<table>
<thead>
<tr>
<th>Title</th>
<th>Establishing Validity of a Novel Eye-Tracking Data Analysis Technique to Chemistry Education Research and Application to Online Chemistry Laboratory Prelab Materials</th>
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<tbody>
<tr>
<td>Name of PI</td>
<td>Justin M. Shorb</td>
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<td>Department of PI</td>
<td>Chemistry</td>
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<tr>
<td>Name(s) of collaborators</td>
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<tr>
<td>Undergraduates Associated with Project: (Give names if known or simply numbers if students are not yet identified)</td>
<td>Two undergraduate students.</td>
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<tr>
<td>Projected start date</td>
<td>May, 2016</td>
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<td>Projected end date</td>
<td>May, 2017</td>
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<td>Total Budget Requested</td>
<td>$13,199.15</td>
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The advent of digital multimedia resources in education has required careful thought as to the best methods for organizing and creating them so as best to help students learn complex concepts. This issue is highlighted within the field of Chemistry Education due to the need to relay concepts that cannot be visualized without some level of abstraction and representation. Recent work in understanding student engagement with digital tools has led to the use of eye-tracking technology to monitor student gaze patterns. Until recently, it has been impossible to correlate gaze patterns across more than two areas of interest (a paragraph, an equation, and a picture would be three areas of interest). Our group’s novel transition-frequency principle component analysis method allows for more complex coupled gaze patterns to be quantified. In order for this method to be proven useful, it is essential that it be validated against a literature precedent. This project proposes to use eye-tracking and our novel analysis method to confirm the pivotal study by Kozma and Russell in 1997 which proved a measurable difference between experts and novices in their representational literacy of chemistry concepts. After validating the new analysis method against the literature precedent, we will then use this method to study the efficacy of a website designed to increase representational competency in general chemistry laboratories. By providing a study that validates the method and a short follow-up study we will be able to demonstrate reproducibility and potential application for the novel eye-tracking data analysis method for broader use.
1 Project Description

1.1 Significance of Work

Higher education is increasingly reliant upon digital learning tools and learning environments such as Course Management Systems with online homework or online textbooks. While at UW-Madison, we designed a prototype online textbook by looking at the literature on hypertext learning. ChemPaths is now an online textbook hosted by the American Chemical Society (ACS) as a product of the NSF National STEM Digital Libraries (NSDL) project with over 170,000 visits during the last school year. This year, our group has been awarded an NSF Improving Undergraduate STEM Education (IUSE) Grant to incorporate the material from ChemPaths into the STEMWiki Hyperlibrary project (http://chemwiki.ucdavis.edu) in collaboration with other institutions across the country.

Prior research into how students navigate online was critical to the success of the ChemPaths project. However, more research is needed to expand our understanding of how students interact with the complex set of representations used to describe chemical concepts. To understand the cognitive approach students take to problem solving, chemistry education researchers have begun to utilize eye-tracking technology. Eye-tracking technology uses a small infrared light and its reflection off of the eye to measure where a subject is looking in a non-intrusive fashion. Because the brain must look at something in order to interpret its semantic meaning, eye-tracking has been seen as a way to indirectly study the cognitive attention of a learner. Tang and Pienta, for instance, studied the complexity of gas law problems. Student’s gaze time was captured as they spent time understanding the information given, used a tablet pen to sketch out an algorithm to solve the problem, and finally used a calculator on-screen to arrive at an answer.

