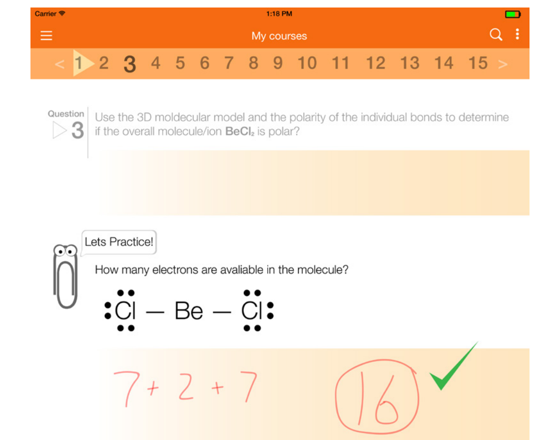
F19: Smartpen integration test 1-2



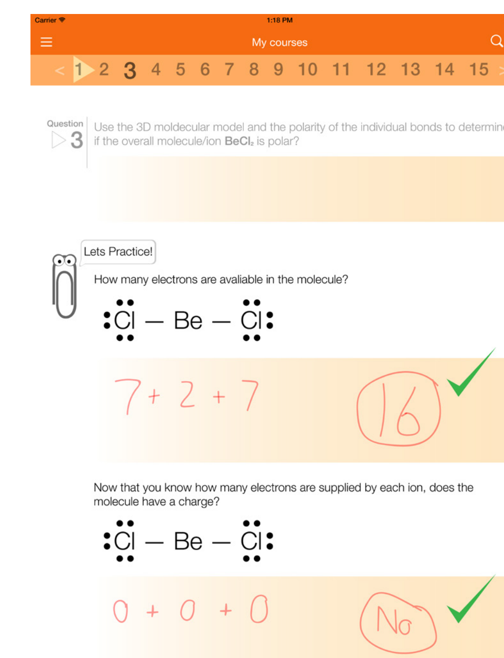
F20: Smartpen integration test 1-3



F15: Answer feedback test 1-3, mobile-based



F16: Answer feedback test 1-4, mobile-based



F17: Answer feedback test 1-5, mobile-based

COMPARATIVE ANALYSES

Smart Pen Affordances

A comparative analysis of smartpens gauged the affordances of existing pens such as the Livescribe 3 and Neo N2, as well as advanced pens currently in development such as the Phree (Figure 21). A limitation of current smartpens is the heavy reliance on specialized paper or infrared (IR) trackers that must be clipped onto each new page. The Phree is the first pen to move from the common IR based method of smartpen tracking and instead use a self-contained 3D laser that can track on any surface, as well as track location precisely without custom paper limitations. This new feature opened development possibilities and allowed for the unique incorporation with non-touch enabled screens. Based on the data of the progression of smartpen technology, I can accurately speculate the affordances of future smartpens and price points.

Comparative Analysis of **Smart Pens**

	Livescribe 3	Neo N2	Wacom Bamboo Folio	IRIS Notes Air 3	Moleskine Pen+	Phree
Cost	$134.99	$169.00	$149.00 (A5) $199.95 (A4)	$132.90	$171.88	$249
Battery Life	14 hours	5 hours	8 hours	10 hours	5 hours	2 days
Accuracy	120 fps	120 fps Detects Pressure	Detects Pressure	Only tracking from dock	120 fps Detects Pressure	1,000 mmps 2,000 dpi Detects Pressure
Weight	1.1 oz	0.9 oz	0.6 oz	0.7 oz	0.9 oz	TBA
Requires Special Paper	Yes	Yes	No	No	Yes	No
Sensor Type	IR Camera	IR Camera	Pad Receiver	IR Clip Tracking	IR Camera	3D Laser
Wireless Technology	Bluetooth	Bluetooth	Bluetooth	Bluetooth	Bluetooth	Bluetooth
Audio Capture	Yes	Yes	No	Yes	Yes	Yes
Software Compatibility	iOS, Android, Amazon	iOS, Android	iOS, Android	Android, Amazon, iOS, Mac, PC	iOS, Android	Android, Amazon, iOS, Mac, PC

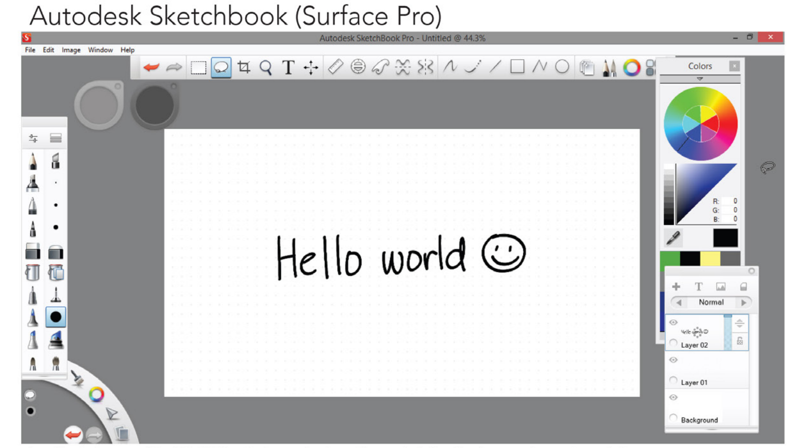
F21: Smartpen affordances comparative analysis

Stylus Drawing

Drawing capabilities are important to chemistry, and students must accurately draw chemical structures for homework and tests, etc. I analyzed the interfaces of Adobe Illustrator Draw, Autodesk Sketchbook, Graphic, Art Rage, and Paper (Figure 22). Each application has slight UI differences, but key similarities. Most use a menu bound to the side of the screen to access things such as pen tip size, erasers, color, etc. Dragging a slider that extends from a tool icon allows users to adjust size or color. Autodesk Sketchbook, Adobe Illustrator Draw, and Graphic maintain layer menus and advanced color wheels for detailed selection, as opposed to basic color block selection. Autodesk Sketchbook, Adobe Illustrator Draw, and Graphic are also the only apps that maintain their windowed barrier. Illustrator is the only application that allows for selection management.

