CILT-2002 Final Report

PROJECT TITLE:

Assessment of Problem-Solving Competence Via Student-Constructed Visual Representations of Scientific Phenomena

PARTICIPANTS

Principal Investigator:

Jerry P. Suits, Coordinator of LS-LAMP Instructional Technology, Assistant Professor, McNeese State University, suits@mail.mcneese.edu

Co-Principal Investigator:

Louis Abrahamson, CEO, Better Education Inc., la@bedu.com

Participants from the following groups:

1. *Chemical Educators:*

Jerry P. Suits, **Melanie Soileau**, **Karen Hypolite**, **& Moustapha Diack** (LS-LAMP)
Tina Stanford, **Anders Rosenquist, & Patricia Schank** (SRI/*ChemSense*)
Rebecca Pease, **Terry Vendlinski** , & Ron Stevens (IMMEX/UCLA)

2. *Physics Educators:*

Louis Abrahamson (Better Education Inc.)& Marty Abrahamson (eInstruction)

3. *Engineering Educators*

Sean Brophy (NTara/Vanderbilt)

WEBSITE: ***Under Construction***

http://briefcase.yahoo.com
Registered with Yahoo:
ID: ciltgroup
PW: chemvis

PROJECT SUMMARY

Introduction: ***What was the work you did?***

The first of two workshop meetings on student-constructed visualizations was held September 27-29 in New Orleans, LA (Appendix I). The session began with presentations describing the learning environments and formative assessment tools currently being used by the attending groups or individuals (e.g. IMMEX, *ChemSense*, Classroom Communication System, etc.). Participants tried to communicate the strengths of these environments and tools such that they could be applied to the objective of the workshop. Many of these ideas were implemented in a college chemistry classroom, CHEM 101 (General Chemistry I), at McNeese State University during November and December of the Fall 2002 semester.

The second workshop meeting was held February 21-23 in Menlo Park, CA (Appendix II). It focused upon plausible ways to coordinate these assessment tools to achieve the specific sub-goals of the workshop (see next section). At the first workshop in New Orleans, chemistry was selected as the domain to be studied due to its emphasis upon quantitative problems that can be modeled through mathematical relations and explicitly expressed through visual representations.

Comprehensive goals: ***For what purpose?***

Goal of the first workshop: The group discussed a variety of ways to achieve the overall goal for the project, which is "to develop a theoretical framework (blueprint) for the integrated design of assessment tools & learning environments to support and evaluate students' constructed visual representations of quantitative problems across several domains". During the meeting the group approached this goal by exploring factors related to designing instruction tools that include learning activities that employ visualizations and provide opportunities to gather assessment/evaluation information.

Goal for the second workshop. The goal for this second CILT-funded workshop was to design a pragmatic pedagogic model that focuses upon technology-based support for and assessment of student-constructed/co-constructed visual representations of scientific phenomena. The group agreed that the primary learning objective is "students are able to use visualization methods as tools for solving quantitative problems" and that this objective should include several other sub-objectives. For example, students should be able to use visualizations as tools to assist in:

1) interpreting data
2) performing mathematical operations on data
3) managing the complexity of information (interrelationships between concepts and causation)
4) explaining/communicating concepts to others (Based on Penuel, 2001).

Each of these application skills requires both conceptual and procedural knowledge at various levels. Assessment items can be created to target each of these objectives. However, the specifics are bound by the domain knowledge to be learned.

Who were the collaborators?

The collaborators were the participants who attended the two CILT assessment-visualization workshops (names in **bold** in Appendix I and II) held in New Orleans, LA and Menlo Park, CA. Also, the Classroom Communication System (CCS) used for assessment in the pilot study was donated by Marty Abrahamson of eInstruction, Inc. Stephen Kosslyn (Harvard) and Maria Kozhevnikov (Rutgers) provided the *Visual Imagers Self-Report Questionnaire* (VIQ) used to classify the cognitive styles of students in the pilot study class as visualizers (two subgroups) or verbalizers.

Research methodology: ***Agenda developed during the first workshop.***

The tasks facing the group were to combine learning/assessment tools into an inquiry model that supports both classroom and individual learning, and to design an instructional sequence that helps students solve a class of problems that requires the synthesis of several core chemistry concepts. Discussion of these tasks elucidated possibilities to work toward. For example, these concepts could be explored through classroom discourse mediated by a CCS (Appendix III) and through learning activities designed with *ChemSense*. The CCS is a natural formative assessment method, but it requires the design of good questions that help students understand the relationships among core concepts. *ChemSense* is a great inquiry environment that encourages peer interaction to help students refine their models (visualizations). Our ultimate goal would be to prepare students to solve problems in the IMMEX system. The group created a "prototype" instructional sequence based on the current configuration of these tools. The main intellectual endeavor was focused on the identification of content specific learning goals, the development of learning activities for *ChemSense*, and the creation of assessment items (that relate to "visualization" objectives) for the CCS and IMMEX. During this process a list of other "visualization" activities that can be supported with technologies could be developed. The "learning approaches" framework could be to help evaluate assessment items that help determine if the instruction tends to drive students toward a particular approach. At the heart of this investigation are the domain concepts and procedures the students should know and be able to do by the end of a course. Therefore, recognizing specific learning goals that identify precisely what students should be able to do should drive the assessment items we design. Second, identification of which concepts are easy and hard for student to comprehend is needed. This will drive the kinds of learning activities (for *ChemSense* and others methods) and questions that must be defined for the CCS and IMMEX. Concepts commonly known to be difficult to understand should be targeted. In addition, research similar to that conducted by some group members could be used to isolate misconceptions or other areas of frequent difficulty.

