AC 2011-1313: CURRICULUM EXCHANGE - EDUCATIONAL ASPECTS OF COMPUTATIONAL MODELING AND KINESTHETIC EXPERIMENTATION

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Curriculum Exchange - Educational Aspects of Kinesthetic and Computational Experimentation

Abstract

Educational theory and research has shown that kinesthetic experimentation and computational modeling significantly influence the way that students learn science, technology, engineering and mathematics (STEM) material. This paper presents evidence that students who have little or no prior knowledge of engineering are able to utilize computer simulations in conjunction with hands-on laboratory experimentation to stimulate their understanding of engineering concepts.

Through a National Science Foundation (NSF) sponsored Research Experiences for Teachers (RET) program at the University of Texas-Arlington (UTA), several high school teachers worked with engineering faculty on research problems related to hazard mitigation. The project used for the work presented here was entitled “Air Dispersion Modeling: Planning for Airborne Terrorism Releases in Dallas/Fort Worth.” The RET participants used AERMOD, a dispersion modeling software based upon Gaussian dispersion principles, to predict the ambient concentrations of chlorine gas that would result if released from sites near highly populated areas in Dallas/Fort Worth. The releases were modeled based upon a number of scenarios that the researchers deemed plausible for a terrorist attack. The research experience was used to develop a lesson plan for a high school chemistry course.

Preliminary assessments (pre-survey) were conducted to collect demographic data, gauge the students’ knowledge of and interest in engineering and measure their knowledge of concepts related to the lesson. The lesson plan was implemented in three phases: a lecture based on the RET dispersion modeling project, a computer modeling lab during which students modeled a chlorine gas release using AERMOD and a kinesthetic lab during which students performed a microscale experiment involving the release of chlorine gas.

In general, the students found that the engineering concepts learned through modeling a chlorine gas release were realistic when compared to their observations in the microscale chlorine gas lab. Post-survey data showed significant improvements in students’ abilities to relate air dispersion modeling and the effects of a realistic gas release to engineering concepts after participating in both the computer simulation and kinesthetic laboratory experiment.

Introduction

In obtaining a modern-day education, students must use technology, whether it be in running experiments in a lab or something as simple as writing a research paper for a journal or magazine. Students are capable of using computers accordingly to gain knowledge from their school system, collegiate system or from their home at a much higher rate than in the past. Many industries depend on students coming out of college programs that know how to use technology and apply it to their daily jobs. One such industry is engineering. Students and professionals alike are required to know how to apply technology to working models and ultimately to project design.

Research shows that Americans are becoming ever more dependent on technology, especially computers, the internet and cell phones.[1, 2] In October 1997 36.6% and 18.6% of American households reported the use of computers and the internet, respectively. This trend continues to increase, with 61.8% and 54.6% reporting use of these same technologies in October 2003. Furthermore, the people using this type of technology most are persons under the age of 54. On average, 7 out of 10 Americans are using the internet. Clearly the people who are using the technology are the up-and-coming generations of the population, with the majority of them being ages 18-24, at 80.8%.[1]

The goal of this research is to determine whether the addition of technology to kinesthetic (hands-on) labs would allow students to better understand how engineering applies to their daily lives. Educational theory and research has shown that kinesthetic experimentation and computational modeling significantly influence the way that students learn science, technology, engineering and mathematics (STEM) material.[4-11]

Through a National Science Foundation (NSF) sponsored Research Experiences for Teachers (RET) program at the University of Texas-Arlington, several high school teachers worked with engineering faculty on research problems related to hazard mitigation. The project used for the work presented here was "Air Dispersion Modeling: Planning for Airborne Terrorism Releases in Dallas/Fort Worth." The RET participants used AERMOD, a dispersion modeling software based upon Gaussian dispersion principles, to predict the ambient concentrations of chlorine gas that would result if released from sites near highly populated areas in Dallas/Fort Worth. The releases were modeled based upon a number of scenarios that the researchers deemed plausible for a terrorist attack. The research experience was used to develop a lesson plan for a high school chemistry course.

The lesson plan was implemented during fall 2010 in Kennedale High School (Kennedale, Texas) chemistry classes, containing primarily sophomores, with a few juniors and seniors. The plan was implemented in three phases: a lecture based on the RET dispersion modeling project, a computer modeling lab during which students modeled a chlorine gas release using AERMOD and a kinesthetic lab during which students performed a microscale experiment involving the release of chlorine gas. Pre and post-surveys were used to gauge the students' knowledge of and interest in engineering and measure their knowledge of concepts related to the lesson.

