Increasing Motivation and Enhancing the chemistry enrichment experience of incoming students' through the use of lectures related to chemistry in engineering and ALEKS® system

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Abstract

This paper is being submitted as Complete Research. Carter Academy is a summer program designed to provide Milwaukee School of Engineering (MSOE) incoming undergraduate engineering students with extra support through providing a bridge experience to refresh their math, science, and writing skills as well as assimilate them to campus facilities. Students are expected to attend all the disciplines regardless of their background and intended area of study. Beginning in the summer of 2013, the chemistry portion has focused on student preparation for Chemistry I, which is required for almost all the undergraduate engineering programs at MSOE. However, due to the diverse student backgrounds and lack of motivation, as noticed through the years by faculty teaching Carter Academy, the chemistry enrichment experience was not always optimal. To enhance the student learning experience and motivate students to be successful, faculty began incorporating *Chemistry in Engineering* lectures along with the *Chemistry Preparation* lectures and ALEKS® system in the summer of 2017. *Chemistry in Engineering* lectures contained two parts: Understanding Chemistry Through Cars and Molecules That Amaze Us. The intention was to show students the importance of chemistry in relation to their fields of study and daily life. Students who completed the corresponding ALEKS® assignment prior to the lecture were permitted to opt-out of attending the *Chemistry Preparation* lectures. Assessments were conducted before and after the program – namely, pre-course and exit exams, motivation surveys, and a program exit survey. Students showed a significant improvement after completing the summer program (pre-course exam score: 15.9 ± 5.3 (2019), 13.4 ± 6.0 (2018), and 17.6 ± 4.7 (2017) and exit exam score: 20.2 ± 4.0 (2019), 20.3 ± 3.6 (2018) and 22.0 ± 2.2 (2017); $p < 0.01$ for all three years). When it comes to the program exit survey, 69 % (2019), 64 % (2018) and 62 % (2017) of the students indicated that they gained a good sense of what to expect during their Chemistry I class during the academic year compared with 40 % of those in summer 2016. Regarding the pre-course and exit motivation surveys, there is a significant difference ($p < 0.1$) in response to the question: Whether the chemistry content is difficult or easy, I am sure that I can understand. Moreover, the motivation survey also shows the differences among majors (e.g., chemistry intensive v.s. non-chemistry intensive). To summarize, the program itself helps ready the students academically, while *Chemistry in Engineering* lectures and ALEKS® help enhance their learning experience and understanding of how chemistry fits into their lives and academic pursuits. Additional assessments will be conducted in the future to validate and expand upon the findings.

Introduction

Since 2011, MSOE has incorporated the Carter Academy program for students granted conditional acceptance into the institution who may need more academic preparation before entering their engineering programs. While these students clearly showed strong academic potential in high school, they may need more preparation to successfully transition from high school academics into an engineering program at MSOE in addition to getting used to the MSOE's fast-passed quarter system and campus facilities. The Carter Academy program is

offered fully-funded to students; participants are not responsible for paying for housing, food or classes. During this summer residential program, which runs for four weeks, the students attend classes in math, engineering, writing, chemistry, and physics, with organized study time during the evenings and projects. These classes are limited to about 18 students per section [1].

The chemistry portion, *Chemistry Preparation* lectures, has always focused on student preparation for Chemistry I, which is required for almost all the undergraduate engineering programs at MSOE and more than 90% of these students take Chemistry I during their first quarter immediately following their completion of the Carter Academy program. Previously, the student survey feedback was not positive and promising as expected. In addition, it has been noticed that the "attitude" of students towards learning chemistry was relatively negative at MSOE, partially due to their majors which are mostly in traditional engineering programs, such as mechanical and electrical engineering. Students studying within these majors generally do not feel the need to learn chemistry but rather choose to simply pass the required chemistry course(s) to obtain their degree. In another observation, the students demonstrated a vast difference in their chemistry background as indicated by their pre-course exam score distribution (large standard derivations as shown in Figure 1). Students who already had strong/adequate chemistry backgrounds tended to get bored in the classroom expressing an ineffective use of their time. In addition, in many cases, they unintentionally produce negative impacts on the overall learning of all students in the program. As observed in the classroom, the students without strong chemistry backgrounds simply gave up after becoming discouraged when they realized their peers have already been exposed to certain concepts or finished certain assignments rather quickly.