Comparative Analysis of **Stylus Drawing**

Autodesk Sketchbook (Surface Pro)

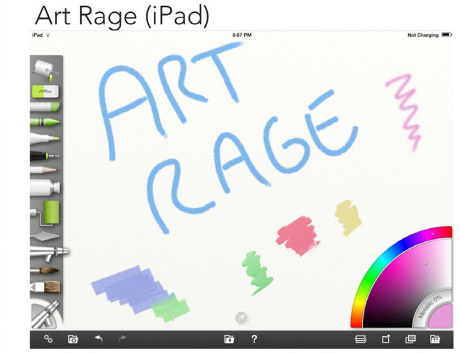


http://sachachua.com/blog/2014/03/how-i-animate-sketches-with-autodesk-sketchbook-pro-and-camtasia-studio/

Graphic (iPad)

https://www.graphic.com/ipad/

Art Rage (iPad)



https://www.imore.com/artrage-review-cheaper-alternative-creating-digital-art

Adobe Illustrator Draw (All Tablets)

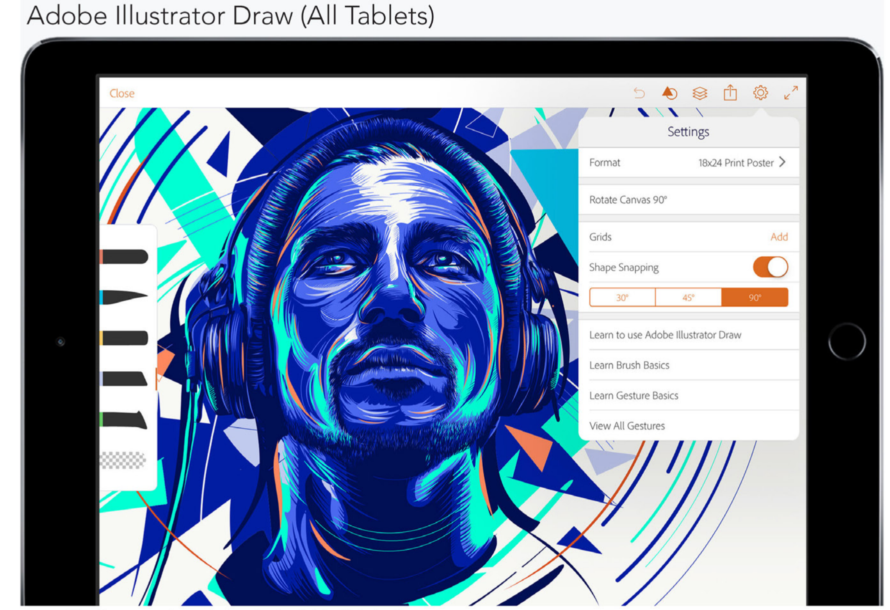
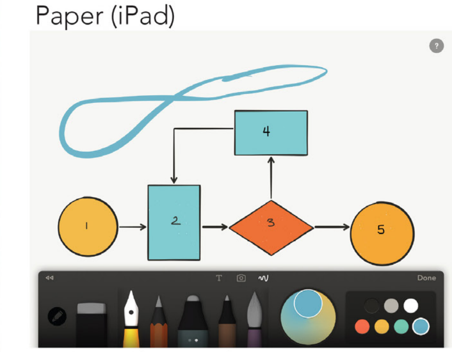


Image: https://www.appannie.com/en/apps/ios/app/adobe-illustrator-draw

Paper (iPad)