Kozma and Russell’s foundational work on multimedia representations in chemistry and expert vs. novice responses was pivotal to recognizing that chemistry educators must design online interfaces to incorporate the Triplet Relationship: symbolic, macroscopic, and submicroscopic representations of chemical phenomena. This same eye-tracking technology can prove immensely useful in analyzing student understanding of chemical concepts by their interactions with the Triplet Relationship. However, until now there has been no way to quantify the interaction between more than two areas of interest in an eye-tracking study. Research in our group has culminated in a novel data analysis method that allows for quantifying coupling strengths between any number of areas of interest during an eye-tracking study. Being able to look at the visual interactions students have with content on-screen creates many opportunities for research into cognitive theories about learning chemical concepts, pedagogical design of online media, and interactive online learning tools. Already, a collaborative project with Jessica VandenPlas and Tom Pentecost at Grand Valley State University has provided more in-depth eye-tracking analysis beyond studies they have already completed.
1.2 Objectives

With this novel analysis method, we can evaluate student engagement with representations in digital media. The first step in establishing the ability of this method to distinguish between novice and expert mental schemas is to reproduce the study by Kozma and Russell. In their study, experts and novices were tasked with sorting various chemistry representations shown to them on paper cards (pictures of real-world experiments, graphs of data, chemical formulas, or equations). In the proposed study, a website has been designed that presents subjects multiple images and asks them to find three that are similar and click on them (see Figure 2). While performing this task, the subjects will also be monitored using an eye-tracker to observe their gaze patterns. The results of the clicking should reproduce the results of Kozma and Russell, and allow for comparison to the eye-tracking data to validate the analysis method. Once validated against prior literature results, another eye-tracking experiment will be conducted to evaluate the ChemLabs@Hope website which has been intentionally designed to integrate the Symbolic, Macroscopic, and Submicroscopic representations relevant to laboratory exercises in General Chemistry. The researchable questions relevant to this proposal are:

Q1. Can the novel eye-tracking analysis method reproduce the novice and expert behavior found by Kozma and Russell?

Q2. Does the layout of the ChemLabs@Hope website effectively stimulate students to interact with all three levels of representation as measured by eye-tracking?

1.3 Methods

Eye tracking studies monitor the gaze of a person by looking at an infrared reflection off of the cornea of the eye. Precision of the gaze point can be less than the size of one letter on a screen, so it offers a way to gain knowledge of precisely where subjects are looking. The Information Processing Model in cognitive psychology reveals that in order to build new knowledge, one must first interact with some external stimuli and store these thoughts in a temporary fashion, referred to as “Working Memory.” As subjects view items on the screen, their working memory becomes overloaded (most people can only hold 4-5 concepts in their working memory at once). Thus, while viewing new information with multiple representations, subjects must move their gaze between various representations in order to build connections. The novel transition frequency principle component approach to analyzing eye tracking data allows for extrapolation of high and low frequency couplings between any number of areas on a screen. The algorithm is designed akin to principle component analysis (from social science applications) or eigenvalue/eigenvalue decomposition (from mathematics applications). For instance, in the multiple choice question shown in Figure 1(a), a heat map of gaze fixations is shown where brighter regions reveal longer and more frequent viewing. After the analysis using our method, a set of strong coupling behaviors are shown in Figure 1 (b,c). Figure 1 (b) shows the strongest coupling behavior of primarily reading the question and reflecting back on the question while reading the answers (strongest focus is on the question with positive correlation with each
answer). The second strongest reading behavior is shown in Figure 1 (c) indicating that this subject had a strong coupling between answers B and C (the correct answer was C).

![Figure 1: Eye-tracking data for a multiple choice chemistry question showing (a) heat map of gaze fixations and the trace of the eye gaze sequence, (b) and (c) the two strongest coupled gaze patterns after performing the novel transition frequency analysis.](image)

This is informative to the analysis as it shows that this subject quickly ruled out the answers involving “polar” and instead focused on comparing two answers involving “non-polar” responses. This same coupled-gaze analysis will be applied to the website shown in Figure 2.

![Figures 2 and 3: Left: Prototype of the website subjects will interact with during the first study. They will be prompted to click on three images they think are most similar and their gaze patterns will be observed during the task. Right: Screenshot of the first step of a laboratory prelab site for acetic acid titrations used at Hope College.](image)

In the second study, participants (both experts and novices) will be asked to write a flow-chart of a laboratory procedure using the online prelab website ChemLabs@Hope, such as the site shown in Figure 3. This website has been designed to use the macroscopic, symbolic, and submicroscopic representations from left to right for each step of the procedure.