Based on these observations, student backgrounds, and MSOE's academic system, the two chemistry instructors of the Carter Academy program incorporated two major changes starting in the summer of 2017. One change was to add *Chemistry in Engineering* lectures to show students the importance of chemistry in their fields of study and daily life to increase the motivation of students to learn chemistry. Motivation is the internal state that arouses, directs, and sustains students' behavior toward achieving certain goals [2]; while Brophy defined motivation to learn as a student's tendency to find academic activities meaningful and worthwhile and to try to derive the intended academic benefits from them [3]. This change focuses on *intrinsic* motivation – the person does an activity because it is inherently satisfying and enjoyable rather than it leads to a separable outcome or consequence (*extrinsic* motivation) [4]. It has shown that if the course is perceived as interesting and important to their future, students may become more motivated and engaged in the process [5].

The other change was to incorporate the ALEKS® system in *Chemistry Preparation* lectures to increase teaching effectiveness. **ALEKS**, **A**ssessment and **LE**arning in **K**nowledge **S**paces, is a Web-based, artificially intelligent assessment and learning system. ALEKS® begins with an adaptive pre-test to determine each student's initial knowledge state. Based on the pre-test results, the program assigns individualized homework problems for the topics which the student is most ready to learn. Each student's starting point will be different; this is extremely valuable for a group of students with diverse high school chemistry backgrounds. To progress through the assigned topics, students must demonstrate mastery by solving multiple problems of the same type. It has been shown than when students master their ALEKS® course material, they tend to be successful in the actual course [6]. Additionally, exposing students to online learning

platforms help them transition into their college study since a significant number of courses have adopted online learning platforms, including Chemistry I.

Methods

Students Selection

Carter Academy students are usually between the ages of 17-19 years old, they are pre-identified by the MSOE Admissions Office (based on their SAT score and high school GPA) and voluntarily agree to partake in the program. The program is only open to traditional and domestic students. There are approximately 45 (ranging from 41-61) students enrolled each year. Students are from diverse ethnic backgrounds (~ 30% of them are from underrepresented groups).

Chemistry in Engineering lectures development

Reference books "Understanding Chemistry through Cars [7]" and "Molecules That Amaze Us [8]" were used as major resources to develop the lectures. The topics were carefully selected to link science and engineering knowledge to daily life while introducing and reinforcing certain chemistry concepts. Moreover, the topics were modified and/or expanded to fit the specific needs and levels of the students. The topics and related chemistry concepts are summarized in Table 1.

Table. 1 Summary of topics and related concepts of the *Chemistry in Engineering* lectures.

	Topics	**Chemistry concepts introduced/reinforced**
Understanding Chemistry Through Cars	Gas, tire, and pressure	States of matter; ideal gas law; gauge pressures *vs.* absolute pressure
	Airbag	Nitrogen gas structure; concepts of mole and molecular weight; basic chemical calculations
	Gasoline and diesel	Combustion; chemical and kinetic energy
	Biofuels	Ethanol structure; chemistry of biodiesel;
	Aqueous fuel emulsions	Intermolecular forces; concept of solution, solutes and solvent; surfactants; hydrophilic, hydrophobic and hydrophilicity;
	Lubricants and wax	Viscosity
	Road salt	Hydration
	Composites, rubber and alloy	Vulcanization; structure-property relationship

Molecules That Amazes	Water; carbon dioxide; hydrogen peroxide; oxygen and ozone; methane	Chemical structures; hydrogen bonds; electronegativity; solvation; greenhouse effect; pH; oxidation; radicals
	Taxol and cisplatin	Natural products; *cis- vs. trans-*

Chemistry Preparation lectures development

The "Calculations in Chemistry" workbook [9] was used as a major resource to develop the lectures and classroom activities. The selected topics focused on foundational skills necessary for success in college chemistry. Topics were organized into seven themed ALEKS objectives (assignments). These topics are summarized in Table 2.

Table. 2 Summary of topics in the *Chemistry Preparation* lectures.

ALEKS Objective	**Topics introduced/reinforced**
Scientific Notation	Moving the Decimal; Calculations Using Exponential Notation; Estimating Exponential Calculations
The Metric System	Metric Fundamentals; Metric Prefixes; Calculations with Units
Significant Figures	Recording Measurements; Counting Significant Figures; Calculations with Significant Figures
Conversion Factors	Single-Step Conversions; Multi-Step Conversions; English/Metric Conversions; Ratio-Unit Conversions
Word Problems	Mining the Data; Solving for Single Units; Solving for Ratio Units
Atoms and Ions	Chemical Symbols; Isotopes and Ions; Atomic Mass; Organization of the Periodic Table
Grams and Moles	The Mole and Avogadro's Number; Molar Mass; Converting Particles, Moles, and Grams

Incorporation of chemistry in engineering lectures and ALEKS® system

Students take two Chemistry Preparation lectures (based on the ALEKS® system) and two Chemistry in Engineering lectures each week. The Chemistry in Engineering lectures 50 minutes long twice a week and are mandatory. The Chemistry Preparation lectures are only mandatory if the student has not yet learned the ALEKS® topics in the current objective. Each Chemistry Preparation lecture is held 12 - 24 hours before the ALEKS® objective deadline. Lectures focus on problem-solving strategies and Q&A for problem types encountered in ALEKS®.

