An eBook in Flash to Support Inductive Learning

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Abstract
A learning system (here called the Inductive Concept Construction [IC2] learning system) composed of an electronic textbook (eBook), out of the classroom group discussion, and an in–class reporting and critiquing was developed and implemented. The eBook was made entirely using Adobe/Macromedia’s Flash authoring tool and was comprised of modules that provided guided inquiry in the form of computer animated presentations and simulations, guided exercises for protocol–driven applied problem–solving, drilling exercises in the form of randomly generated word problems and arcade style games. The eBook was then used as the main content source for out of the classroom student group discussions. Classroom time was devoted to reporting on pre–established questions and discussion topics, and students’ critiques of their classmates’ presentations. The process was well–received and student performance, especially in concept learning, was enhanced over that of traditional textbook and lecture systems.

Introduction
There is a growing disparity between the practice of science and the teaching and learning of chemistry. The practice of science is an inductive process whereas the teaching and learning of chemistry has become a deductive one. Practicing scientists develop new knowledge through the iterative process of developing a hypothesis, gathering specific empirical data to test this hypothesis, and developing new general statements: an inductive process. The teaching of chemistry, especially courses such as General Chemistry which are deemed to have a large body of foundational knowledge, is increasingly taught (and learned) as a process of applying known foundational knowledge to specific problems in order to solve them: a deductive process.

1 This is my new position and contact information. The research described here was done primarily in my former institution: the Department of Chemistry, University of Texas–Pan American, Edinburg, TX.
This disparity in practice and teaching has been implicated in the decrease in interest in science and the decreased enjoyment of chemistry [1], and in the poor performance of students [2, 3]. It has been observed that the students who perform well in algorithm– or protocol–type of problem solving do not necessarily understand the underlying concept thought necessary in order to solve such problems [2–4]. In my own studies, I have observed that students taught in the traditional textbook and lecture format have a difficulty in expressing concepts in their own words, and are generally unable to extend studied concepts into new, but related, areas.

Several teaching protocols have been developed that have shown some success in alleviating this problem. Process–oriented Guided–inquiry Learning (POGIL) [5], Peer–led Team Learning (PLTL) [6], Calibrated Peer Review (CPR) [7], and the augmentation of the traditional textbook and lecture system with online tools such as Blackboard [8] and computer–aided instruction such as Online Web–based Learning (OWL) [9] and Assessment, Review, and Instruction System (ARIS) [10] have shown some success in improving students’ performance.

Hoping to contribute to the reform of science education, I decided to focus on the support material used in the learning process. My contention is that the traditional printed textbook is inherently –and constrained to be– deductive. By extension, any learning process that uses the printed textbook as the primary support material will also be deductive. At best, a textbook and lecture system hopes to construct the information for the students. Studies have shown that, in such a lecture–based process, the concept constructed for students is not necessarily what is constructed by the students for themselves. While some would argue that the textbook and lecture teaching system is a very efficient mode of delivering information, there is, however, a discrepancy between delivered and received of information.

My early work on using PowerPoint (.ppt) as an authoring tool met with mild success [11, 12]. While students performed better in a system that used an instructor–developed .ppt “textbook” in combination with a lecture, such improvements were mainly in the performance of rote–memorization and protocol–driven problem solving questions. There was no statistically significant difference observed in concept learning. Moreover, further investigation suggested that such .ppt notes/textbooks served only to
focus the study of the already diligent student, making that students study time more efficient since they were made very aware of what I wanted them to learn. No observable effect was seen on the less interested students’ performance.