Suggested tasks for group members to achieve before the second meeting were to perform a few experiments to identify students' difficulties as well as opportunities to apply the tools we explored in the first session. A list of such actions would include the following:

1) Define specific chemistry concepts to be investigated and the learning objectives associated with these concepts.
2) Use of a CCS system by group members where appropriate
3) Define CCS questions that can be used as part of class time
4) Define exam question(s) that meet objectives of display both conceptual and procedural knowledge
5) Define a rubric for scoring exam question(s)
6) Score exam to identify what students are still having trouble understanding

During the second workshop the group reviewed these exam items and began designing other learning activities for *ChemSense* to support the development of students' conceptual understanding as well as potential problem sets for IMMEX.

RESULTS AND IMPLICATIONS

Findings: ***What findings/products did your work produce?***

The participants of the New Orleans CILT Workshop on Visualization and Assessment decided to perform a pilot study using a college chemistry class, CHEM 101-A (General Chemistry I), taught by the P.I. during the Fall 2002 semester. The primary learning objective of this study is described in the section on Comprehensive Goals. The workshop inspired the use of two technology-based instructional interventions (see below): (1) an interactive gas law multimedia module, and (2) an interactive CCS, which was used for formative assessment of student misconceptions during an in-class review for the comprehensive final examination.

Thirty-seven of the 58 students who initially enrolled in the course completed the course with a passing grade. During the first week of instruction a standardized pretest of prior knowledge of chemistry (California Chemistry Diagnostic Test) was administered to the class. They also took the *Visual Imager Questionnaire* (VIQ) (Kozhevnikov, Hegarty, & Mayer, 2002) that classified the cognitive style of each student as being a verbalizer, object visualizer, or spatial visualizer (Appendix Iv, Fig. 1). Only the spatial visualizer style produced a significant correlation with the achievement measures used in the course (Appendix IV, Fig. 2). For the students who completed the course, only a few of them had good prior knowledge (13.2 % of the students), whereas most had either a fair prior knowledge (47.4 %) or a poor knowledge (39.5 %) of chemistry. The final grade distribution was as follows: 10.5 % A, 39.5 % B, 34.2 % C, 13.2 % D, and 2.6 % F.

Visualization Aided by an Interactive Gas Law Multimedia Module.

For the hour examination (Test 3) on the gas laws, students in the pilot study class participated in an in-class review in which they interacted with a gas law multimedia module that featured visual animations (App. IV, Fig. 3) and sketches of chemical phenomena. Most of the 29 students who participated filled out an anonymous questionnaire immediately after using the module as a learning tool. They like the module for a variety of reasons. First, and foremost, five students appreciated the visual features of the multimedia module: One student wrote that "I learned how to visuilize the problem." Another one commented that "It helped give me a visual picture of the calculations." These two written comments support the premise of this CILT research project, i.e., when students interact with visualizations of chemical phenomena, they can develop both their procedural and conceptual knowledge as it applies to the phenomena. Five students expressed positive affects about the module and its value. For example, "The dude talking was funny & it explained before it gave a problem." Five other students liked the real world applications featured in the module, e.g. "The Questions about the air bag w/ the information that went along with it." Finally, seven students focused on its value as a formative assessment tool that helped them prepare for the examination, e.g., "It asked good questions and it wasn't graded so I wasn't afraid to answer wrong."

Apparently one particular student benefited greatly from the module (Appendix III) because she scored a "96" on that examination, which exceeded her scores on the other hour exams (78, 64, and 67) and her score of 67 on the comprehensive final examination. Indirect evidence that the module may have contributed to her success was that she did well on questions that required both conceptual and procedural (computational word problems) knowledge (App. IV, Fig. 4). Her integration of these two types of knowledge gives some evidence that she truly understood chemistry. Conversely, normally only those students with very high averages perform well on problems requiring both types of knowledge. Her greater level of success on this examination, might be due to an interaction effect between her cognitive style and the objects visualized and animated in the multimedia module. That is, she was classified as an "object imager" on the VIQ due to her high score (+1.33) on the object imagery subtest as compared to her neutral score on the spatial imagery subtest (+0.20) and her negative score the verbalizer subtest (-0.60). Direct support for this inference may be drawn from one of the conceptual/procedural questions, Question 5 (App. IV, Fig. 4) of the 8 questions on the exam. She drew a detailed sketch of a boy, "Cajun Charlie," (see Appendix IV, Fig. 4) who was using bubble gum to blow a large bubble. She also correctly answered the quantitative gas flow problem, i.e., moles of gas needed to re-inflate the bubble to a different volume.

Use of a Classroom Communication System (CCS) for Formative Assessment.