Motivation Research Procedure

Motivation is important as it plays an important role in students' conceptual change processes, critical thinking, learning strategies, and science learning achievement [9]. A survey has been developed to measure students' motivation toward chemistry learning (Appendix A). Background questions (Q1-3) are used to gain an understanding of students' chemistry education background as well as their intent of study to be able to analyze the results based on their majors (majors will be clustered and included in the drop-down list). The questions related to motivation assessment are selected from the attached reference to mainly focus on the three factors of motivation: self-efficacy (Q4 and 5), active learning strategies (Q6-8), and science learning value (Q9-11). Q11 looks particularly at whether the response is major-dependent. The questions with the highest loading of these three factors have been chosen. Moreover, to ensure the survey quality, a reverse question has also been included (Q5).

Voluntary Qualtrics surveys containing an informed consent statement were sent to students through their MSOE issued e-mail accounts at the beginning and end of the program (pre and post surveys). 84% of students responded to the pre-survey and 69% of students responded to the post-survey in Summer 2019. The same questions were used. Each survey was available for completion for a specified time period. Safeguards have been put in place to make them nonidentifiable, and class time (10 minutes) was allocated for students to complete the survey without an instructor/researcher present. Data were placed in Minitab for analysis. No identifiable personal information was available to the researchers. The MSOE's Institutional Review Board (IRB) has determined this project is exempted from IRB full board review according to federal regulations. Regarding answer options for Q4-11, 1 is strongly agree, 2 somewhat agree, 3 neither agree nor disagree, 4 is somewhat disagree, and 5 is strongly disagree.

Results and Discussions

Incorporation of *Chemistry in Engineering* lectures and the ALEKS® system were conducted during the summers of 2017 to 2019. The same pre-course and exit exams that were used in previous years were given to the students in the summers of 2016 to 2019 for assessment. The student scores from the summer of 2016 were used as the control. Prior to 2017, students in MSOE did not use ALEKS or Chemistry in Engineering Lectures. Instead, they were taught using traditional chemistry preparation lectures. The same professors have been teaching the Chemistry portion of Y since 2013. Also, pre-course and exit exams have the same number of questions, structure, and levels of difficulty. Statistical analysis was performed using the Microsoft® Office Excel software (t-test). As shown in Figure 1, students showed a significant improvement after completing the summer program for all three years (pre-course exam score: 15.9 ± 5.3 (2019), 13.4 ± 6.0 (2018), 17.6 ± 4.7 (2017) and 17.3 ± 4.7 (2016) and exit exam score: 20.2 ± 4.0 (2019), 20.3 ± 3.6 (2018), 22.0 ± 2.2 (2017) and 21.9 ± 2.8 (2016); $p < 0.01$ for four years). In addition, when comparing the percentage mean score increase, the data showed that there is a 51% percent mean score increase in 2018 compared with 27% in 2019, 25 % in 2017, and 27% in 2016. This might be largely due to the overall student background differences as the average score for the pre-exam of 2018 was the lowest.

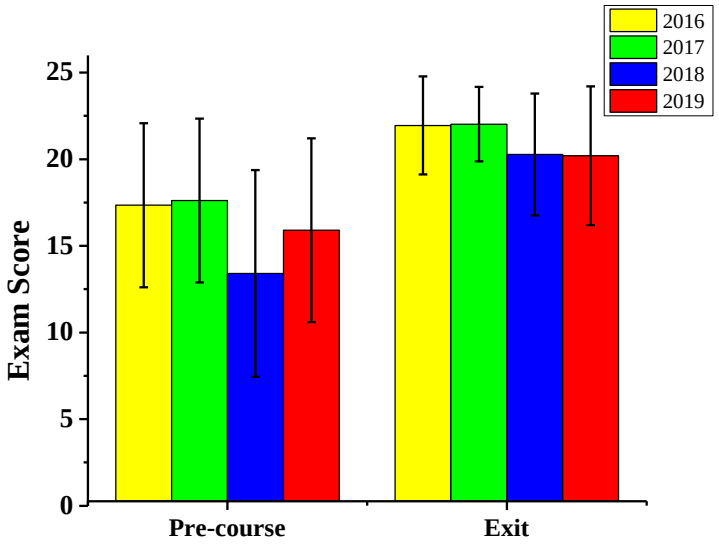

Figure 1. Student pre-course and exit exam performances during the summers of 2016-2018. Error bars represent the standard deviations. The number of students in the program per year was 61, 41, 46, and 48, respectively.