Research Methods

Chemistry students were in one of two groups: an experimental group (n = 123), which completed the RET lesson, and a control group (n = 85), which did not complete the RET lesson. The students were randomly placed at the beginning of the school year through their counselors in their respective chemistry courses, except for the pre-AP classes that had to be taken through one teacher (n = 38 of 123).

The students involved in the experimental group received pre/post surveys which gauged their interest in attending college, choosing a STEM major, interest and understanding of engineering, whether they preferred kinesthetic (hands-on) labs versus traditional book work, and whether they would like to use technology (computers, laptops, internet, etc.) in conjunction with a hands-on lab. Students in both the experimental and control groups received the same post survey after the experimental curriculum was completed.

Sex and ethnicity were recorded according to the student's interpretation of where they fit into the newest federal education recording guidelines.[3] Students were given a unique ID # that used a period and number combination so that their pre and post surveys could be matched. No names, social security or school ID numbers were collected before, during or after testing.

The survey questions used a Likert-style scale based on four response choices and two types of questions. The first two questions used the following response choices for likelihood: *very unlikely, unlikely, likely, and very likely*. The final five questions use the following response choices for agree/disagree: *strongly disagree, disagree, agree, and strongly agree.* In order to quantify answer responses, a point system was applied to the survey results. From lowest to highest answer choice, a scale of 1 to 4 was used. When determining how to read the scores for both likelihood and agreement, we decided to use the following scale:

Average Range	Classification
≤1.4	Very Unlikely/Strongly Disagree
≥1.5 - ≤2.4	Unlikely/Disagree
≥2.5 - ≤3.4	Likely/Agree
≥3.5	Very Likely/Strongly Agree

Experimental groups were t-tested (α=0.05) for positive scores between pre and post survey results. Experimental groups and control groups were compared using a t-test (α=0.05) to check for significance. Groups were broken down into the following categories: sex, ethnicity, sex-ethnicity, regular chemistry and pre-AP chemistry. Lab scores on the same lab from the previous year were also compared to the same lab scores from this year. The data was disaggregated several ways to compare experimental and control years: overall average, pre-AP only average, regulars only average, by grade distribution (Letter grades of: A,B,C,F) and all of the above excluding those who did not turn work in to receive a grade.

When determining significant versus non-significant t-test results some sub groups were excluded from being included in the results. The reason for this is that we felt even though some of these subgroups exhibited one or more significant results, the populations sizes were too small to be considered for any serious evaluation in regards to the whole population size. The results of those very small subgroups ($n \leq 5$) also exhibited a lack of variability and thus could not have t-test results ran on them. The number of subgroups not tested for t-test results and variability was very small by our definition of $n \leq 5$ [Native Hawaiian/ Pacific Islander (NH/PI) and Alaskan Native/American Indian (AN/AI)].As for ethnicities $n > 5$, we calculated the averages, standard deviations and t-tests for all subgroups. Only the subgroups found to be significant were reported.

The difference between a regular chemistry student and a pre-AP student, other than by student and/or parental choice is as defined by the College Board.[20] Students following the pre-AP track tend to have qualifications specified by the College Board, which include but are not limited to: *ability for higher intellectual engagement* and *students whom perform well in rigorous academic fields* such as STEM. All students, we can hope, perform up to these standards although only a small percentage at most schools ever reach these types of standards and are thus generally involved in these types of pre-AP courses.

Curriculum

Students at this point in the year (approximately 2 months into the school year) are learning to convert numbers (Customary to Metric, Metric to Metric, etc.), how to write lab reports and are beginning to apply some of the knowledge gained through lecture and lab to further their understanding of chemical reactions.

Students began the curriculum with an introduction to the research performed via a PowerPoint presentation created during the time spent researching the material with the RET program at the University of Texas-Arlington. The students were introduced to the research question: *What if a terrorist event took place here in the Dallas/Fort Worth area?* They were shown and asked to analyze a video clip from the HBO movie *Dirty Bomb*.[12] In the clip, 3 terrorists of middle eastern descent in the financial district of London, United Kingdom, blow up a van packed with a dirty (nuclear) bomb. The point of showing this video clip is to introduce what terrorism means, how it affects the area where it happens, and how the public profiles terrorists. We discussed how this type of weapon is used as a terrorist device, how this device is a hazard to the London infrastructure and the people contained within, and if anything could be done to help mitigate the situation.

After the video and hazard discussion we dove right into an ethics issue for the remainder of the class (the class length is 50 minutes). The students were told to answer three primary questions: *What does this video mean to you? Does race/ethnicity/sex play a role in your overall judgment of the situation you have just seen? Elaborate. Finally, devise a plan to help prevent something like this happening in the future if money and resources were no object.*

The following class period, students were told that they will be modeling a gas release (either accidental or terroristic in nature) from the Dallas Cowboys stadium in Arlington, Texas. They were shown the second portion of the PowerPoint presentation that discusses the modeling software and the pertinent vocabulary that will allow them to comprehend the manipulations to the data and how that may or may not change their output graph.