There is a growing body of research on multimedia learning as applied to chemistry. Johnstone [13] has argued that one of the sources of difficulty in learning chemistry is that, unlike the other science disciplines which have the observed phenomena (macroscopic) and the representation of those phenomena (symbolic), chemistry also has a particulate conceptualization of those phenomena (microscopic). Such particulate conception is often difficult to express in a static textbook (or a .ppt alternative) and may be addressed efficiently with animation/multimedia. The early work by Greenbowe [14] and later by Sanger [15, 16] showed that the Flash (.swf) authoring tool [17] facilitates the development of material that can promote concept learning. At the minimum, such .swf materials aid students in visualizing concepts. My own efforts showed that concepts are learned faster and retained longer when learned from such .swf modules [12, 18]. Mayer’s [19–22] extensive research into the cognitive learning process using multimedia allowed for the development of principles –best practices– in the development of such .swf learning materials. These design principles are rooted in Sweller’s Cognitive Load Theory [23] which suggests that learning is enhanced when no one particular learning mode (including long and short term memory) is overwhelmed, and Paivio’s dual coding theory [24] which suggests that learning is enhanced when both visual and auditory learning channels are used.

Thus armed with the objective of developing an inductive focused learning material, theories and previous data on why such a learning system should work, and principles on multimedia materials design, I set out to prepare an eBook that would support a cooperative learning scheme for the whole one year program of General Chemistry.

**Description of the eBook Components**

**Multimedia Principles**

Apart from design principles for electronic media (usage of font, sans serif versus serif font, color schemes and contrasts – especially important for color blind viewers, dark versus light backgrounds, etc.) every effort to adhere to the principles developed by
Mayer [19–22] has been made. The modality principle required that both visual and auditory senses were addressed. The contiguity principle required that such visual and auditory lessons/cues be closely associated in time, and that if text is used, that this be arranged as close as possible to the graphics. Gratuitous “bells and whistles” were kept to a minimum in accordance to the coherence principle.

The two principles that I couldn’t strictly adhere to were the redundancy principle and the personalization principle. The redundancy principle suggests that, when narration is used along with graphics, text becomes counter–productive. However, the Americans with Disabilities Act (ADA), and the fact that at the time of this research I worked at a state university, required that I provide “closed captioning” to the audio channel. The default for this option is “off” but, as I found, students would often resort to the close captioning if they could not understand the lesson – even if they understood the words in the narration. The personalization principle suggests that a first person tone using a layman’s language is far more effective than a formal language. Since one of my objectives is for students to develop facility with scientific and technical language, personalization could not always be employed.

Note: In the excerpts to follow, readers using Internet Explorer 6 (IE6) on a PC, or users using Safari for the Mac, may click on the underscored text or allied image to open a new window with the excerpt. The excerpt will resize to maximum if the window is maximized. Firefox users on the Mac should click on the allied image only. Clicking on the underscored text will produce a small view of the excerpt. Readers may also choose to go directly to the website developed for this article (http://thedrgreg.googlepages.com/ic2home), navigate through the website pages and view the excerpts from there (this may be particularly useful if you’ve read the article already and simply want to go back to the excerpts.)
Simulations

Whenever possible, I developed simulations of macroscopic phenomena. The objective here was not to give the students an experience of doing the actual experiment but rather to allow the students a chance to explore a situation and formulate some kind of conceptualization of the phenomenon. As such, only the deemed minimum of guidance was given. In the excerpt of a simulated gas experiment (excerpt of gas concepts), the students were instructed to understand the different components of the apparatus. Then, with some guidance on what they should be trying to determine (as seen in the green inset box), the students were invited to explore the macroscopic gas relationships. In the next section of that same module the students were asked to make conceptual connections between the macroscopic phenomena and the particulate conception.

A similar approach was used in the simulation of a galvanic cell. Again the students were asked, after viewing the macroscopic and particulate conception of a simple galvanic cell (excerpt of galvanic cell concept), to express their understanding of the process.

It is important to realize that in such simulations, while some background information is necessary, the information provided must stop short of telling the students any concept that they are expected to develop for themselves. If the target fundamental knowledge is expressed in the module, or if the students have a sense that they will somehow be told what the target fundamental knowledge is in the follow–up discussions, then students will be less likely to try and formulate such ideas on their own or for themselves. In the gas simulation, students have to know and remember what the state functions are for an ideal gas. In the galvanic cell, students get a better understanding of what they are seeing if they have some prior knowledge of oxidation–reduction reactions. However, the information they are given is limited to such necessary prior knowledge. The students are never told the relationship between pressure and temperature, or why faster gas particle motion means an increase in the temperature
measured. Likewise, the students have to formulate for themselves why it is that the spectator ions travel through the salt–bridge.