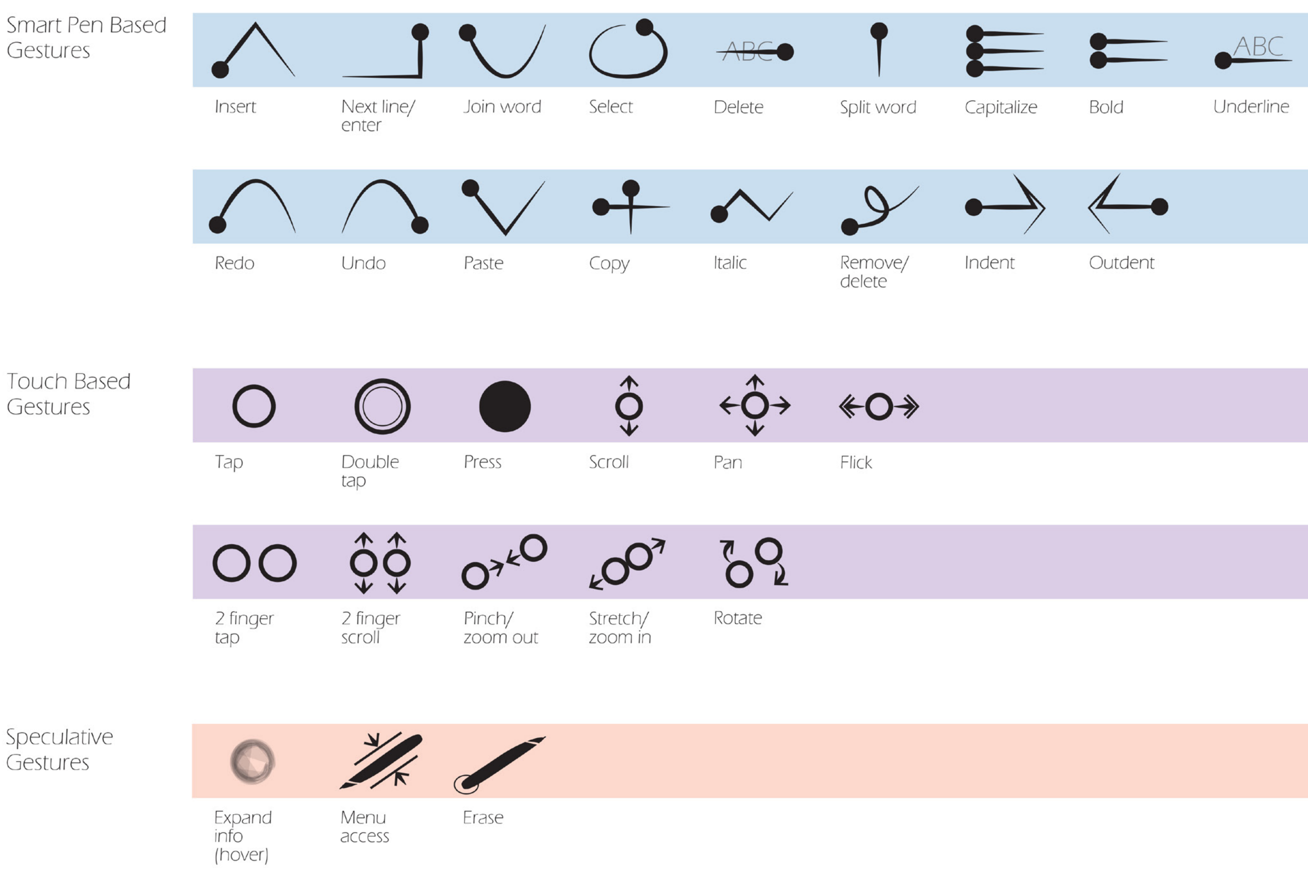


https://zapier.com/blog/best-note-taking-apps/

F22: Smartpen affordances comparative analysis

Pen-based Gestures

An analysis of existing touch, pen, and stylus interaction with devices gave a thorough understanding of existing navigation (Figure 23). Most touch-based interfaces use multipoint gestures, which are not possible with pens as they have a single point system. However, I was able to establish a connection between many existing pen navigational gestures and editors' marks intended for editorial uses. Speculative gestures include integrating pen buttons and hovering sensor capabilities. This investigation expanded with an analysis of gesture-based alphabets and provided insight into the detailed function of OCR (Figure 24). Of the three alphabets considered, Graffiti was the most complex, while Unistrokes was the most minimal. As OCR is a staple of smartpens, this analysis was important to verify how accurately an OCR-based system can function