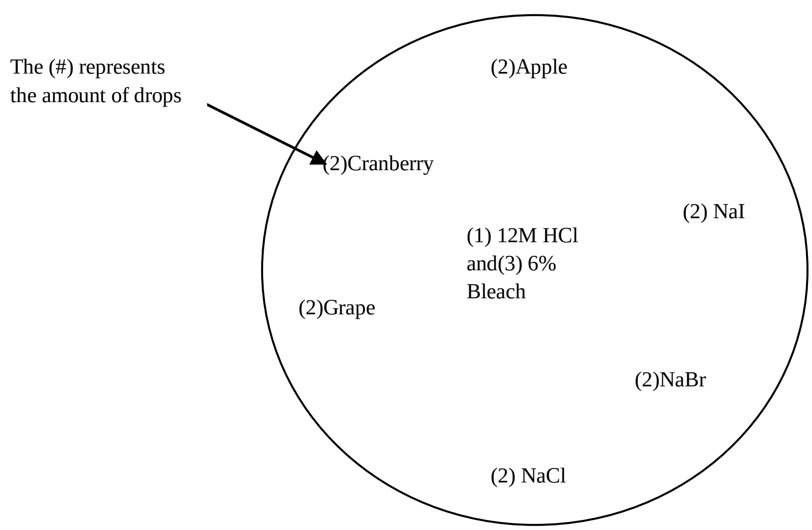
The modeling program is called AERMOD (American Meteorological Society/ **E**nvironmental Protection Agency **R**egulatory Model Improvement Committee's Dispersion **Mod**el).[13] The model that was used was the Lakes Environmental version of the AERMOD software.[14] This model version was used because this was the same modeling software used by the University of Texas-Arlington RET program. This program was developed using Gaussian dispersion methods for downrange gas releases over short distances. Some of the most important inputs for this program are the emission rate (gs^{-1}), exit gas velocity (ms^{-1}), stack height and diameter (m), and meteorological data from SCRAM.[15] All data was plugged into the program ahead of time except the emissions rate, stack height, stack diameter and exit gas velocity. The reason this was done was to save time in the classroom so that the students would have more time with the program and less time trying to figure out where the numbers were placed in the program software. From previous experiences with the software, the authors chose to only have the students model these four variables because they showed the greatest variability in output data and graphs. In order to have enough time to run this program and check for output variations the author devoted an entire class period to this section of the experiment.

The students were able to manipulate the model and see the effects of changing the parameters. Students asked questions about the population size affected by the release and at this point were able to relate modeling with reality. It seemed that a light had come on in their heads and they finally realized the extent of damage that could be caused by a gas release in a heavily populated area. Students were then shown the author's previous work from the RET program and now had the ability to compare and contrast the models created and their affect on the population versus their own models created in class.

In the final phase students were introduced to the kinesthetic portion of the experiment. Students were shown a video about chlorine gas from *Periodic Videos* on how dangerous chlorine gas is and its uses in industry.[16] These videos are extremely educational, humorous and give a sobering view of elemental characteristics. Students were given a specific set of procedures that they were required to follow without deviation due to the inherent danger in producing even small amounts of chlorine gas. Students were closely monitored for compliance with the procedures and those out of line were asked to leave the lab. The gas itself could quickly become overwhelming if not appropriately controlled.

Students took a plastic (or glass) Petri dish and labeled the Petri dish according to Diagram 1. (Note: It is extremely important that the students had both the top and bottom of the Petri dish in order to safely perform and control the experiment. The students used a Sharpie to label the bottom of the bottom Petri dish and used the top to cover the experiment.) The following materials were needed to complete the experiment: concentrated HCl (≥ 6M, preferably 12M if available), bleach (store bought, composed of sodium hypochlorite), concentrated NaOH (≥ 6M), all sodium or potassium based halides (chloride, bromide and iodide), apple, cranberry and grape juice (the juices are optional) and a plastic pipettes.[18] All of the reactants were placed on the Petri dish as shown in Diagram 1 with the numbers in parentheses standing for the number of drops per reactant.