Data Visualization

In such situations wherein the development of the concept would have taken too long to go through and understand in a simulation (it is surprising to find out how many actual simulated chemical reactions would be necessary in order for an average student to develop a conception of the law of multiple proportions), or I simply couldn’t think of an appropriate simulation that could lead to the target knowledge (Schrödinger Model of the atom for example), then the students were led to the target lesson using some form of visualization of the data. The objective was to guide the students to the point where there could be some expectation that an average student could formulate the target concept.

For example, trends in the periodic table (excerpt of periodic table trends presentation) were easily visualized and I found that students could readily formulate some idea of what the trend was. More importantly, with a few well–placed hints, most students could actually make a connection between such visualized data to theories and concepts they had learned previously. Likewise, a highly visualized lecture was used –stopping short of actually stating the fundamental knowledge objective of the lecture–which allowed the students to formulate a conception of the learning objective in basic thermodynamics (excerpt of basic thermodynamics presentation). I used such lecture–like approaches when I couldn’t think of a reasonable simulation or data visualization. In such linear presentations, I made sure to keep each section limited to one idea and to speak only to the target learning objective –minimizing extraneous and distracting (even interesting) information.

As in the simulations modules, it is important to emphasize here that at no point did the data visualization module state the target concept. The students were given what was deemed sufficient for them to discover and formulate the ideas for themselves. Also,
formal definitions of technical terms were often purposely omitted to further allow the students to formulate and verbalize their own understanding of such technical issues. Technical terms were introduced later in the classroom discussion.

Protocol–driven Problem–solving and Rote–memorization

For applied science content that I thought would benefit more from a well–defined protocol or algorithm, such objectives—the learning and efficient use of a protocol—were clearly expressed to the students, the protocol was laid out, and exercises and drills were provided. In the case of stoichiometry, I chose to use a more visually–oriented protocol (excerpt of mass stoichiometry protocol). Students, who had trouble with basic algebra and could not—for whatever reason—take to the dimensional analysis approach that most textbooks use, found this protocol easier to remember and use, and had fewer errors in implementing it. Whenever possible—as shown in the preceding excerpt—protocols were developed as a modification (such as the extension of stoichiometry rules from moles, to grams, to limiting reagents, to molarity) rather than teach a new protocol as an independent process.

Several levels of exercise were made available: guided exercises which were essentially a walk–through of the protocol, answered exercises with feedback on the most likely source of error, and randomly generated exercise where the answers given by the students were checked but the students were not told what the correct answers were (excerpt of gas law exercises). In this sense, exercises provided in the eBook were similar in approach to what can be found packaged as online tutorials with current textbooks.

Interestingly enough, while students who had good math skills and had been taught the dimensional analysis approach at the high school level (even if their understanding of it was—by their own admission—weak), would use the dimensional analysis approach while admitting that the ratio approach promoted in the eBook was faster and less likely to cause error.
Whenever rote–memorization was necessary (as in the case of inorganic binary nomenclature) arcade–style games were developed to encourage students to get some practice or exercise. (nomenclature game) Such games were provided after the protocols/algorithms had been presented earlier in the eBook.

Usage of the eBook as Part of an Inductive Concept Construction (IC2) Learning System

While the eBook was used as the main source material, this was coupled with cooperative learning, group–oriented processes. Students were randomly assigned to groups of six. This number was thought to be the best compromise between increasing student participation within a group (lower numbers better), having enough resources and idea input (higher numbers better) and a manageable number of groups per class (higher numbers better in a class of 85 students on average) so that all groups were called at least once per class session. The groups were reassigned after each series examination to avoid the possibility of bad group dynamics affecting individual student grades inordinately.