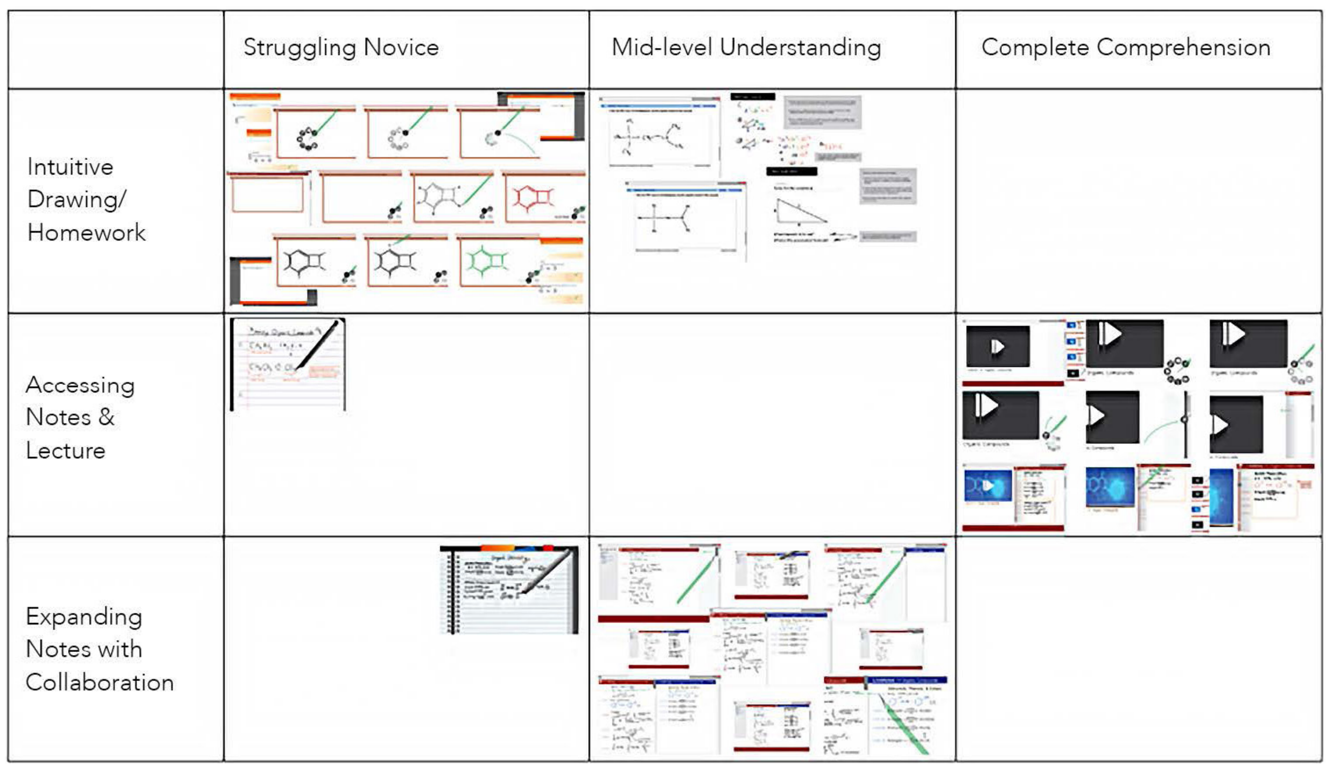


F23: Gesture comparative analysis

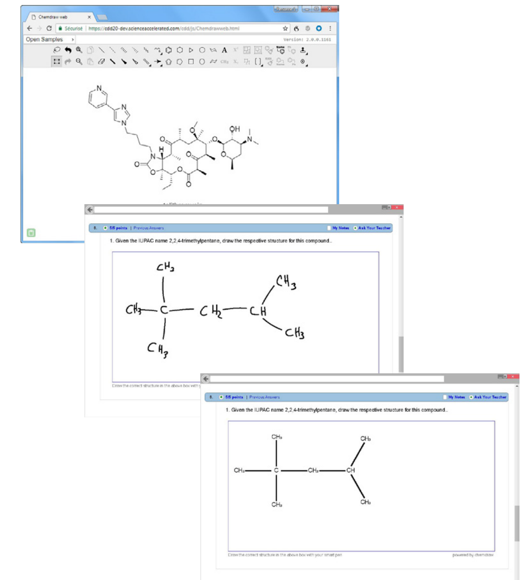
F24: Gesture alphabet comparative analysis

DESIGN MATRIX

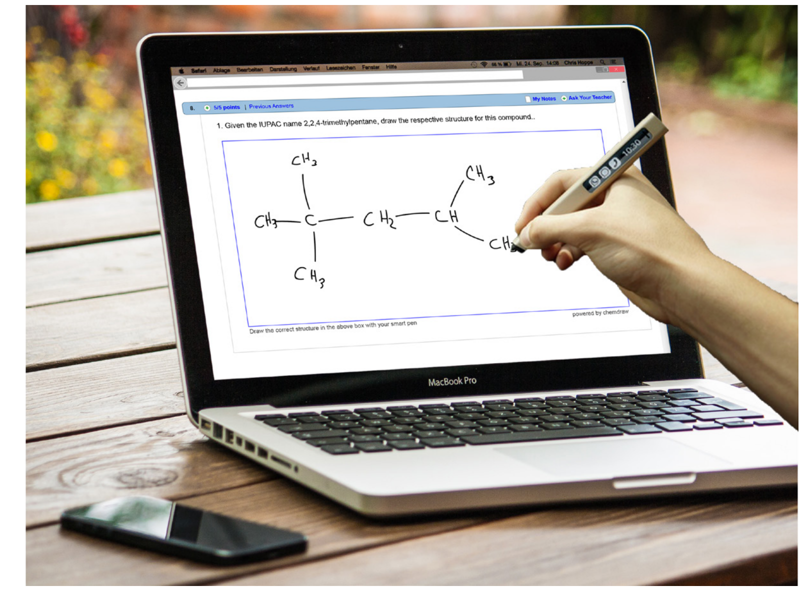
Utilizing my mini-studies, frameworks, personas, comparative analyses, and precedents, the next step required a design matrix to ensure I designed for key LMS tasks and kept users in mind (Figure 25). I identified key tasks as intuitive drawing/homework, accessing notes/lecture, and expanding homework with collaboration (Figures 26-29). I then paired these tasks with the personas indicating a struggling novice, mid-level understanding, and complete comprehension.



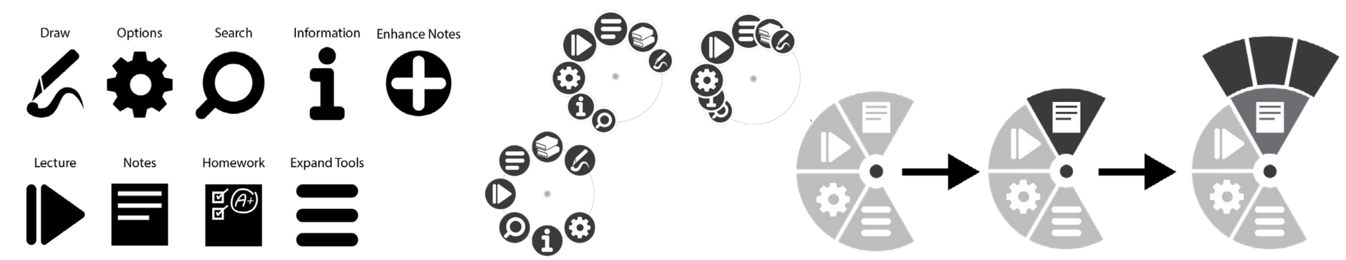
F25: Design matrix



F26: Smartpen starts replacing ChemDraw



F27: Early live drawing on screen with smartpen



F28: Smartpen icon development and prototyping

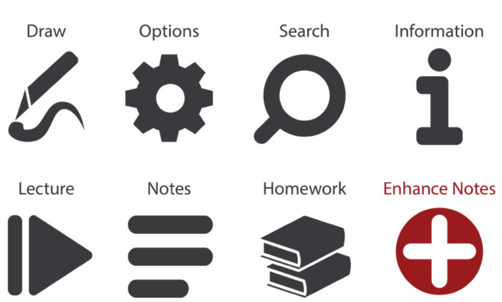
F29: Early interface iteration and development

PROTOTYPE

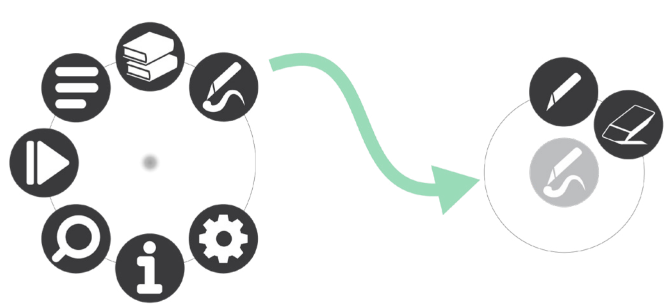
My final design focused on a simple interface for a futuristic smartpen known as Recollection. The name stems from the idea that handwritten notes and practice are a mnemonic practice that assists with remembering or recollecting study material. Recollection utilizes the same features as the smartpen still in development, Phree. Features include a microphone, speaker, OCR, 3D laser tacking, writing and stylus mode, haptic feedback, tactile side buttons, and Bluetooth connection technology. The pen interface includes three key sections: a navigation menu, interaction gestures, and editing gestures. The interface expands across drawing, note taking, and lecture-listening. The interface also naturally adapts to the users' level of experience using an LMS, giving more assistance and feedback to novice users and less to experienced users.

