Teaching General Chemistry Using Information Technology and Interactive Engagement Methods

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The recognition that students who are exposed to cooperative learning in the classroom perform better than those taught in a lecture - based system has led to many recent efforts to encourage active participation by students to acquire knowledge. In the last few years many approaches such as the ConcepTests devised by Mazur for physics, Interactive Engagement methods promulgated by Hake for physics and Active Learning espoused by Felder in engineering have been gaining acceptance. Recently a pedagogical strategy known as Just-in-Time Teaching, devised by Novak, Patterson, Gavin and Christian for physics, which combines high tech (the www etc.) and low tech (classroom) to create a learning environment that responds to the needs of the students and encourages active participation. The adoption of these techniques to teaching First Year General Chemistry is in a formative phase. This paper will describe the use of Information Technology to implement the Gutenberg Method (the students pre-read portions of the textbook to study before they come to class and are tested on the web) and Interactive Engagement Methods employing ConcepTests in a First Year General Chemistry class. The implementation and experiences with this approach will be described. Preliminary statistical data from a multi-section First Year General Chemistry class at will be presented.

Introduction:
Of all instructional methods, lecturing is the most common, the easiest, and the least effective. Unless the instructor is a real spellbinder, most students cannot stay focused throughout a lecture: after about 10 minutes their attention begins to drift, first for brief moments and then for longer intervals; they find it increasingly hard to catch up on what they missed while their minds were wandering; and eventually they switch the lecture off altogether like a bad TV show. McKeachie [1] cites a study indicating that immediately after a lecture students recalled 70% of the information presented in the first ten minutes and only 20% of that from the last ten minutes.
The lecture method has traditionally been employed in teaching first year General Chemistry. In the 30 plus years that I have taught at UBC I used this tried and true method. During these thirty years progressively comments like the following could be heard in discussions between faculty members:

Professor A: "All these students can do is memorize--give them a problem that makes them think a little and they're helpless." Professor B: "I don't know how most of them got into university. The average on my last test was 47 and some of them went to the department head to complain that I was testing them on things I never taught them, even though the chapter we just covered gives them everything they needed to know." Professor C: "It's this whole spoiled generation--they want the grades but don't want to work for them!" [10]
Clearly things were not working properly, so I decided to change my approach to teaching. In order to accomplish this I sought out a different environment in which to teach.
The Science One program at UBC provided the catalyst I needed. In this program a cohort (70) of first year students are team taught by a physicist, mathematician, biologist and a chemist so that the links between these branches of science can be emphasized. The teaching methods involved much active participation, in the form of discussion and group work, so that the students became involved with the subject during the class. After two years in this program I returned to teaching in the regular stream of students and wondered How could I transfer this approach to a large class of regular students?
At this time, about six years ago, I was vaguely aware of Eric Mazurs [2] approach to active engagement in the class

using ConcepTest this approach appealed to me as I had always posed questions in class but as usual had to answer them myself. To implement this approach it seemed to me that I had to get away from the blackboard or overhead and be able to roam around and talk to the students. Therefore I decided to use electronic presentation software.
Finally an essential component of the Mazur approach is the requirement for the students to pre-read the material to be covered in class. This requirement was first promulgated by Frank Herbert [3] in 1963, who named it the Gutenberg method. What does the Gutenberg Method involve? Simply this. You assign the students portions of the textbook to study before they come to class. When they come into the classroom, they are already acquainted with the material. You don't waste your time doing what Frank Lambert calls 'presenting a board full of elegantly organized material to questions that the students have not asked.' The students have read the material, they have thought about it, and they have questions to ask about it. You answer these questions, or, better still, try to get them to answer their own questions, or get other students to give the answers. You ask questions. You have a discussion. If they're slow to come alive, you take up points that you know give the students trouble. You lead them through difficult problems. The entire class hour becomes like those few golden moments at the end of an old-fashioned lecture when a few students manage to rise above the system and gather around your desk."
A question naturally arises, How can we be sure that the students have pre-read the material? To encourage the students to participate we use the web to post a pre-reading quiz that the students complete before the lecture, the quiz is part of the final grade. In the next section I describe how all of the ideas described above can be put together to provide an exciting and rewarding, for the students and me, learning environment.