Diagram 1 – The Petri dish layout and drop amounts[17]

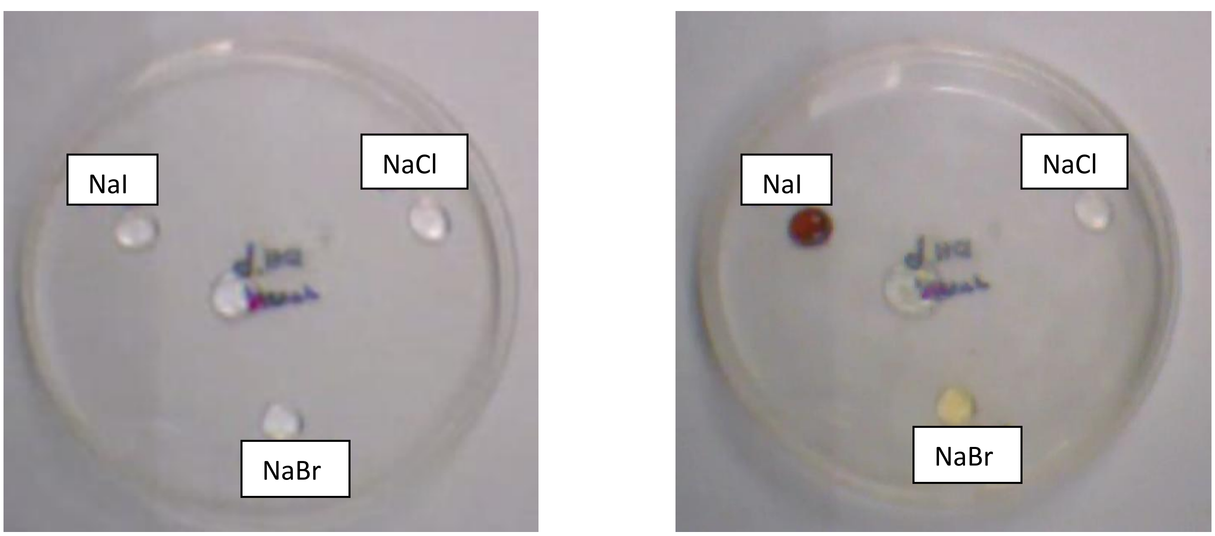


Students followed Diagram 1 adding everything except the 12M HCl. The reason this reactant was added last was that it is the center reaction that produces the chlorine gas. While conducting the experiment it was very important that as soon as the chlorine gas production begins the top portion of the Petri dish be placed over the reaction to prevent accidental release of chlorine gas into the classroom. This reaction was very well controlled when this was followed, and when it was not followed the students began to pick up on the smell very quickly. The smell of chlorine gas is defined as pungent, suffocating bleach like odor with a yellowish-green color.[19] After producing the chlorine gas, the students were required to take extensive observations for approximately 10 minutes as can be seen in the before and after in Diagram 2. Students should find that all compounds changed colors except NaCl (sodium chloride). The NaI (sodium iodide) changed from clear to a light brown and then very dark, crystalline brownish-black color. While the NaBr (sodium bromide) took a little longer to start changing but eventually changed colors from clear to a light to darker yellow color. All fruit juices faded to near colorless while the chlorine gas bleached out the color pigments in the juice. In order to stop the reaction several drops of 6M NaOH were placed on top of the middle chlorine gas producing reaction.

The students were required to also answer several post-lab questions, the most important of which is: *If another class performed this lab with sulfuric acid instead of hydrochloric acid but obtained similar results, how might this happen and what compound is causing this to take place?* This line of questioning made the students think critically about what happened in the chemical reaction and lead them down the path to comprehending how one compound might influence another in the grand scheme of the experiment. The students were asked to write conclusions that discussed all reactions, why only some compounds changed, and to critically analyze their results from the perspective of the model previously created in class using AERMOD and the hands-on experiment ran using chlorine gas.

Diagram 2 – Before (start) and after (10 minute) photos of the chlorine gas experiment

Before | After 10 Minutes



On the final day of the experiment phases, students were asked to reevaluate their experiences both before and after the experiments and how those experiments affected their judgment of STEM. The students again got into groups and discussed the following questions: *Reanalyze the effect that chlorine gas would have on the population of people affected by such a terrorist event or accidental release. Knowing what you know now, is there anything productive or proactive that we as a society can do to reduce or eliminate the chance of this occurring?*

Results

Table 1 provides demographic data collected from the surveys. Two of the ethnic subgroups contained few or no students. These subgroups were included in calculating the overall score but were not found to have no or very little significance in their respective categories as compared with the overall population.