The navigation menu uses what I call a "flower" effect and is easily accessible at any moment while interacting with the LMS screen by a quick, double-press of the pen's side button (Figure 30). The gesture menu contains key navigational icons (Figure 31)and expands from the center of the pen tip location on the screen and lists all categories for easy navigation. As the pen user selects a category, the other categories reduce in size and opacity to indicate the user's selection (Figure 32).

F30: Smartpen showcasing side button, image from otmtech.com



F31: Final iconography, what was needed

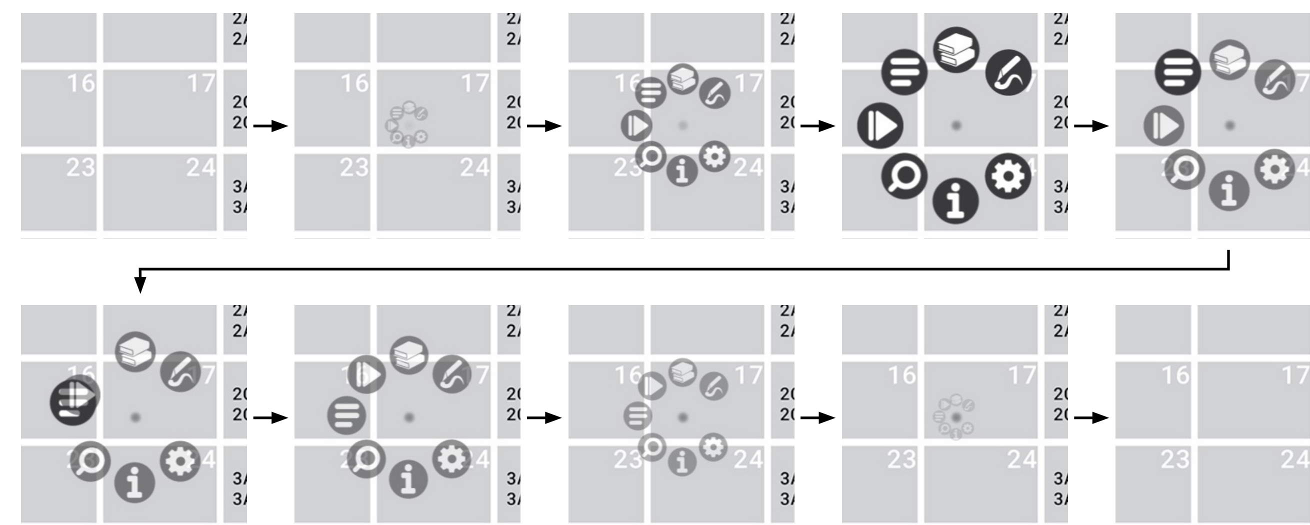


F32: Smartpen menu base design

Users can rearrange categories by tapping and holding for two seconds before rearranging the icon location. Lifting the pen tip will drop the icon in that location on the flower menu (Figure 33).

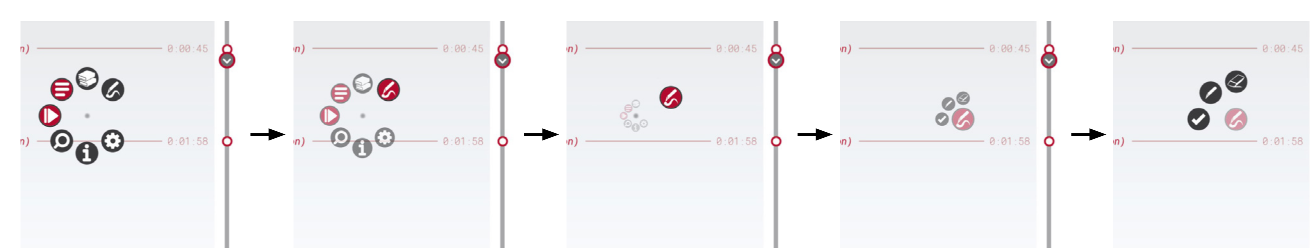
The student can then hover over a selection before touching and dragging the pen in stylus mode to pull the item away for opening on screen. The selection can open beside the currently open process by dragging the icon to the left or right fifth of the screen or open full screen closing other processes by dragging the icon to the center (Figure 34).

If a category has subsections these also appear when dragging the main category from the flower menu. Holding a category menu in place for three seconds locks the menu as active and opens the category in the designated area (Figure 35).