The questionnaire developed by Tuan et.al. [10] has been adequate construct validity and reliability by other researchers [11-12]. The survey was developed based on this questionnaire – questions were selected/modified based on their relevance to our purpose. Comparisons between students who did and did not take high school chemistry were not performed due to the fact the majority (> than 95%) of the students came into the program indicating they had high school chemistry experience. For the same reason, the authors did not conduct comparisons between students who were planning to and not planning to take Chemistry I. Students not planning to take Chemistry I totaled less than 10% of those who responded to the survey. Statistical analysis was performed using the Minitab 18™ software. The survey results are shown in Figure 2. There was a significant difference ($p < 0.1$) in the response to Q4 (relating to self-efficacy): *Whether the chemistry content is difficult or easy, I am sure that I can understand it*. However, no significant statistical difference was observed regarding the responses to the other questions.

Moreover, the survey data was analyzed based on student majors. Mean scores of Q4-11 were used (Figure 3A). The results show the differences among majors. Unsurprisingly, the Q11(major-dependent question) results by major show a very similar trend (Figure 3B). Students majoring in Architectural/Civil Engineering, Biomedical/BioMolecular Engineering, and Electrical Engineering's mean scores decreased from post-course to exit survey indicating the increased motivation in learning chemistry. Computer/Software Engineering/ Computer Science and Industrial/Mechanical Engineering students' results were different. The possible explanations are they do not need to take a Chemistry course and/or they do not see the direct "application" of chemistry in their majors. Computer Engineering does not require students to take chemistry courses; while software engineering and computer science require a science elective during the first year, chemistry is suggested but may be substituted for biology. Interestingly, ME/IE-majored students showed relatively high motivation (comparable to the BioE/BME group) both before and after the program (Figure 3B). When it comes to the Carter

Academy program exit survey, 69% (2019), 64 % (2018) and 62 % (2017) of the students indicated that they gained a good sense of what to expect during the academic year compared with 40 % of those in summer 2016.

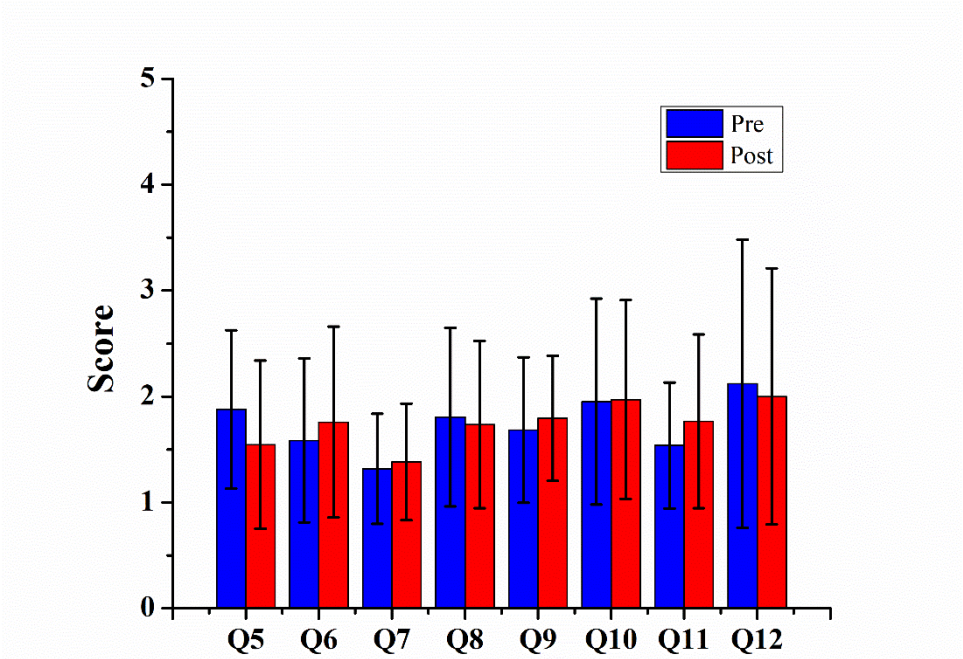

Figure 2. Student pre-course and exit motivation survey results with Q5 scores reversed. Error bars represent the standard deviations.