During an in-class review session for the final examination in the pilot study, students used response pads, similar to TV remotes (see Appendix III), to answer multiple choice questions that incorporated visual representations. Students read the question presented on the projection screen (LCD projector and PC), and then keyed in their answer on a response pad with a particular carrier frequency. As they responded, their assigned number on a grid below the question underwent a change from a white background around the number to a blue background. When most of the students had responded, the P.I. signaled the CILT administrative assistant to stop the process and to display a histogram of the results. To resolve any conflicts, the students were given one or two minutes to discuss answers with their neighbors and then re-answer the same question. For four of five cases in which the student responses were initially divided among several answers, their discourse produced a shift in response frequency from an incorrect answer to the correct answer. In the other case, a shift was made to another incorrect answer. In this last case, the P.I. described how the correct answer could be obtained. This process tended to expose misconceptions in a manner that allowed them to see why their answer was incorrect.

As indicated by their comments, written immediately after they took the final examination, most students were very enthusiastic about the pedagogic value of this visually-based formative assessment method. Of the 25 students who responded, six stated that they thought the CCS method helped them prepare for the final examination. One student stated that the method was "very helpful to me, it gave me a better understanding about the final." Eight students focused upon the positive affect they felt about using the method, e.g. "a great study guide and it was very fun to do!" Three students cited reasons that expressed the goal of this research project, i.e., the method was "very helpful. I could visualize the experiment." Another student wrote that it was "interesting, I can picture things better." One student appreciated the feedback feature of the method, "I thought it was really cool. The technology & discussion helps me learn better. I can learn why I got the answer wrong." Four students were impressed with the collaborative aspect of discourse stage. For example, it was "wonderful, it made us think and work well as a team." Overall, these comments seem to indicate that the interactive and discursive aspects of the ICRS method established a conducive visually-rich learning environment.

Implications: ***What are the implications of these results for the field?***

Our tentative results, based upon a small sample, seem to indicate that visually rich learning and assessment environments can be especially beneficial to students with certain cognitive styles based upon VIQ classification scheme (App. IV, Fig. 1). Those students who preferred the "object imagery" style seem to achieve much higher than their prior knowledge and abilities would predict for this exam. Conversely, students who have a very strong preference for a more verbal style might do well with the traditional lecture method. These implications are extremely tentative, and should be subjected to further study.

LESSONS LEARNED: COLLABORATION

How successful do you consider this collaboration to have been?

This collaboration among the diverse groups of CILT participants at our New Orleans Workshop was very productive. Each research group presented ideas that made for a viable prototypic instructional design model that could increase the diversity of students who can be successful in the sciences at solving quantitative problems. Therefore, the absence of any one group would have resulted in a model that was lacking in at least one essential attribute of the model.

What did you learn about the challenges of cross-institutional collaboration and ways to combat those challenges?

We learned that ideas can be generated during both formal presentations and informal discussions among participants. An example of the latter aspect occurred during a cab ride to the airport between two of the participants. Our findings might have been greatly limited, if they had taken separate taxis

Many of you used yahoo groups (aka egroups) to communicate. Was this tool useful? In what ways?

We are just now beginning to use this tool. We would like to use it as a nucleation site for any future work that the group might attempt.

Are there other tools and support that would have made the process easier for you?

Perhaps some sort of telecommunication in which participants could see each other and discuss ideas in both formal and informal modes. We have not been overly impressed by facilities used in distance learning courses, which seem to be difficult to reserve and logistically awkward to use.

NEXT STEPS

Where will you go from here?

Discussion of this question was one of the focal points for the second workshop held at SRI. Our goal is to embed a tracking tool, e.g. IMMEX, within a learning environment, e.g. *ChemSense*, that allows student exploration of a phenomenon and its representations. Furthermore, the output of this interactive construction can be exported as data that can be parsed as saved as an XML file. This data set can be reconstructed such that it can serve as an artifact that allows student dissection and discussion of its efficacy with respect to scientific conceptions. Thus, student creativity is initially encouraged and the subsequently guided towards more scientifically correct conceptions.

Has this project resulted in any subsequent grants or proposals, or ideas that you will carry forward to future work?

No, however, this goal was discussed during formal and informal gatherings at the second workshop.

(1) Student Exploration of Representational Competence in Chemistry

The goal of this potential grant proposal is to use visualization and assessment technologies to support the development of student representational competence with respect to the construction of increasingly sophisticated chemical conceptions from the high school level to the college level of chemistry coursework. In the high school chemistry course, these technologies should scaffold student exploration of representations for nascent conceptions within a learning environment, i.e., *ChemSense*, which provides little or no constraints imposed by scientific conceptions. This creative exploration allows misconceptions to be externalized as artifacts that are subject to classroom discourse. It also supports student engagement in the construction of dynamic models through the linking of concrete components, i.e., icons, together to illustrate abstract relationships (Frederiksen, White, & Gutwill, 1999; White, 1993). At the college level, student exploration should be tempered by a set of constraints imposed by scientific models (e.g. three-dimensional molecular modeling based upon VSEPR theory). If the students make improper choices based on a lack of prior knowledge, then they should be greeted with corrective feedback messages. Conversely, if they are making decisions based upon their current nascent knowledge, then feedback should come directly from the underlying scientific model. When their decisions are guided by a misconception or misinformation, the model should generate a simulation that shows an undesirable outcome. For example, in a melting point simulation, the decision to heat a liquid would result in its increased vapor pressure until the boiling point is reached. This action could prompt a feedback message which states that the goal of the melting point experiment was not obtained by this inappropriate decision. Overall, students would begin by exploring a phenomenon at a coarse level, then they would receive feedback for their peers within a classroom culture that strives towards scientific understanding of phenomena and its representations. Subsequent exploration would help students develop this understanding and their representational competence at successively more refined levels.