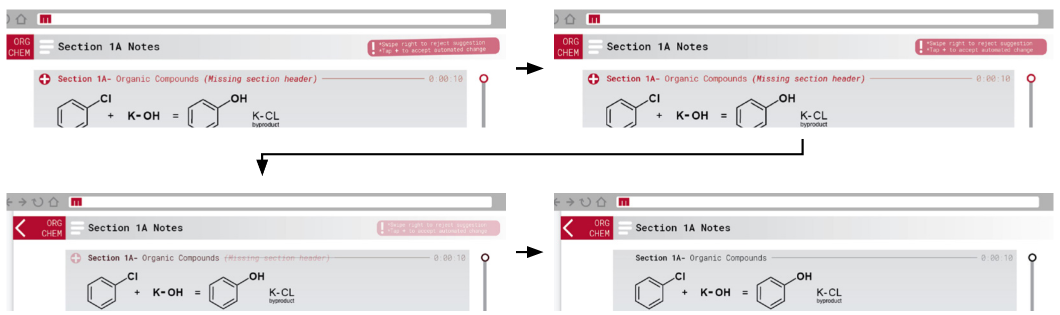
F33: Opening the smartpen flower menu and rearranging categories

F34: Opening a category on the flower menu bv dragging to center

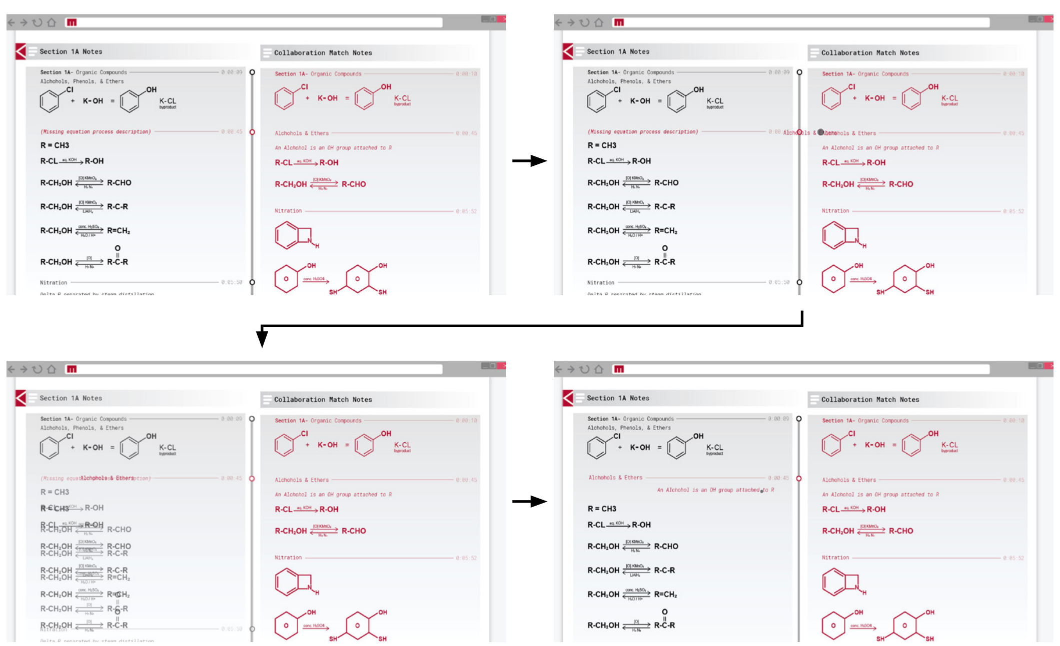


F35: Dragging a category in the flower menu to one point on screen and locking menu as active

Interaction gestures are how the user interacts with the content of an open category. Due to laser tracking, Recollection keeps track of screen location and users can directly interact by tapping video controls in lectures, toggle notifications, and confirming suggested changes (Figure 36). While comparing notes, swiping a selection from matched peers notes to your own will enhance your notes with the desired piece (Figure 37).

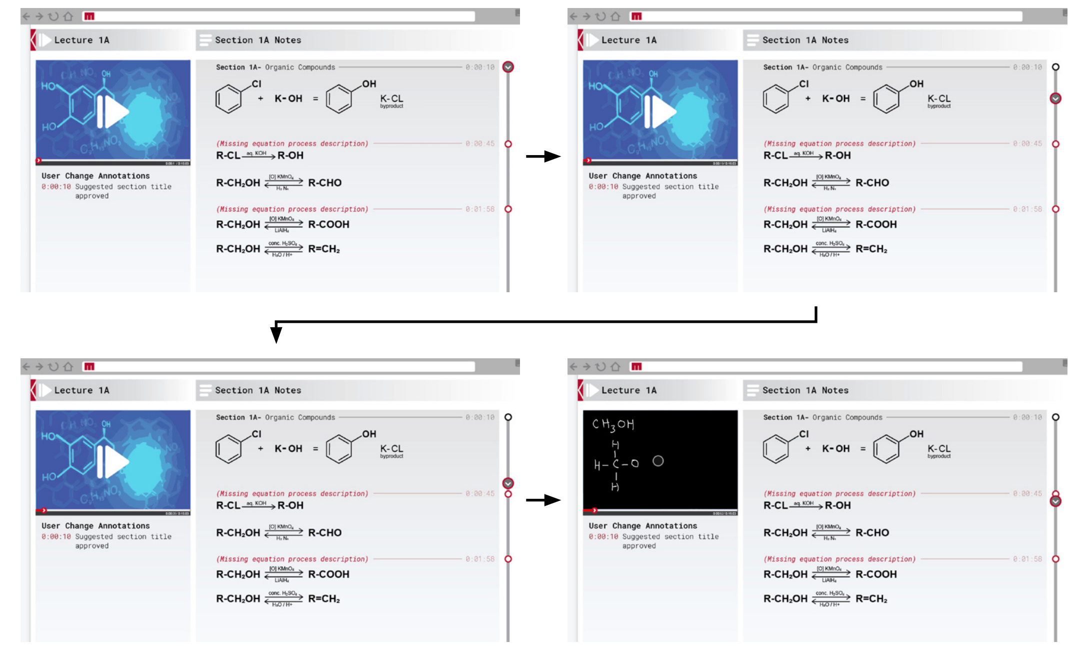


F36: Approving a suggested document change indicated by the red "+"