Methodology

Information Technology: All lecture parts of a class and concept questions are projected using electronic presentation (yes, PowerPoint). Electronic presentation software is a powerful way to display the images of chemistry. The ability to be able to project molecules, electron density map, chemical reaction profiles etc. brings the subject to life for students of the television era. There are a number of pitfalls in the use of PowerPoint, as there are in the use of overhead transparencies. In particular it is possible for the user to go too fast, have too much on a slide. The style I have adopted in presenting chemistry is to recreate the blackboard by bringing the material in incrementally and always obeying, wherever, possible the Rule of Six, which is no more than six ideas or items per slide. If you put too much on a slide the students heads go down as they scramble to write everything down and you have lost them.
To avoid some of the pitfalls of using PowerPoint it is possible to provide pre-view presentations on the web. These presentations contain gaps that have to be filled in during the discussion of the material to be covered. The complete presentations are put on the web subsequent to the class. It is important to stress to the students that these are not notes but just the presentation that is discussed in class, the students create the notes.

Whilst using PowerPoint it is also important to have an overhead projector nearby on which to demonstrate how to draw orbitals, reaction mechanisms, conformations etc. However in all of this one is facing the students and assessing their comprehension by their body language. Another important aspect of using PowerPoint is the freedom that can be obtained if a non-directional mouse is employed. The Gyromouse [4] permits the user to move around anywhere in a lecture hall so that during the discussion period of a ConcepTest the instructor can move around and participate in the discussion. This is a priceless piece of independence.
As mentioned earlier the students are required to pre-read a portion of the assigned textbook and answer a pre-reading quiz on the web. At UBC the quiz questions are posed on WebCT, this or any other web authoring tool can be used of course. WebCT is also used to post the preview and post class presentations.

Interactive Engagement: Traditional teaching uses a transmittal approach in which students are assumed to gain knowledge while passively listening to lectures. If one were to use electronic presentation software to transmit the knowledge then the lecture is just like television. The transmittal style of teaching does not actively engage the students. A constructivist view of learning is that students must actively construct their knowledge through testing concepts on prior experience, applying these concepts to new situations and integrating concepts into prior knowledge [2], [5]. In order to facilitate active learning the notion of concept questions, also called concept tests, and termed ConcepTests by Mazur [2], which have used extensively in active learning environments. According to Mazur, good concept questions focus on a single concept; are not solvable by relying solely on equations and have several plausible answers based on typical student misconceptions [2]. The form of the concept question is that of a carefully crafted multiple - choice question. There are now good sources of these questions [6].
The use of concept questions as a form of interactive engagement follows the following approach. Concept questions

are given to the students by projecting them using electronic presentation software and time is given for individual thought and discussion with their peers. After this time the student responses are checked, if the students have clearly mastered the concept the instructor can move on, if not the instructor clarifies misconceptions and further discussion of the concept takes place. In the multi-section first year General Chemistry course where these techniques have been applied we assessed student response using flash cards and a personal response system (PRS) [7]. Interactive student response systems, such as PRS, have a number of advantages over flash cards, for example, anonymity, the ability to provide a participation grade, and the accumulation of assessment data for subsequent analysis. A typical response is shown in Figure 1.

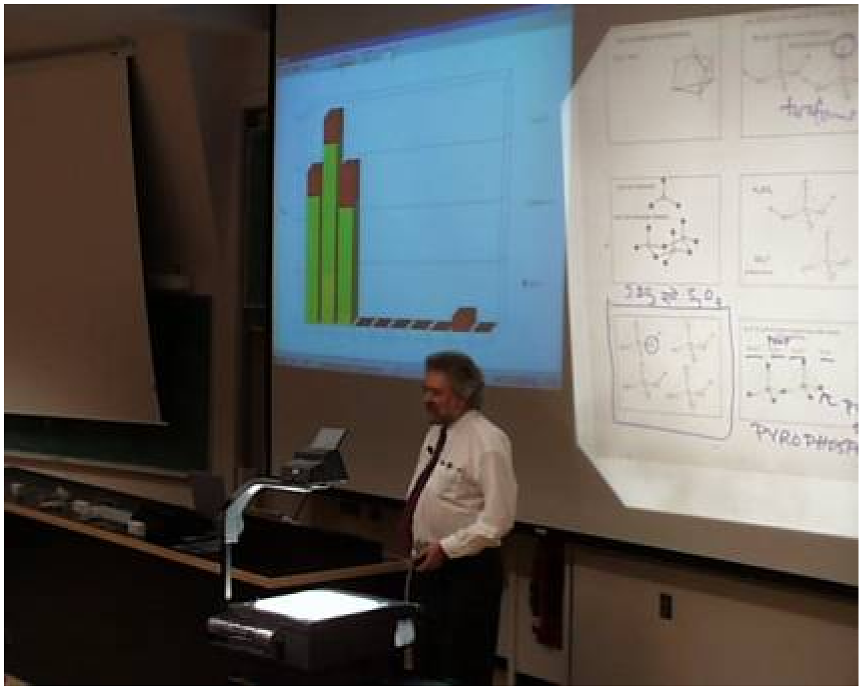

Figure 1 PRS response to a ConcepTest. The lecture theatre is not as dark as implied by the photo and the lone bar to the right is a response from a student with a sense of humour.