(2) Use of the Classroom Communication System to Support Knowledge Co-construction

The CILT workshop participants are convinced that the classroom communication system (CCS) has a large potential for increasing students' learning. The system can provide diagnostic information teachers could use to refine their instruction to meet the needs of the students. Plus the public nature of the data helps students identify when they need help and what more they need to know. Louis Abrahamson used a diagram in his presentation to illustrate the cycle of students generating information that results in an "artifact" the class can use as a centerpiece for discussion, or that can be accessed privately by students as part of a self-assessment process. The current CCS's are one instance of a system that can collect students' information and quickly convert it into a representation the class can inspect and discuss the results. As we mentioned above more can still be pursued to explore the use the existing system in various context and use it in various ways. The next generation of CCS could have the ability to focus more on students' process skills (e.g. construction of a three-dimensional molecule from its concrete components—electron pairs and high-electron density regions).

(3) Use of Visualization Tools to Support Construction of a Model from Its Components

ChemSense, and the Free Body Diagram tool both have the capability of representing various states of students' construction process of visual models. One possible project to pursue is how to take these models and use them as artifacts for discussion in a classroom setting. Both *ChemSense*, and the Free Body Diagram tool outputs XML code to store various states of students' work. Both the *ChemSense* group and our ISIS group agree that these files can be easily parsed for specific information. The major issues include what data is interesting to inspect and how do we represent it in a way that could be easily interpreted by a class or teacher to help facilitate a class discussion or provide meaningful feedback to students? Both Patty and Larry (from Vanderbilt's ISIS group) feel parsing the files is not a huge technical issue if we know what data we want. Therefore, the chemistry experts in the group need to identify what is key to each representation. Some interesting research on learning could be generated from this investigation. We are considering writing a grant to support the construction of a general purpose-parsing tool that would help us parse and aggregate the data from these XML files. We believe both SRI and VaNTH have exactly the same goals in mind and would benefit from a joint venture to tackle this issue.

(4) Use of Formative Assessment Tools to Support Construction of Visual Models

Coupled with the project above the participants would like to develop methods for interpreting the data we gather from students' constructed artifacts. IMMEX is a system that already posses the capability of tracing students' decision-making process during a problem solving task, and then using neural networks to interpret this process. *ChemSense*, the Free Body Diagram tool, and Mous Diack's virtual lab all have the ability to track the various states of students' decision making process as they construct models or conduct experiments. If the project described above is successful, then we will have a method for gathering student data that could be interpreted by the neural network engine in the IMMEX systems. The expertise of the IMMEX team will be needed to help use develop methods for interpreting the results of this data. As a quick aside, Sean Brophy recalls a comment made by Alan Lesgold at the first CILT Assessment Workshop. Lesgold was impressed with Ron Steven's use of neural networks and thought more of this kind of work should be pursued as an analysis tool. He recommended that someone explore the benefits and limits of this approach within various contexts. We want to contact Ron's group to see if we could collaborate on this part of the project. Therefore, we see this grant option focusing on analysis methods of data items that represent intermediate stages of students' thinking rather than just the final stage. If we can automate the process and create a meaningful representation of this information, then it could potentially provide real time information that a teacher and students can use as a centerpiece for conversation. They could talk about various strategies used by the cohort of students, etc.

(5) Incorporation of Formative Assessment Tools Within Rich Learning Environments

Finally, Vanderbilt been working on a browser-based version of the CCS to use with the wireless laptops every undergraduate engineering student will soon own. We tested this system out last semester with great success. Patty and Larry expressed an interest in creating their own system using a lot of the infrastructure they already have in place. We would be interested in working together to define the next generation of these tools that is robust enough to use in our engineering courses and the classrooms using *ChemSense*. We should explore potential funding sources to support this effort.

RELATED RESOURCES

If someone else is interested in this topic, where should they go for more information? If you can, please provide links to related websites and other resources of interest.

Our CILT 2002 Visualization and Assessment website is as follows:

http://briefcase.yahoo.com

Registered with Yahoo:

ID: ciltgroup

PW: chemvis

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Appendix I: **CILT-2002 Assessment and Visualization Workshop # 1**

Clarion Hotel, 1300 Canal Street, New Orleans, LA September 27 to 29, 2002

Friday, 27th September

Arrival via vehicle or New Orleans Airport shuttle

7:00 – 8:30 pm Dinner and Social Mixer @ New Orleans Restaurant (Courtesy of McNeese Chemistry Department)

Saturday, 28th September

8:00-8:40 am Continental Breakfast

POWER POINT PRESENTATIONS		***Title:***
8:45–9:10 am	Jerry P. Suits & Melanie Soileau	Parameters for Student-Constructed Visualizations
9:15–9:40 am	Tina Stanford/ Patricia Schank/ Anders Rosenquist	Visualizing Chemical Concepts at the Fundamental Particle Level
9:45– 10:10 am	Karen Hypolite/ Mous Diack	Student Misconceptions, Visualization and Atomic Phenomena
10:15–10:30 am	*Morning Break*	
10:30– 10:55 am	Sean Brophy	Visualizations that Support Analysis, Decision Making and Concept Building
11:00– 11:25 am	Terry Vendlinski & Rebecca Pease	The Interactive Multi-Media Exercises: Assessing realistic problem solving
11:30–11:55 am	Louis Abrahamson	Ideas on a General Framework for Partially Automating Assessment of Complex Student Work-Products
Noon – 1:00 pm	***Catered Lunch***	