Using WebCT’s (now Blackboard) calendar and document upload functions, a set of questions and discussion topics were posted online for each day of the semester. Students were encouraged to meet ahead of the scheduled class time for a particular topic, discuss the materials based on what they gleaned from the eBook, and essentially prepare each other for the class discussion period.

In the classroom, groups were asked to pick randomly from a set of questions which were designed to properly develop the objective concept for that classroom day. Thus, a posted discussion guide might have the following suggestions: “Relate isotope nuclear stability to: atomic mass and mass number ratio within an isotope, binding energy, Gibbs’ Free Energy or enthalpy of nuclear transformation.” Some of the questions drawn and answered in the classroom might be: “Based on the data presented in the eBook, suggest the possible function of neutrons in isotope stability.” “Explain nuclear stability from the

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3 My apologies to Firefox–users. The original Flash file has been corrupted and I have not yet recovered the file. I only have an IE6, PC .swf version. I believe the file can still be accessed using Safari.
point of view of binding energy.” “Why can we say that iron–56 is the most stable isotope against nuclear transformations?”

Groups were given ten minutes of discussion at the beginning of each class to allow them to formalize their answers and make sure that everyone in the group understood and agreed on their answer (this ten–minute period was assumed to be too short to formulate a response and was not a replacement for the out–of–the–classroom group discussion). A student would be randomly chosen from each group to answer the question and a group grade would be assigned based on that answer.

Answers were modeled for the students and made as formal as possible. Answers to concept focused questions were required to follow the following format: the first sentence was the thesis statement, the statements after that were expansions of the thesis statement as necessary, and this could then be followed up with one or two well–chosen examples as required. If the questions were applied problems, the group answers were required to first state the protocol used and to show how this protocol was followed, step–by–step, in obtaining the answer. Whenever a mathematical equation was involved, a pattern was also followed: the mathematical expression was stated, expanded as necessary, rewritten to solve for the unknown, the variables were replaced with data, and the final number–answer was stated.

Another student, chosen randomly from a different group, would be asked to critique the given answer. This ensured that each group would not be focused solely on the question they had picked. More importantly, this part of the process allowed students to develop critical thinking skills, learn to assess an answer, and make recommendations. The individual student would be given a grade for that critique.

Critiques were also modeled for the students and formalized. Critiques were limited to statements concerning the completeness of a particular answer, possible alternative explanations, possibly more appropriate examples, corrections of misconceptions, possible additions to the answer given.

I only interjected if the answer contained misconceptions, required further clarifications or expansions (despite the given critique), or to guide groups to other ideas that were not included in the answer and/or critique.
For grading purposes the cumulative average of all the group discussion grades and individual critiquing grades constituted one exam. Grading the group presentation and individual critiques was thought to be necessary in order for there to be some definite and clearly defined consequences for class discussion and participation.

**Discussion**

**Student Attitudes**

A survey of student attitudes toward the IC2 system was conducted both in mid-semester (during the early trial runs of this process, as a formative and progress evaluation) and a few weeks before the final examinations of each semester. These surveys were anonymous, conducted online, and on a voluntary basis. A total of 173 (out of a possible 297) students have responded. Results of the end-of-semester survey are excerpted in table 1 (highest percentage [mode] response are bolded for easier viewing). Table 1.1 shows the mode of students (41%) as spending 2–3 hours per week on the eBook and 33% spending 1–2 hours per week in group discussions (table 1.2). It is interesting to note that, while 60% of students report that they spent the most time on concept presentations in the eBook, only 10% of the students reported spending the most time on simulations (table 1.3). In the design of the eBook, I thought that too many simulations would require too much time from students as it would require them to learn about the particular simulator and then try to extract information from the simulation. I thought that concept presentations or raw data were more efficient ways to present the material and would still allow the student the opportunity to construct concepts for themselves. The results of this survey prompted me to interview several students regarding the unexpected time spent on the simulations and most responded that the simulations were easy to understand and led them to correct interpretations, whereas concept presentations were more “lecture-like” and required more study to understand. I intend to investigate ways to convert the current concept presentations and raw data in the eBook into effective simulations.
Table 1. Summary of excerpted survey questions (survey questions relating to the students’ home–life, SAT’s, ACT’s are not reported).