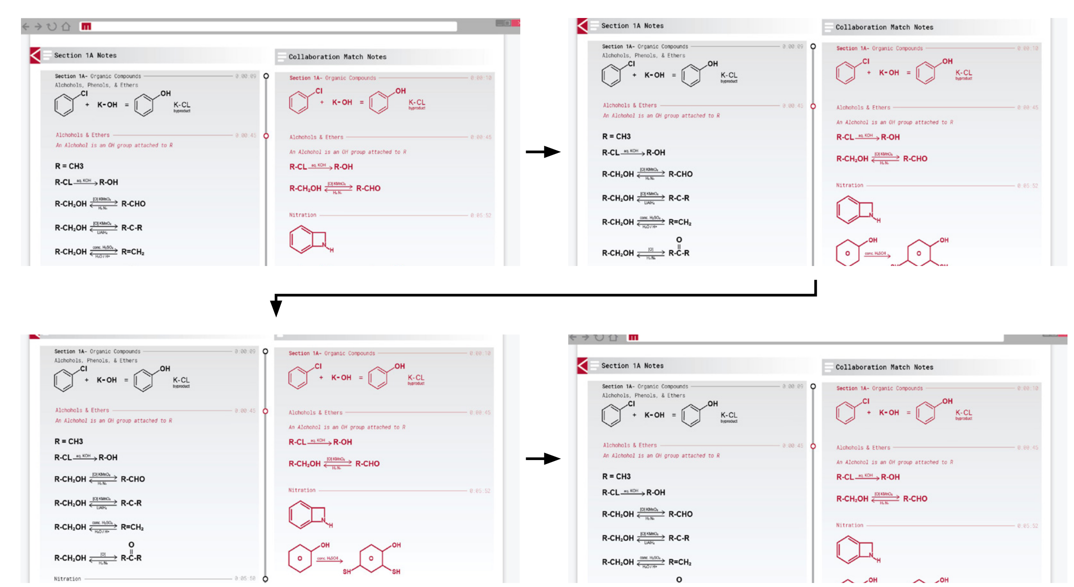


F37: Swiping left on a peer's note during collaboration

While taking notes, Recollection uses its microphone and connection to the LMS to record the lecture time and position of the note. Using this information allows Recollection to provide timestamps for digital notes and allows for easy lecture navigation using these markers. This extends to the notes of peers and any notes you bring to your own from the collaboration include a lecture timestamp. A single tap and hold of the Recollection pen side button allows for simple navigation gestures such as scrolling through notes until the button is released (Figures 38 and 39).