### 1.4 Expected Outcomes

Q1: It is expected that the method will reveal coupled-gaze patterns that differ between experts and novices in chemistry based on their ability to find connections between different representations. The gaze patterns will be quantified so that this difference can be compared between the two groups similar to the work done by Kozma and Russell.\(^9\)
Q2: It is expected that the level of depth in the students’ flowcharts will correlate to their gaze patterns of different representations on the prelab website. This fundamental research will allow further exploration into testing design principles in multimedia design in chemistry education.

In addition to the outcomes of the research, itself, it should be noted that past undergraduates on this project have moved on to graduate careers in computational genomics and in computational biology. The mathematical skills involved in this sort of analysis prepares students for a wide range of future careers in the computational sciences (PCA approaches are common in biochemical fields, structural analysis, and in social science research).

1.5 Potential Difficulties

Hope College does not have an eye-tracker, thus this research will be performed in collaboration with VandenPlas at GVSU. We expect to still be able to work with her group (see letter of support). Thus, part of the grant budget is for paying for subjects in the study (once we recruit subjects, they can perform more than one eye-tracking experiment in a short amount of time).

1.6 Connection to other HHMI Programs

This work supports ongoing efforts for course development in chemistry, but only in an indirect way as we use the information in this analysis to develop more online educational tools.

1.7 Plans for External Funding To Continue Work

The current NSF grant for the ChemWiki/STEMwiki only covers adding new content to the existing site and recruiting other STEM fields to join the project. It is hoped that this validation study will allow for future grants with this consortium to study pedagogical design of a cross-disciplinary STEM online hyperlibrary. The validation of this novel method will allow for other cognitive science research to be conducted, expanding the depth of the more preliminary eye-tracking analysis of Chem Tutor.5

1.8 Timeline

Activities falling within the realm of this study are categorized below as either in response to Question 1 (Q1) or Question 2 (Q2).

Fall 2015: Pilot study is being conducted as part of an existing study at GVSU (Q1).
Spring 2016: Analyze pilot study data (Q1) and write HSRB protocols for Q2 for summer.
Summer 2016: Run both experiments with the same subject pools at GVSU (Q1 and Q2). Undergraduate researchers will work on recruitment of subjects, conducting eye tracking studies, and analyzing the data. Begin writing manuscript for Q1 and Q2.
AY 2016-2017: Write manuscripts for publication (Q1 and Q2).
2 Bibliography/References

(1) Shorb, J. M.; Moore, J. W. In Enhancing Learning with Online Resources, Social Networking, and Digital Libraries; ACS Symposium Series; American Chemical Society, 2010; Vol. 1060, pp 283–308.

(2) Lubliner, D. In Learning with Online Resources, Social Networking, and Digital Libraries; Belford, R., Pence, H., Moore, J. W., Eds.


3 Biographical Sketches

Justin M. Shorb

A. Professional Preparation
Hope College    Chemistry (A.C.S. Certified)  B.S. 2004
Hope College    Mathematics    B.A. 2004
University of Wisconsin–Madison    Chemistry    Ph.D. 2011

B. Appointments
Assistant Professor of Chemistry and First-Year Laboratory Coordinator,
Hope College. 2014 to Present.
Assistant Professor of Chemistry,
University of the Virgin Islands. 2011 to 2014.

C. Selected Publications
Shorb, J. M.; Moore, J. W. In Enhancing Learning with Online Resources, Social Networking, and Digital Libraries; ACS Symposium Series; American Chemical Society, 2010; Vol. 1060, pp. 283–308.