<table>
<thead>
<tr>
<th>Survey Statements</th>
<th>Percentage of Students (173 respondents of a possible 297)</th>
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<tbody>
<tr>
<td></td>
<td>Number of hours spent</td>
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<tr>
<td>1. The number of hours I spend viewing or working with the eBook by myself on average is approximately:</td>
<td></td>
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<tr>
<td>2. The number of hours I spend with my group per week on average is approximately:</td>
<td></td>
</tr>
<tr>
<td>3. The section of the eBook I spend the most time in is the:</td>
<td>Type of animation</td>
</tr>
<tr>
<td>4. I liked the eBook.</td>
<td>Rate how these statements would apply to you (whether you would make these statements)</td>
</tr>
<tr>
<td>5. I liked the concept presentations.</td>
<td></td>
</tr>
<tr>
<td>6. I liked the simulations.</td>
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<tr>
<td>7. I liked the guided exercises.</td>
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<tr>
<td>8. I liked the random exercises.</td>
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<tr>
<td>9. I prefer the eBook to the printed textbook.</td>
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<tr>
<td>10. I think that with the eBook presentation, the classroom discussion is unnecessary</td>
<td></td>
</tr>
<tr>
<td>11. I think that the eBook supports the classroom discussion properly.</td>
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<tr>
<td>12. I found that I needed additional supporting material to properly prepare for the classroom discussion.</td>
<td></td>
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<tr>
<td>13. I think the combined eBook and classroom discussion is an effective learning system.</td>
<td></td>
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<tr>
<td>14. I think that the classroom discussion will work with a traditional textbook.</td>
<td></td>
</tr>
<tr>
<td>15. I think my performance was enhanced by just the eBook (and not the classroom discussion).</td>
<td></td>
</tr>
<tr>
<td>16. I think my performance was enhanced by just the classroom discussion process (and not the eBook).</td>
<td></td>
</tr>
<tr>
<td>17. I think my performance was enhanced by working in groups.</td>
<td></td>
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<tr>
<td>18. I believe that I learn more in the eBook/discussion type system than in the traditional printed textbook/lecture system.</td>
<td></td>
</tr>
<tr>
<td>19. I believe that I performed better in the eBook/discussion type system than in the traditional printed textbook/lecture system</td>
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</table>
Most of the students liked the eBook, 41% strongly agreed and 39% agreed that the statement, “I like the eBook” applied to them (table 4.1). There was a small but significant difference in the students’ attitudes over each subsection with 40 – 60% of the students strongly liking the concept, simulation, and guided exercises sections (30 – 40 % liking it), whereas only 27% strongly liked and 38% liked the randomly generated exercises (table 1.5–1.8). Comments on this subject revealed that the students’ dissatisfaction with the randomly generated exercises stemmed from not having any feedback when they got the answer wrong. It seemed that, despite the protocol walk–through and the answered exercises, students still wanted an authority to tell them what they did wrong. I am currently looking for ways to satisfy the need for more feedback without doing away with the unanswered random questions which, to my mind, is necessary so that students will acquire a sense of authority over the process.

53% strongly preferred (16% preferred) the eBook to a printed textbook (table 1.9). However, 53% strongly disagreed (24% disagreed) with the statement “I think that with the eBook presentation, the classroom discussion is unnecessary.” (table 1.10) This strongly supported my notion that the eBook should not be considered as a source material similar to a textbook. The eBook did not simply deliver information. The eBook was designed specifically to initiate inquiry and allow students –in conjunction with their group– to construct concepts.

Interestingly, while 48% strongly agreed (39% agreed) that the eBook ably supported the discussion (table 1.11), 42% agreed that they needed additional supporting material to prepare for the classroom discussion (table 1.12). Interviews of students indicated that printed textbooks and online materials were often consulted to “get the proper wording”, “check if the group came to the right conclusion”, or to “support (defend) my ideas [in the group discussion]”. I’ve taken this to mean that while the students felt that they did get the proper guidance from the eBook content, they still felt a need for some authority –be it a printed textbook or online material– to corroborate or formalize their statements. There are no plans at the moment to make the eBook the sole source of information. I feel that allowing for students to look at other sources is part of the scientific inquiry process, and that the need to consult an authority “to get the
wording right” will eventually correct itself as the students mature into constructing concepts for themselves.

42% of the respondents were unsure and 39% disagreed that a printed textbook could be used in place of the eBook to support classroom discussion (table 1.13). This was further supported by 50% strongly agreeing and 36% agreeing that it was the combined eBook and classroom discussion that made for a good learning system (table 1.14). This data showed that students were cognizant enough to know that it was the combined eBook and discussion that made for a good learning system and not either eBook or discussion alone. This was further corroborated by the responses shown in table 1.15–1.17 where the students reported on their expected performance vis–a–vis the two components of the IC2 system. Most students did not agree or were, at a minimum, unsure with statements wherein only one component (eBook, discussion, group–work) is said to be the main contributor to their performance gains.

44% strongly believed (32% believed) that they learned more in the IC2 system than they would have in a traditional textbook and lecture system (table 1.18). Moreover, 36% strongly agreed (27% agreed) that their performance was better in the IC2 system than it would have been in the traditional textbook and lecture system (table 1.19).

**Student Performance Data**

A comparison of the over–all student performance for the first semester General Chemistry students taking the course in the Fall across different teaching and learning systems (two years worth for each teaching/learning method) is shown in figure 1. Figure 1a showed a 36±1% drop–out and failure rate using a traditional lecture and printed textbook format. This did not change when the traditional lecture and textbook format was augmented with a CD of lecture notes in PowerPoint (PPT) format and WebCT course tools such as online quizzes, online forums, and calendar of class schedules (fig. 1b). The only difference was in the percentage of “A” grades going from 15±2% in the traditional system to 26±5% in the PPT and WebCT augmented format. This seemed to indicate that such augmentations only served to help the active and engaged students to focus their study onto materials that the instructor tended to test for. An increase in the drop–out and failure rate was observed when 30% of the exam questions were focused on
Figure 13. Final grades for students in different teaching and learning systems for students in the first semester General Chemistry course taken in the Fall using (a) traditional methods, (b) traditional systems augmented by PowerPoint notes and online course tools, (c) same as “b” but with 30% of the exam questions testing concept learning, (d) similar to “b” but with 60% of the exam questions testing concept learning, and (e) the IC2 system.

concept learning (from $36\pm1\%$ to $47\pm7\%$, fig. 1b and c)$^4$. This was further corroboration of the idea that traditional teaching methods, and even those augmented by lecture notes and online support, do not allow students to learn concepts efficiently. The limited ability of traditional and augmented, deductive–focused teaching methods to encourage

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$^4$ A sample of an exam with 60% concept questions may be viewed in this link: [http://thedrgreg.googlepages.com/1301E3F06.pdf](http://thedrgreg.googlepages.com/1301E3F06.pdf). Note that in this exam, while there are an equal number of multiple-choice concept and analysis questions, there is an additional 2 essay questions towards the end. This can be compared to a sample exam with no concept questions: [http://thedrgreg.googlepages.com/1301Exam2F97.pdf](http://thedrgreg.googlepages.com/1301Exam2F97.pdf). Both these links are to .pdf documents.
conceptual learning was further emphasized when the student drop-out and failure rates increased to 81±12% with the increase of concept questions to 60% of the written exams (fig. 1d).

When the IC2 system was used –and despite 60% of the written exam questions still focused on concept questions– the drop-out and failure rates decreased to 37% (fig. 1e). This was taken to mean that the IC2 system, with its combination of eBook, out-of-the-classroom group discussion, and in-class presentations and critiques, was a very effective process for students to learn concepts. A more in depth and comprehensive discussion of student performance in various learning environments and learning protocols will be presented in a separate paper [18].

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