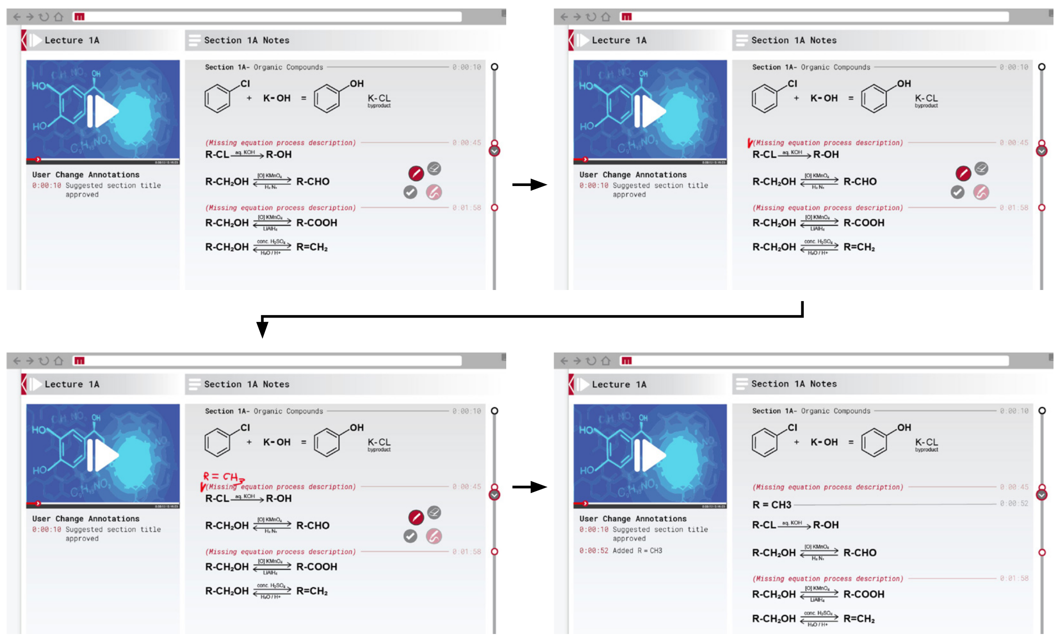


F38: Scrolling through a lecture video using the notes timeline



F39: Scrolling through a notes as a gesture using the side button

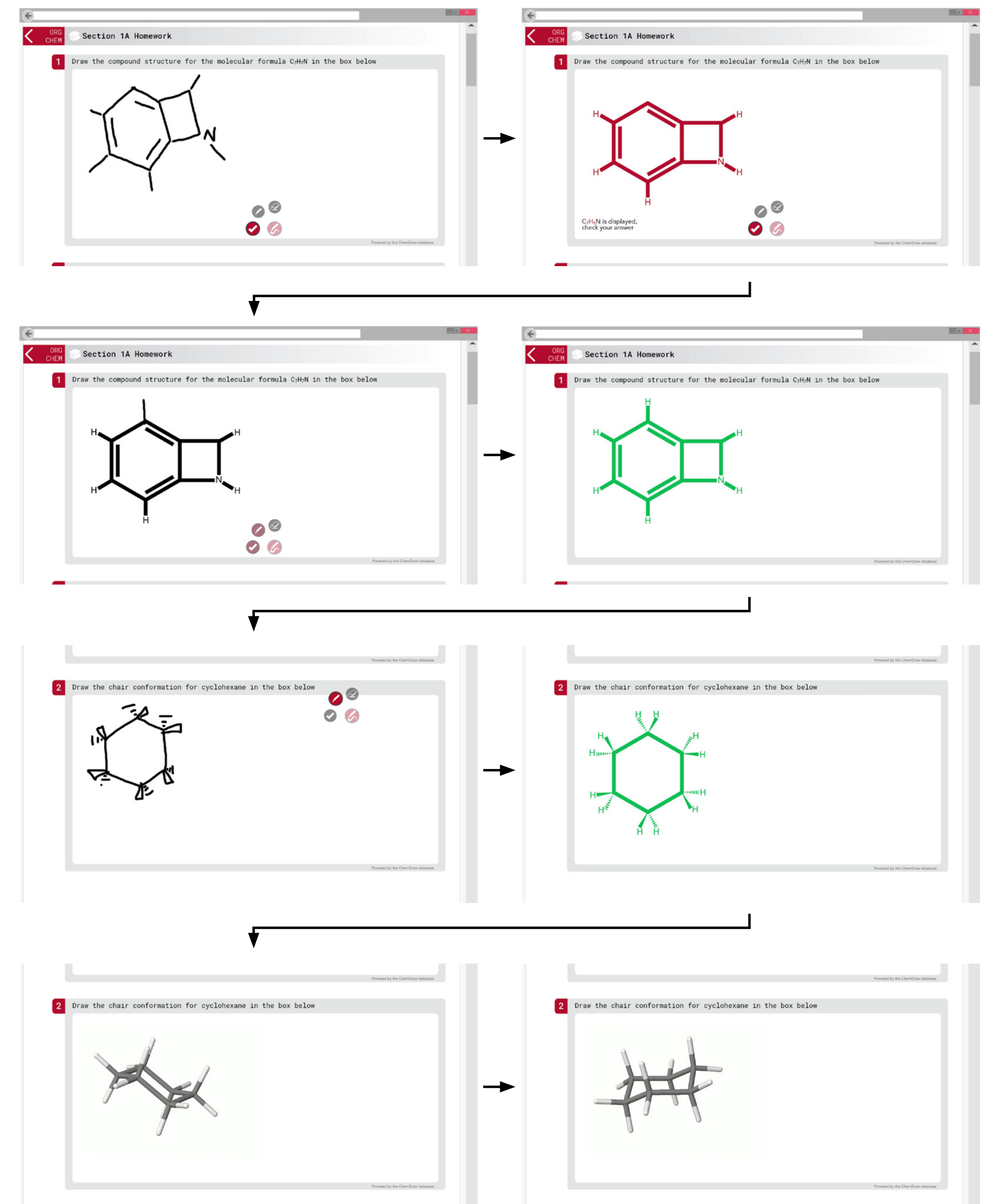
Editing gestures include both text and drawing. To access the editing menu the user either taps in a drawable area with Recollection or selects the pen tool from the flower menu (Figures 35 and 41). With the pen tool active, drawing key editors' marks such as insert or remove will transitions notes into an editing phase where you can directly write notes on the screen and add to what you already have. These added notes will share the timestamp of the already existing note. (Figure 40)



F40: Adding notes to existing using gesture

Drawing occurs in both notes and homework. OCR utilizes ML to ensure recognition and clean-up of everything that users write or draw for use on screen. Pressing the side button on Recollection and holding allows you to do things like spin the chemical model in 3-dimensional form.

When completing homework, a student can check their answer by selecting the check icon on the pen tool menu. If correct the answer turns green, and if wrong the incorrect area will turn red. ML ensures that reactive feedback indicates where the student strayed. (Figure 41)



F41: Drawing for homeworks equations and recieving feedback

"There is **potential for handwritten notes** in digital spaces with the **integration of smartpens.**"

(Mueller and Oppenheimer, 2014)

DISCUSSION

LMS have already changed how we learn, but now they need refinement to become a more efficient and helpful system. A finalized, full LMS overhaul would require the collaborative efforts of graphic designers alongside computer scientists. My investigation indicates how beneficial the potential smartpen Recollection would be to an LMS. I was able to explore how students would interact with the Recollection interface and what affordances it has to offer. I was also able to track the path of technology developments to design a pen that would best fit future implementation with the fewest drawbacks while exploring individual problems such as answer feedback and memory retention within an LMS. A smartpen allows for creative user interfaces that help break away from the window-confined experience. By exploring creative ways to navigate and interact with an LMS, I break the trend that limits an LMS to a filing system of assignments.

While revolutionary, a smartpen interface opens the door to further exploration. With privacy becoming a large concern inside of all digital systems and devices, future students may not be as open to collaboration, even if the collaboration is anonymous, as is the case with my UI system. Future exploration could focus on new ways to enhance notes from the practice of homework or even expand ML integration to suggest changes to student notes from the lecture or a teacher's set of expert notes. In this case, an LMS may even gain the potential to teach good note-taking skills that are specific to a course.

Further research would also need to consider accessibility to multi-language courses and to users with physical or visual disabilities. Multiple languages would require an extensive OCR database that could identify different languages, which would allow the Recollection UI to work in international courses where students might otherwise not understand one another. Concerning accessibility, students may not be able to write or draw due to a physical (e.g., motor) disability, and for these cases, the UI will need to adapt to allow equal access.

The Recollection UI is only the beginning stage of potential interfaces that can change how we interact with software. In the future, potential input devices will emerge that need unique UI designs. It will be important to emphasize quality alongside efficiency to build the most user-friendly and helpful systems. As designers, it is our job to collaborate as we respond to a new era of input devices and interface designs.

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