D. Selected Presentations
BCCE 2014 Conference (08/14)
Use of water quality tests as a foundation for a more inquiry-based general chemistry laboratory.
ACS 240th National Meeting, Boston 08/10
Online textbooks are more than an online book: The development of ChemPaths online student portal
BCCE2010, 08/10
Using Social Networking in Chemical Education (workshop co-leader);
ChemPRIME wiki-text: The chemistry behind your favorite subject;
UW–Madison Teaching and Learning Symposium, 05/10
Making Online Resources Cohesive in a Chemistry Course
1st Annual Conference on Multi-Sensory Science Education, 10/09
Incorporating Multi-Sensory Education in an Advanced General Chemistry Course
Social Networking Symposium, ACS National Meeting, 08/08

E. Collaborators and Other Affiliations
Jessica VandenPlas (Grand Valley State University)
Thomas Pentecost (Grand Valley State University)
Kelly Neiles (St. Mary’s College of Maryland)
John W. Moore (University of Wisconsin-Madison)
F. Graduate and Postgraduate Advisors
Graduate Thesis Advisor and Postdoctoral Advisor: John W. Moore (University of Wisconsin – Madison)
Graduate Thesis co-Advisor: James Skinner (University of Wisconsin – Madison)

F. Undergraduate Students Supervised
At Hope College:
Sarah Mattioli, Elizabeth Ensink, Yong Chul Yoon, Daniela Aguilar, Kirsten Monson, Emma Ropski, Laura Persenaire, Morgan Ricker, Joshua Dykstra
At University of the Virgin Islands:
Murchricia Charles, Chantel Ible, Clyde Joseph, Micadel Hazell, Keturah Bethel, Lorne Joseph
4 Current and Pending Support

**Current:** Departmental discretionary funds for supplies and laboratory space and student staff workers during summer months.

(a) NSF DUE-1524990: $35,741 October 2015 until September 2017.
(b) **Collaborative Research: Developing and Assessing Effective Cyberlearning within the STEMWiki Hyperlibrary**
(c) **Intellectual Merits:** Although just having started, this grant aims to increase the potential of massive online free textbooks by expanding the start from ChemWiki to an entire hyperlibrary of STEM textbooks that are interlinked. **Broader Impacts:** This high-quality free textbook alternative gives open access to students from all backgrounds. This helps to alleviate inequalities in the earlier parts of the STEM pipeline. Grant just started and funding is for work primarily starting in January of 2017.
(d) No Publications.
(e) Currently, the entirety of the ChemPRIME Wiki textbook (resulting from prior work) exists and is freely available under Creative Commons license online (http://wiki.chemprime.chemeddl.org). This will be incorporated into the ChemWiki.

**Pending:** MSGC Research Seed Grant. $5000 with $5000 matching from the Dean of Natural and Applied Sciences at Hope College.
November 2, 2015

Dr. Justin M. Shorb  
Assistant Professor of Chemistry  
Hope College  
35 E. 12th st.  
Holland, MI 49423

Dear Justin:

I am excited to continue our collaboration involving eye-tracking studies in Chemistry Education and I support your efforts in seeking funding from Hope College’s HHMI Faculty Research Award Program. Thus far, our groups have worked collaboratively in facilitating a summer training program at Hope College (The 2015 SciEd Research Summit on Pedagogical Design and Evaluation), in analyzing eye-tracking data collected here at GVSU (including shared data), and in our current efforts to share participants in ongoing eye-tracking experiments.

By way of this letter, I acknowledge this ongoing collaboration and my willingness to continue to work with your group in sharing non-identifying subject data and the use of GVSU’s eye-tracker for collaborative studies. Collaborative work allows our group’s to benefit from each of our individual strengths as your group continues to focus on statistical methodology and pedagogical design and my group continues to focus on cognitive psychology and problem-solving analysis.

I look forward to our continued collaboration!

Thank you,

Jessica VandenPlas  
Assistant Professor of Chemistry  
Grand Valley State University  
1 Campus Dr.  
Allendale, MI 49401