Table 1 – Student demographic data

	Experimental	Control
All (n)	123	85
Sex (n)		
Male	53	37
Female	70	48
Ethnicity (n)		
African American or Black (AA)	25	20
Asian (As)	3	1
Hispanic or Latino (H)	20	19
Mixed (M)	4	8
White, Non-Latino (W)	71	35
Native Hawaiian/ Pacific Islander (NH/PI)	0	2
Alaskan Native/American Indian (AN/AI)	0	0
Regulars (n)	85	85
Pre-AP (n)	38	0

The first survey question addressed the likelihood of college attendance at a 2-year or 4-year college/university or trade school. Students overall and across all subgroups said that they were *very likely* to attend college. Both the experimental and control groups averaged a 3.5, with no discernable difference between the two according to a t-test, as shown in Table 2.

The second question addressed the student's likelihood of majoring in a STEM field. This question was used to measure any change in the students' interest in a STEM field pre and post experiment. One of the research goals was to see whether interest in STEM increased due to implementing the RET lesson. Students overall showed they were *unlikely* to attempt to major in a STEM field, as shown in Table 2. The pre-AP students, however, showed that they were *likely* to attempt this type of major, with a pre/post survey score of 2.7 for both surveys. This was to be expected, as these types of students are generally the ones who are driven to pursue these high demand majors.

Table 2 – Question 1 and 2 Results for All Students

Question	Experimental Group		Control Group
	Pre	Post	
Question 1: Likelihood of college attendance	3.6±0.5	3.5±0.8	3.5±0.7
Question 2: Likelihood of majoring in a STEM field	2.3±1.0*	2.3±0.9*	2.4±1.0*

* T-test statistics were not run because the averages were identical. Although the standard deviation is quite high, the trend for this standard deviation is primarily in the positive direction. This was calculated by taking the overall summation of the pre and post and then dividing by the population sizes associated with those trends.

$$\left(\text{Trend} = \frac{\Sigma\ (\text{pre or post responses})}{n_x}\right)$$

Survey Question 3 was used to determine how much the students knew about engineering. The post-survey results show that overall students *disagree* that they know a lot about engineering; however, the results from pre/post survey testing show a significant increase (see Table 3). The group who benefited the most from the RET lesson was the *regular chemistry* students, with a pre-survey result of 1.8±0.7 and post of 2.0±0.6. This was statistically significant, with a t-test result of 2.000 (threshold: 1.658) All experimental students averaged 1.9±0.7 for the pre-survey and 2.1±0.7 for the post-survey. The subgroup with a significant increase was the *white* group with pre/post survey results of 2.0±0.7 and 2.2±0.7, respectively, with a t-test result of 1.702 (threshold: 1.658)

Table 3 – Question 3 Results: Knowledge of Engineering

Students	Experimental Group		Control Group
	Pre	Post	
All Students	1.9±0.7[A]	2.1±0.7[A]	2.1±0.8
Regulars Chemistry	1.8±0.7[B]	2.0±0.6[B]	2.1±0.8
Pre-AP Chemistry	2.1±0.8	2.3±0.8	----------
White (Not Latino)	2.0±0.7[C]	2.2±0.7[C]	2.1±0.8

[A] This result is significant with a t-test of 2.241 (threshold: 1.653)
[B] This result is significant with a t-test of 2.000 (threshold: 1.658)
[C] This result is significant with a t-test of 1.702 (threshold: 1.658)

Survey Question 4 asked whether a student would prefer to do an experiment instead of reading about the topic in a book. The results were profound and we will discuss these in the discussion section of the paper. Students in the experimental group said that they *strongly agreed* with the notion of doing experiments instead of reading about the topic, whereas the control group *agreed* (average: 3.4), as shown in Table 4. When the experimental and control groups were compared, the averages differed significantly: 3.6±0.6 for the experimental group, compared to 3.4±0.8 for the control group, with a with a t-test result of 1.956 (threshold: 1.645). *Hispanic/Latino* students *significantly* felt that they would rather be working in the laboratory, with pre/post averages of 3.5±0.8 and 3.8±0.4, t-test of 2.095 (threshold: 1.671).

Question 5 asked whether they would prefer to use technology (computer, laptop, iPad, etc.) to access information for chemistry as opposed to using a textbook. All students, both experimental (avg. 3.1) and control (avg. 3.3), said that they *agreed* that they would rather use technology, as shown in Table 4. Students in regulars agreed at a higher rate (3.2) versus pre-AP (3.0). This result will be explained further in the discussion section.

Question 6 asked if the students would prefer to use a computer for experimentation instead of performing a hands-on lab. Students resoundingly *disagreed* (pre: 1.7±0.6; post: 1.6±0.7; control: 1.8±0.8) with this idea. The Hispanic/Latino subpopulation was one of two populations that still preferred to use a computer for labs (pre: 1.5±0.5; post: 1.6±0.5) after the

RET lesson, although the results were not statistically significant. The other subgroup was the pre-AP students (pre: 1.6±0.6; post: 1.7±0.8).

The final question asked whether the students preferred to use a computer first to simulate the experiment and then perform an actual experiment to verify to simulated results. Students in the experimental group *agreed* (pre: 2.5±0.7; post: 2.6±0.7) that they would like to simulate their experiments first and then perform an actual lab experiment. The only group with a significant pre/post change for this question was the African American/Black subpopulation (pre: 2.0±0.0; post: 2.6±0.6). Neither the regular chemistry nor pre-AP chemistry students changed their pre/post survey results, which were 2.6 and 2.5, respectively.

Table 4 – Questions 4-7 Results

Question	Students	Experimental Group		Control Group
		Pre	Post	
Question 4: Preference for experiment vs. textbook	All Students	3.6±0.6	3.6±0.6[A]	3.4±0.8[A]
Question 4: Preference for experiment vs. textbook	Hispanic/Latino	3.5±0.8[B]	3.8±0.4[B]	----------
Question 5: Preference for technology vs. textbook	All Students	3.1±0.7	3.1±0.8	3.3±0.8
Question 6: Preference for computer experiments vs. lab experiments	All Students	1.7±0.6	1.6±0.7	1.8±0.8
Question 7: Preference for computer experiment preceding lab experiment	All Students	2.5±0.7	2.6±0.7	2.6±0.8
Question 7: Preference for computer experiment preceding lab experiment	African American/ Black	2.0±0.0[C]	2.6±0.6[C]	----------

[A] This result is significant with a t-test result of 1.956 (threshold: 1.645)
[B] This result is significant with a t-test result of 2.095 (threshold: 1.671)
[C] This result is significant with a t-test result of 5.000 (threshold: 1.684)

In order to compare lab grades from last year's classes (control group, no curriculum modification) to this year's classes (experimental group, curriculum modification applied) the data was disaggregated several ways: overall average, pre-AP only average, regulars only average, by grade distribution (A, B, C, F) and all of the above excluding those who did not turn work in to receive a grade. (see Table 5) Due to variable conditions from year to year, and student group to student group, we decided to use averages and percentages that removed the outliers (those not turning in work) and therefore felt that these averages would give us better analysis of the data.

Table 4 – Comparison of Control and Experimental Lab Scores

	Averages (Max 100)		Averages excluding work not received (Max 100)	
	Experimental	Control	Experimental	Control
Complete Average	59.5	86.4	78.9	91.9
Pre-AP Average	27.9	72.9	85.5	94.9
Regulars Average	73.7	95.7	74.7	89.6
Grade Distribution	Percentages		Percentages excluding work not received	
	Experimental	Control	Experimental	Control
A (89.5-100)	34.9%	67.3%	45.8%	71.6%
B (80-89.4)	14.3%	12.9%	18.8%	13.7%
C (70-79.4)	7.9%	9.9%	10.4%	10.5%
F (≤ 69.4)	42.9%	9.9%	22.9%	4.2%

Discussion

This study presented some very interesting results that may apply to future studies about hands-on labs and how they may be used to increase student learning in engineering and other lab intensive subjects (STEM subjects especially). Most students are willing to at least attempt to go to college, and our results showed that these students (n = 208) are no different. Students genuinely wanted to succeed in both their personal and professional lives. One of the limitations here is that the students that were tested were primarily tenth graders (ages: 15-16), and at this point in their high school career are not really sure what they want to do. It seemed that when the students were asked, they change their minds every other week. This is indicative of the changes between both the pre and post survey results. Students when asked the same question changed their minds over a week (Pre: 3.6 and Post: 3.5).

One of the research goals was to see if this type of curriculum (the RET lesson) would enhance the students' college degree track. We wanted to attempt to foster interest in engineering and other STEM related fields. Although the results did not show any discernable change, we feel that with more curriculum changes and possibly different types of lab scenarios that still heavily incorporate the hands-on lab approach, we will begin to see change in the positive direction. Due to the nature of the study and this being the first year the study was performed, it is impossible at this point to say whether any of these students will attempt a STEM major and/or eventually graduate with one, although we can only hope that they will choose this important path of education. We plan on tracking these students over the next three years to see what majors they choose when attending college. These tracking results will give a good indication of whether the curriculum helped to generate positive opinion or open new doors in education to the students.