An essential aspect of the successful implementation of interactive engagement using concept questions requires that students have some experience with the material prior to class. In the current implementation of this in a first year General Chemistry course reading assignments are given and the students are required to answer a number (between 5 to 9) multiple choice on the web prior to discussing the material in class. The use of pre-class homework is a significant shift from traditional pedagogy in teaching chemistry in which normally homework is assigned as a post-class task. Not only are the pre-reading and pre-reading quizzes critical to the success of active learning in the classroom but it also encourages student self-learning.
The other important outcome of the pre-reading assignment is the just - in - time [8] aspect which arises from scanning the statistics of the pre-reading quizzes, which are machine marked by WebCT, so that student misconceptions and common difficulties can be detected immediately rather than later. In particular we have adopted asking the following question as the last question of the Pre-Reading Quiz:

What did you find most interesting about the pre-reading and what in particular was the most difficult?"

The responses to this question can be collected together and printed out for the instructor to read. Usually a common theme of difficulties for a particular topic, such as buffers, becomes apparent. With this knowledge the instructor can adjust the class discussion to highlight this difficulty by posing a concept question that embodies this, and thereby induce active learning by the students in the area of difficulty. Thus, in the spirit of active learning, pre-class assignments decrease feedback time between students and instructors.

The advantages of Interactive Engagement methods are well established by the studies of Hake [9] and Felder [10], student performance is better. The other advantage of interjecting concept questions is the ability of interrupting students from their normal passive lecture practices of writing, copying, looking, listening, yawning, shuffling, scratching, clockwatching, daydreaming etc, to actively participating in the class by asking questions, answering questions, recalling material, problem solving, critical thinking, discussing, making decisions etc. As mentioned earlier [1] an exit poll of a class reveals that students remember 70 % of the first 10 minutes of a traditional lecture and only 20 % of the last ten minutes, by introducing the concept question a wake-up call is provided and the students attention is regained, see Figure 2.

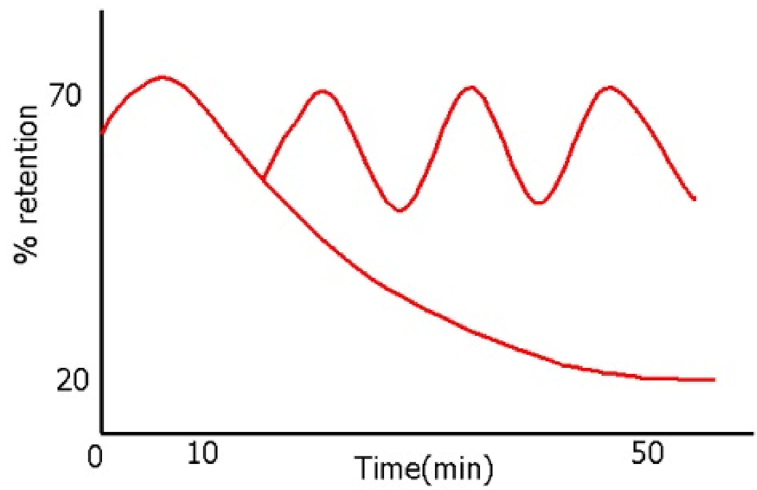

Figure 2: An illustration of the effect of Interactive Engagement, retention is increased. The top curve suggests the effect interactive engagement in the class.

Concept Question Format: The format suggested by Mazur [2] is as follows

Question Posed 1 minute
Students given time to think 1 minute
Student record their answers (optional) 1 minute
Students convince their neighbours 1-2 minutes
Students record revised answers (optional)
Feed back to instructor (flash cards or PRS)
Explanation of correct answer 2+ minutes
Once a satisfactory number of students (90% or greater) have chosen the correct answer the instructor proceeds to the next topic.

Class Presentation Outline: In a typical class presentation (I am avoiding the word lecture), the following scheme is adopted:

15 minute electronic presentation discussing pre-reading and student concerns
Concept Question (about 7 min)
A further 15 minute presentation
A final Concept Question (about 7 minutes)

The above is a minimalist approach to using concept questions. The number of concept questions can be increased as desired and depending on the topic.

Discussion and Conclusion:

How well does this work? Does it make a difference? How do you cover all the material? These are the types of frequently asked questions that are often posed when the above approach is discussed. The immediate concern of most instructors is that of covering the syllabus. This can be answered in one way: as you discuss a body of material or go through a problem solution, instead of just posing questions to the class as a whole and enduring the subsequent embarrassing and time-wasting silences, a concept question is inserted to get the students actively involved in the material. That is the concept question takes the place of showing examples in class; this is an excellent way of discussing organic nomenclature!

The other two questions are harder to provide quantitative answers to. In order to provide some quantitative data I undertook to teach two sections of our first year General Chemistry course which had eight sections in total with a total student population of 1800. One of the two sections consisted of a general group of students who had selected the 9:00 am time slot (Section 109 in Table 1); the other section was a special section, called the Coordinated Science Program (Section 122 in Table 1)." In the Coordinated Science Program students select to be timetabled as a cohort that take mathematics, physics, biology and chemistry together. The instructors in the programme meet weekly to coordinate class content as much as possible in order to emphasize the connectivity between the branches of science. The students also participate in weekly workshops designed to promote the theme of coordinated science.

The analysis performed was an ANOVA of the raw examination mark at the end of term. The exam results contain no scaling or additions. In addition an ANOVA analysis of the incoming high school grades was also performed. The results are shown in Table 1. In order to use the results of an analysis of variations (ANOVA) we look at the computed value of F and compare it with $F_{critical}$, if $F > F_{critical}$ then the sections are statistically different from each other. The $F_{critical}$ corresponds to the 95% confidence level. It is at this level we will use the data, a more profound analysis will be presented at a later date.

Table 1

Sections	Number of Students	Average High School Grade (%)	Average Exam Mark (/130)	Average Exam Mark (%)
101	242	86.5	81.4	62.6
102	239	82.4	70.5	54.2
109	253	86.5	83.1	63.9
110	229	84.2	71.6	55.1
111	249	84.6	79.5	61.2
122	162	88.8	90.3	69.5
188	223	83.4	72.3	55.6
199	235	84.1	72.7	55.9
F	N/A	61.0	20.1	
$F_{critical}$	N/A	2.0	2.0	
P value	N/A	2.76E-86	3.85E-26	

A few words about the registration process at UBC are appropriate before the results are discussed. Students register in turn based on their high school grade, that is the better students get to choose their timetable first. The result of this is that the better students tend to cluster in particular sections. Thus the 109 (9am MWF section) and the 101 (1 pm MWF section) tend to fill up first with the better students closely followed by the 111 (11 am MWF section), 110 (10 am MWF section) and 199 (9 am Tu, Th section , 75 min lecture instead of 50 min lecture), and then comes section 188 (8 am Tu, Th section , 75 min lecture instead of 50 min lecture) and finally the 102 section (2pm MWF). The section numbered 122 is the Coordinated Science Programme, which described above is a self-selected group of science students who have chosen this enriched programme.

The sections I taught were Sections number 109 and 122. The section numbered 122 was the Coordinated Science Program, it is apparent that these students have a higher entering high school grades and this is reflected in there higher average score in the final exam. It should also be pointed out that the CSP section is on the whole a highly motivated

group of students. What about the remaining sections? Sections 101 and 111 were taught by the same instructor using traditional lecture methods with weekly quizzes. The other sections were taught by instructors in a traditional manner without additional quizzing except for a midterm test that all sections gave. Student evaluations showed that all instructors were well appreciated by the students.
What conclusions can we draw from the statistics? The statistics show that all sections are distinct to the 95% confidence level and that in general performance in the exam correlates with high school grades, as would be expected. However a couple of interesting observations can be made. Those students in sections 102,110, 188 and 199 where no additional assignments or quizzes were given did worse than those in the three sections, 101, 109 and 111, where additional requirements were required. The degree of poor performance appears to be greater than the difference in high school grades. When a comparison of sections 101, 109 and 111 is made we see that the section (109) in which the interactive engagement method were employed pulled ahead in their performance on the exam. The major effect of the interactive engagement methods and just in time teaching appears to be on the cohort of students with middling ability, the top end will survive whatever we try! The conclusion is that the methods employed in teaching section 109 had a positive effect. The other conclusion that can be made, based on the relatively better performance of sections 101,109 and 111, is that the more we encourage students to stay up with the material in the course the better. This is, of course, to be expected.
Anecdotally, the use of interaction engagement and just in time teaching methods was a great success as judged by a nearly 95% participation in the pre-reading quizzes, constantly high level of attendance at class, positive comments on student evaluations regarding the pre-reading requirements and in class ConcepTests. In conclusion the results of this study shows that this approach can have a very positive effect on student performance in large general chemistry classes.

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