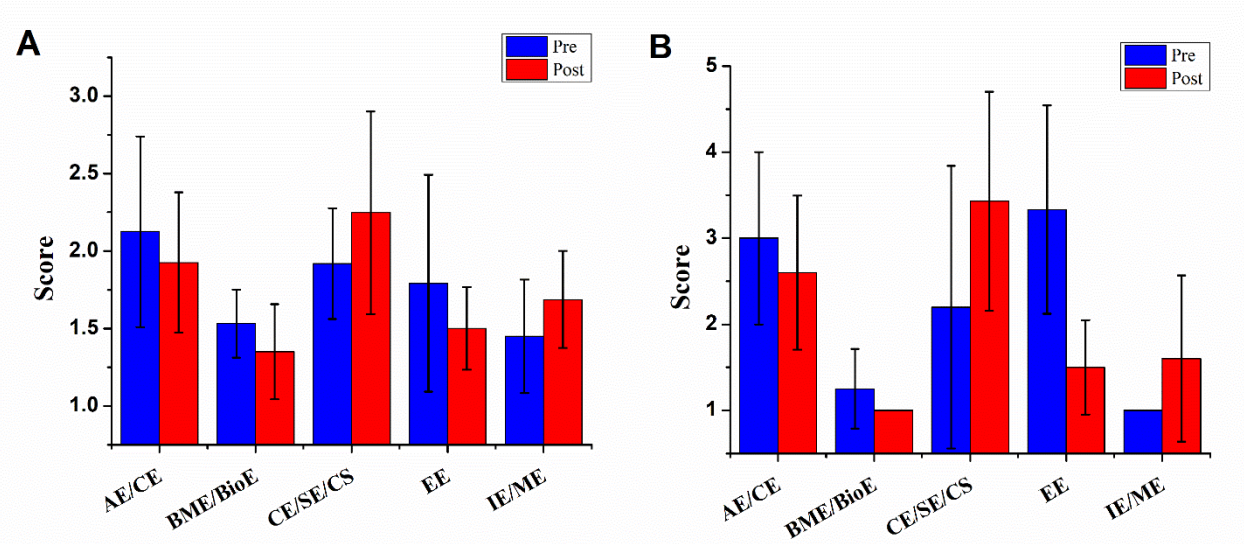

Figure 3. Student pre-course and exit exam survey results based on their majors. Error bars represent the standard deviations. A: average cores of Q4-11 with Q5 scores reversed; B: Q11 only.

In summary, the program itself helps ready the students academically, while *Chemistry in Engineering* lectures and ALEKS® help enhance their learning experience and prepare them for

their undergraduate chemistry courses. Particularly, *Chemistry in Engineering* lectures shows the connection between chemistry and daily life including how it specifically relates to a student's engineering discipline and increased students' motivation in learning chemistry but major-dependent. The ALEKS® system keeps the chemistry portion of the Carter Academy program more organized while increasing the learning efficiency.

Future Directions

Additional assessments will be conducted in the future. The motivation survey questionnaire will be modified by collaborating with experts in the field. The feedback will be used to improve the *Chemistry in Engineering* lectures as well as the organization of the chemistry portion of the Carter Academy program.

Acknowledgment

The authors would like to acknowledge Brendan Monahan, Dan Meiser, and Angela Moureau for their technical assistance.

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Appendix

Questions:

Major – *Q1* (Drop-down list)

Did you take high school chemistry? – *Q2 (Yes/No)*

Are you going to take Chemistry I? – *Q3 (Yes/No)*

Whether the chemistry content is difficult or easy, I am sure that I can understand it. *Q4*

No matter how much effort I put in, I cannot learn chemistry. *(reverse coded)* – *Q5*

When learning new chemistry concepts, I attempt to understand them. *Q6*

When I do not understand a chemistry concept, I find resources that will help me *Q7*

During the learning processes, I attempt to make connections between the concepts that I learn. *Q8*

I think learning chemistry is important to learn to solve problems. *Q9*

It is important to have the opportunity to satisfy my own curiosity when learning chemistry. *Q10*

I think learning chemistry is beneficial to my potential field of study. *Q11*

Majors (Q1):

1. Architectural/Civil Engineering (AE/CE)
2. Biomedical/BioMolecular Engineering (BME/BioE)
3. Computer/Software Engineering/Computer Science (CE/SE/CS)
4. Electrical Engineering (EE)
5. Industrial/Mechanical Engineering (IE/ME)