When asked whether students knew a lot about engineering, the negative results were somewhat unexpected; however, the post-survey results showed that the hands-on chlorine gas lab and computer modeling simulation increased their awareness of the field. Although disagreeing with the notion that they knew a lot about engineering, the students noted that they felt better about the field (Pre: 1.9±0.7; Post: 2.1±0.7). We think that it is important to note the direct significant improvement to the score (t-test: 2.241; threshold: 1.653; α=0.05). Regular chemistry students (n = 85) showed a significant increase in their pre/post survey results, as can again be attributed to the new curriculum. The other subgroup was the White (not Latino) group that also showed a slightly significant result (Pre: 2.0±0.7; Post: 2.2±0.7; t-test: 1.702 [threshold: 1.658]).

One of the results that we were not anticipating was the equal response to the engineering question by the control group (n = 85). We believe this could be explained if we had taken more data about the students' parents' employment. It is quite possible that because of this unknown data, the control group may have had several students whose parents were in some way related to the field of engineering. In the area where the school is located, there are several major engineering firms (Lockheed Martin, Vought Aircraft, Raytheon and Bell Helicopter Textron/Boeing, etc.) at which these parents could be employed. This idea alone may be able to explain several of the control group's responses to the survey questions.

We believe that the most profound result in this experiment was that all students preferred to perform a hands-on lab as opposed to reading about them in a textbook. There seems to be a lot of qualitative data to support the idea that students are hands-on learners; however, there is very little if any data to support the idea quantitatively. This research showed definitive quantitative support for the hands-on lab theory. These students, regardless of the whether they were in the experimental or control group, overwhelmingly supported the idea of performing a hands-on lab as opposed to simply reading about the topic in the textbook. This type of quantitative result confirms the idea that a change needs to occur in the way that we teach concepts in the STEM fields. Teachers and professors alike should be using labs that allow the students to investigate the topics instead of the traditional lecture delivery method. Even though this experiment focused on sophomores in a high school setting, this result we believe could be applied to younger and older students. Across the board, students in the experimental group strongly agreed (Experimental Post: 3.6±0.8; Control: 3.4±0.8).

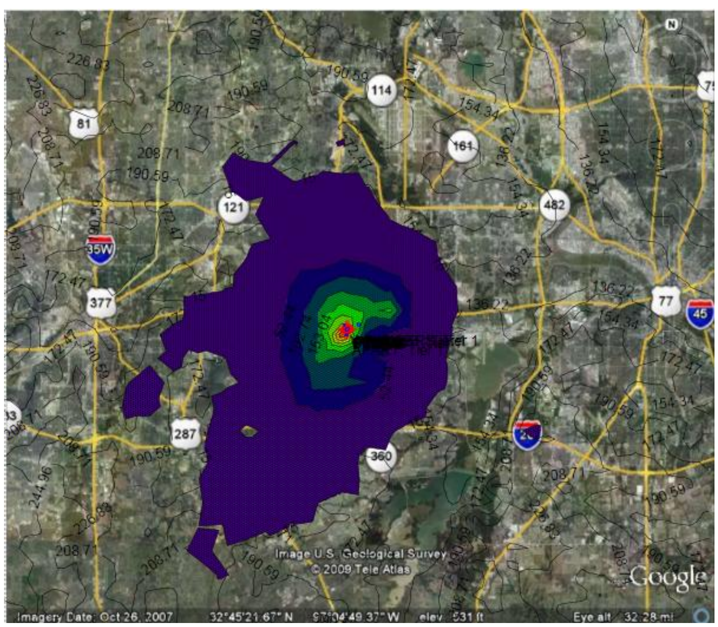
We felt that the current college and high school students were more likely to want to perform labs because of the immediate feedback that they provide as opposed to reading about what someone did in the past. A perfect example of this is Facebook and related social networking websites. Why do students put their "lives" on Facebook? By this we mean, one student posts what they are eating for a snack or when they are going to take a shower. Why is this important? Students feel as though it is important to get immediate feedback from the public and their friends and family. The results of our experiment could clearly be related to this idea of a feedback system, whereby simply reading about the labs in a textbook or reading about the people who, some of which are not living anymore, performed the experiments simply does not suffice; instead they chose to get the results for themselves.

Although the lab results showed a decrease in averages from control to experimental groups we feel this can be explained. The student base from year to year may very drastically in talent and skill level as well as the grading of the teacher or professor. Although educators are good at what they do, there will always be variation from year to year in grading techniques although using strict rubrics and other techniques may help to prevent this. Students in the control group clearly obtained higher averages than the experimental group, 91.9 vs. 78.9, respectively. We felt that through the removal of the students who did not turn in their work the overall averages would increase to comparable levels and allow us to better assess the application of the curriculum. The data did not support our curriculum; however there was a slight improvement in the grade distribution as highlighted in Table 5 for students obtaining a letter grade of B, 18.8% (experimental) vs. 13.7% (control).

Currently in the STEM courses especially in high school and college, students are not involved in the laboratory. In the State of Texas, high school students are required to only be in the lab 40% of the time, and in many lower level college courses there is not even a lab associated with the course curriculum.[21] This data supports the idea of change in the way that information is presented to the student. Future research in this area is of utmost importance if we are to progress in the way the information is given to and received by the students in this new generation of technology.

The control group results showed that they prefer technology (computer, laptop, tablet, etc.) over the traditional textbook. Students in the experimental group also agreed with the notion that they would rather gain information from technology instead of a textbook; however there was no discernable change from pre and post survey results. This may have been due to the fact that students did not like the way the information was presented to them while using the AERMOD program to model a chlorine gas release. Students understood the supposed impact of the graphs when presented the information about deaths or severe injuries but appeared not to understand the intricacies of the measurements on the graphs, such as emission rate or stack height. Even after presenting this information prior to performing the simulation, students were still asking questions about what exactly they were looking at. Once the author picked up on this, he simply changed his approach to cover just the basics of the model, such as death rate in the impacted area. An example of one of the created pictures is below in *Picture A.*

<u>*Picture A*</u> – Gas Release over the Dallas/ Fort Worth area.



This picture shows the simulated gas release impact. The largest impact of this gas would affect several hundred thousand people. AERMOD was used to create this image.

When the results of Question 4 are combined with those for Question 5, a hierarchy emerges, as shown in Table 6, where students prefer hands-on labs, then technology, and finally the use of a textbook.

Table 6 –Learning Technique Preference Hierarchy

Learning Technique	Role of the Technique
Hands-on Lab →	Most important learning technique
↕ Technology →	Bridges the gap between the innovative learning technique and the traditional technique
↕ Use of Textbook →	Traditional and possibly outdated (for the new generation) form of learning

For some teachers and professors, the notion of doing away with or drastically reducing the use of the textbook as a teaching tool may come as a shock. As our students continue to grow and change in future generations, teachers and professors need to change and adapt as well to fit their needs. As we are taught, our pedagogy must fit the needs of the students that we teach and if we cannot adapt, we will struggle to get students to follow us into the fields of study that we love.

In the learning technique preference hierarchy mentioned above, (*see Table 6*) technology must be used to bridge the gap between what the traditional textbook has to say and what the hands-on lab presents in terms of the student gaining and retaining knowledge. Students disagreed with the idea of strictly using a computer for experimentation instead of performing a hands-on lab. Students felt as though they were losing a sense of tactile sensation, which was one of the main reasons for doing labs. We believe that students felt a sense of accomplishment when something explodes, changes colors or gets really cold in the lab. The main reason for this perception is that they got to mix, light on fire or get immediate feedback on a job well done in the laboratory. A computer can offer a sense of knowledge; however a computer cannot, yet, provide a sense of tactile feeling that a good hands-on lab will. A teacher in anatomy and physiology once told the author that in order to really understand the function of an organ, one must feel the form of an organ. He suggested that instead of using gloves that we actually touch and manipulate the organ. We believe that the teacher might have been on to something here. Students are more likely to gain knowledge or the perception of "function follows form" if they are able to touch the "organ." A limitation of technology must be noted here as we decipher the difference between technology and hands-on labs. One current trend in education is online courses that provide students the ability to gain credit while not actually attending the course on campus or going to campus only once weekly. For some courses, this may work great; however, this too has its limitations. Students can take a chemistry course online, but must still go to campus at a specified time every week or two to still use the laboratory to gain the knowledge learned in the classroom through experimentation. We, as scientists, pride ourselves on experimentation and say that without quantitative values, technology is meaningless. We should pass the same things onto our students, teach them how to use their senses, teach them how to use technology as an aide, and teach them to love what they do.

Conclusion

Educators must be aware of the changing trends that our future generations are growing up with. We must give credence to new ways of learning the same concepts. Students find significantly that hands-on labs, more so than technology alone, will give them the perception of success in the STEM classrooms. According to the hierarchy of learning technique preferences, students feel that the least helpful of all resources is the textbook. Why might that be? It could be that the textbook is a leftover vestigial apparatus from many years and educators ago. The perception of students now is that they want immediate feedback, they want to utilize their tactile skills and senses and they want the world to know about it. Should we change the way that we present information in the classroom to our future engineers, chemists and physicists? We believe this can be answered with a resounding yes.

Future research in this topic will be directed at investigating how hands-on labs can be implemented more so in the classroom in place of traditional textbook style lessons. We will also research different classifications of students both in the secondary and post-secondary levels to see if our findings are supported.

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