INTERACTIVE DEMONSTRATIONS		***Title:***
1:00 – 1:40 pm	Terry Vendlinski & Rebecca Pease	Knowing how you know, what you know…
1:45 – 2:25 pm	Tina Stanford/ Patricia Schank/ Anders Rosenquist	Demonstration of ChemSense Software
2:35 –2:50 pm	*Afternoon Break*	
3:00 – 5:00 pm	Brainstorming Discussion of Presentations and Demonstrations	
6:00 – 7:30 pm	Dinner @ New Orleans Restaurant	

Sunday, 29th September

8:00 – 8:35 am ***Continental Breakfast***

8:40 – 10:00 am Brainstorming Goal: Prototypic Visualization/Assessment Software

10:00 - ?? Departure to New Orleans Airport

Appendix II: **CILT Visualization and Assessment Workshop # 2**

SRI, Menlo Park, CA
February 21 -22, 2003

Overview:

The goal of this second CILT-funded workshop is to design a pragmatic pedagogic model that focuses upon technology-based support for and assessment of student-constructed/co-constructed visual representations of scientific phenomena. At the first workshop in New Orleans, chemistry was selected as the domain to be studied due to its emphasis upon quantitative problems that can be modeled through mathematical relations and explicitly expressed through visual representations. Also, several participants have used their expertise in either this domain or related domains for several relevant purposes (subgoals):

(1) To develop, implement and evaluate a technology-based learning environment that allows student exploration and utilization of visual images and/or animations, e.g. *ChemSense.*

(2) To study the effectiveness of interactive response technology (IRT), e.g. *eInstruction,* in accomplishing the workshop goal for chemistry students with different cognitive styles (e.g., visualizer or verbalizer) and prior knowledge levels.

(3) To determine the extent to which a tracking tool, e.g. IMMEX, can provide feedback and formative assessment regarding the problem-solving pathways of students (novices) when they are engaged in learning within a technology-based learning environment.

(4) To describe the interactive nature of the visual experiences made possible when simulations of scientific phenomena are embedded in a virtual reality laboratory environment.

(5) To describe how visual components can be combined and used to facilitate problem-solving strategies in selected quantitative domains, e.g. biomedical engineering and physics; and to use ideas from these domains to design learning environments in chemistry.

Overall, we hope to integrate these five factors (subgoals) into a prototypic technology-based model. This model should focus on support for and assessment of student co-constructed visualizations as they are engaged in the collaborative solving complex learning tasks.

Friday, February 21, 2003

8:30 Arrive at SRI gate in rental van & get pre-prepared passes

9:00 Set up equipment (*InFocus* projector(s), laptops connected to internet)

9:15 Introduction to the Second Workshop **Jerry P. Suits**

9:30 Overview of the Workshop Goal **J. P. Suits, Melanie Soileau, & Rebecca Pease**

10:15 Morning BREAK

10:30 *ChemSense*—A Rich Exploratory Learning Environment **Anders Rosenquist, *Tina Stanford, Patti Schank, &*** *Vera Michalchik*

11:15 Discussion of morning session papers

NOON Lunch (meal covered by grant)

1:30 *Visualization in Biomedical Engineering: Its Implications for Chemistry* **Sean Brophy**

2:15 Afternoon BREAK

2:30 to 5:00 Informal Discussions and Brainstorming Session

6:30 Travel to Restaurant

7:00 DINNER at a Restaurant (covered meal—courtesy of McNeese Chemistry Department)

Saturday, February 22, 2003

8:45 Arrival at SRI gate in rental van with SRI employee escort(s)

8:50 Set up equipment (*InFocus* projector(s), laptops connected to internet)

9:00 *Virtual Reality Labs: Visualization of Chemical Phenomena* **Mous Diack**

9:30 *Demonstration of Interactive Response Technology (IRT)* **J. P. Suits, Melanie Soileau, & Rebecca Pease**

10:15 Morning BREAK

10:30 *Enhancing Classroom Interactivity and Collaborations with IRT* **Louis Abrahamson**

11:30 Brainstorming Session: *To integrate ideas ◴ prototypic model*

12:15 Lunch (meal covered)

2:00 *IMMEX—A Tracking Tool for Student Problem-solving Strategies* **Rebecca Pease** & Ron Stevens

2:45 Where do we go from here? Future Grants, Publications, and/or Symposium

5:00 Adjourn

6:30 Travel to Restaurant

7:00 DINNER at a Restaurant (meal not covered)

Appendix III: **Classroom Communication System**

Figure 1:

Figure 2:

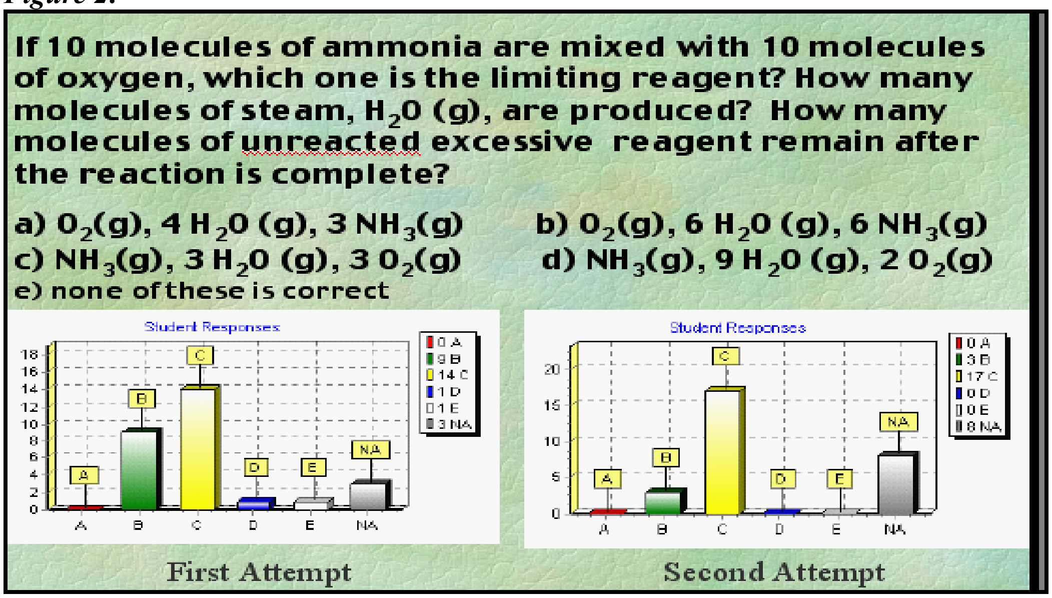
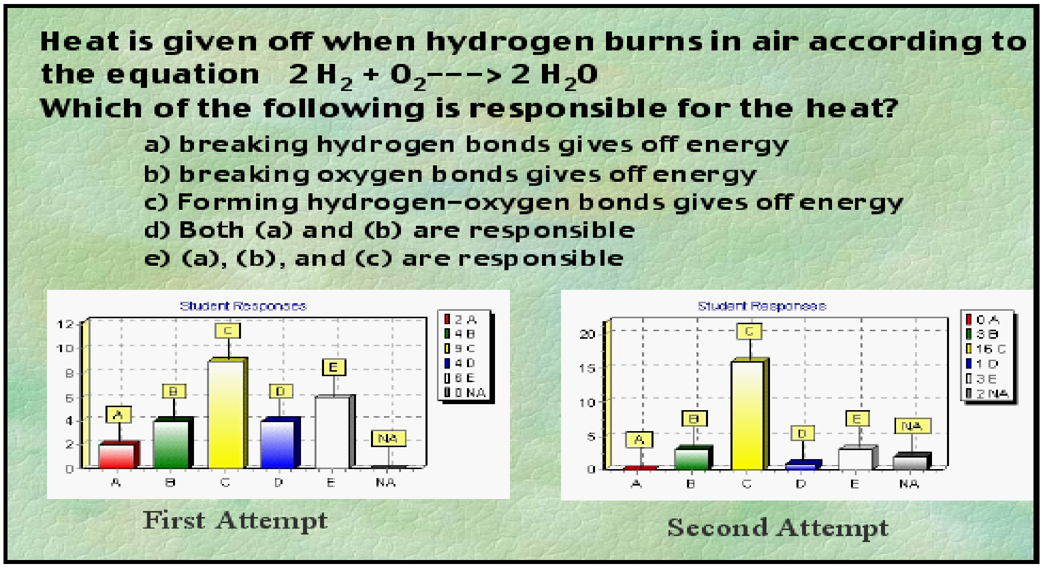


Figure 3:


Heat is given off when hydrogen burns in air according to the equation $2H_2 + O_2 \text{---}> 2H_2O$
Which of the following is responsible for the heat?
a) breaking hydrogen bonds gives off energy
b) breaking oxygen bonds gives off energy
c) Forming hydrogen-oxygen bonds gives off energy
d) Both (a) and (b) are responsible
e) (a), (b), and (c) are responsible
Student Responses
2 A
4 B
9 C
4 D
6 E
0 NA
First Attempt
Student Responses
0 A
3 B
16 C
1 D
3 E
2 NA
Second Attempt

Appendix IV: **Visualization and Assessment Research Study**

Figure 1:

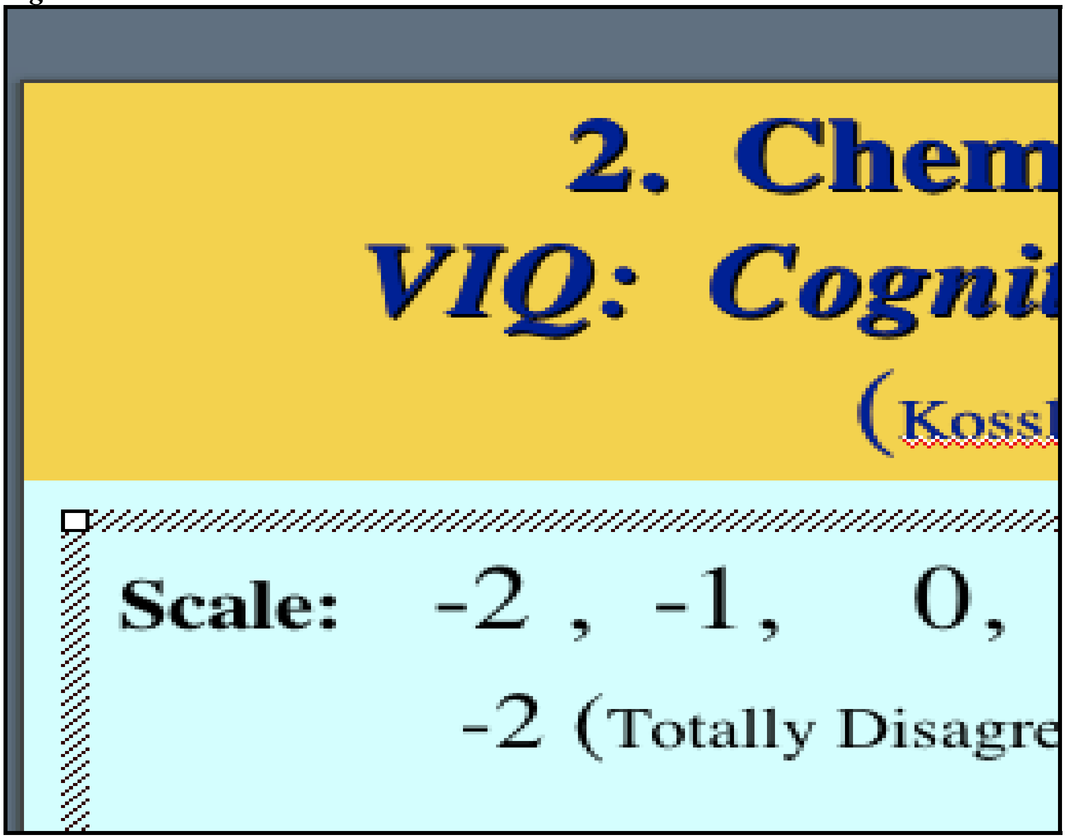


Figure 2:

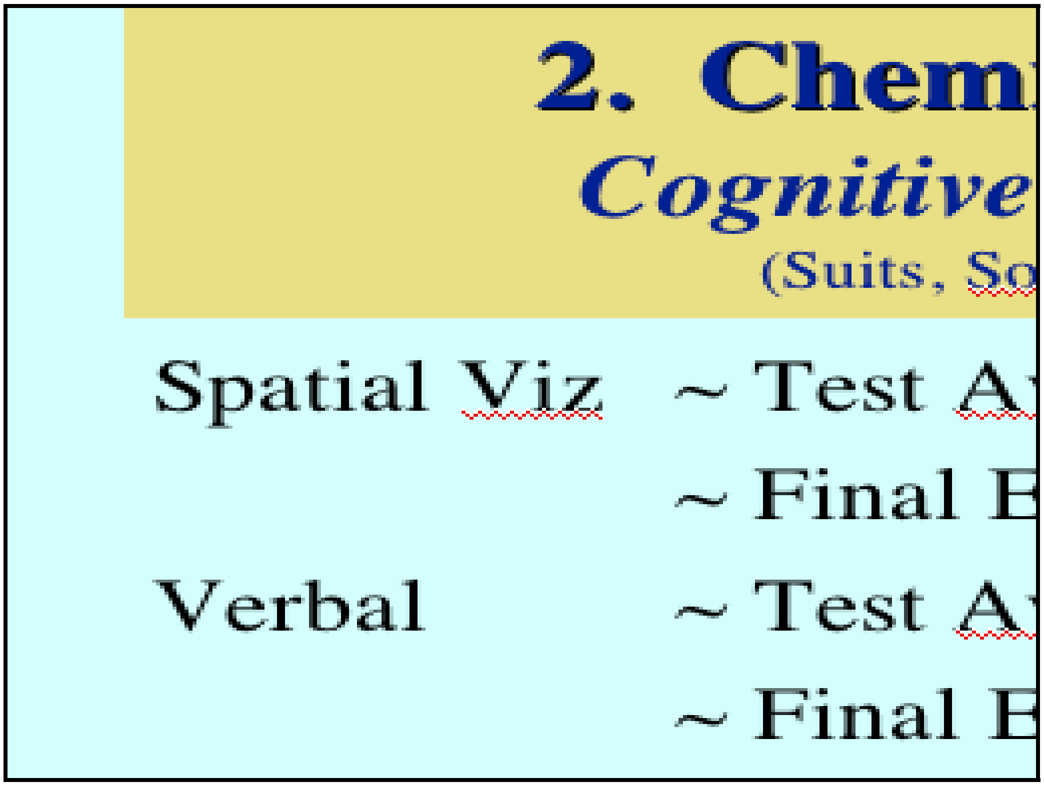

2. Chem
Cognitive
(Suits, So
Spatial Viz
~ Test A
~ Final B
Verbal
~ Test A
~ Final B

Figure 3:

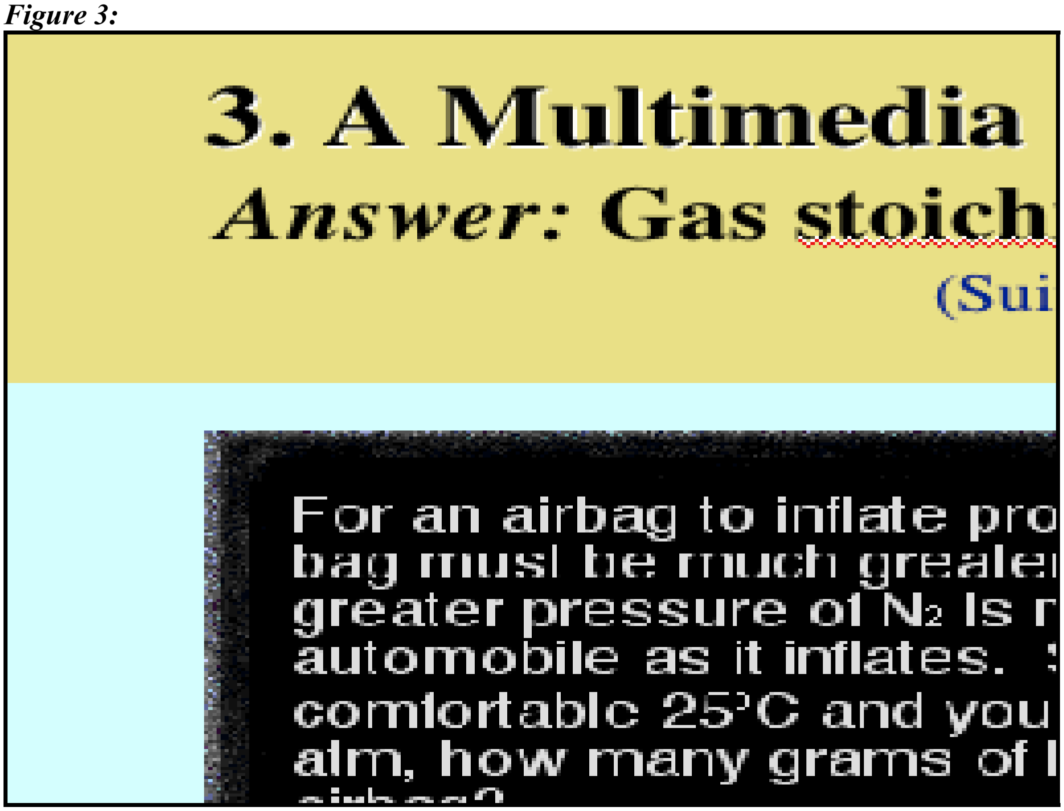

3. A Multimedia
Answer: Gas stoich
(Sui
For an airbag to inflate pro
bag must be much greate
greater pressure of N2 is r
automobile as it inflates.
comfortable 25°C and you
atm, how many grams of

Figure 4:

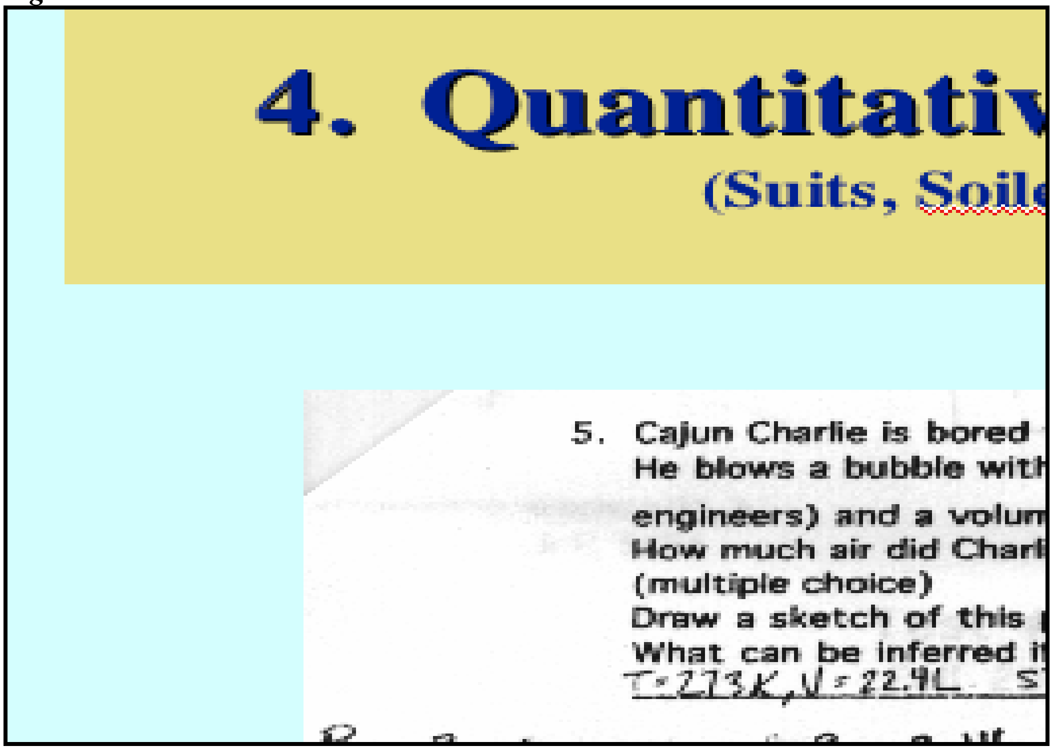


Figure 5: