Integrative Activities for First-Year Engineering Students – Fuel Cell Cars as a Linking Project Between Chemistry, Mechatronics Concepts and Programming

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Abstract – *In Mechatronics Engineering at the University of Waterloo, a joint project involving small, inexpensive fuel cell cars was introduced to show how courses in the first term relate to one another. Additionally, the project was designed to provide the students with hands-on learning, to give the students a taste of what to expect in later years, and to start incorporating many of the CEAB's graduate attributes at an introductory level. The fuel cell car consists of two low-voltage fuel cells, a low power microcontroller and several sensors mounted on a motorized platform. Students employed concepts from chemistry, programming, and mechatronics systems throughout the project, submitting reports at key milestones. During the project, students needed to make decisions in a team environment on which strategies to implement to meet the goals of the project. The project culminated in a final competition and report. Students were surveyed at the start, and end, of the term to measure any changes in attitude with regards to the courses as well as their satisfaction with this project. The project was well received by the students, but significant challenges remain to be solved.*

Keywords: Integration, Chemistry, Fuel Cell, First Year, Hands-on Learning

1. INTRODUCTION

1.1 Motivation

First-year students are keen to start working in the field related to their selected career of engineering by designing and building. The reality of their education is a bit different, however. In the first term of mechatronics engineering (MTE) at the University of Waterloo (UW), the students are required to take two courses in mathematics, one in chemistry, one in programming and

one in engineering practice. There are three issues with this “traditional” approach to teaching first-year engineering. First, the mismatch between the desire to practice engineering design and the reality that much of the term is spent in lectures, has the potential of seeding disillusionment among students. This issue of disillusionment is not unique to MTE but can also be found in other engineering programs. Second, students are required to develop their communication skills, as shortly they will be searching for co-op jobs and working in industry. This is an area of weakness (and dislike) for most engineering students. Finally, the programming experience in high school is lacking.

In the first term of mechatronics engineering, students engage in hands-on activities that integrate concepts from multiple courses. This accomplishes several goals: to show that chemistry is integral to mechatronics engineering, to avoid disillusionment, to increase the relevance of the communication activities, and to provide practical experiences. The integration process began with the “Engineering Practices” course which was converted into “Mechatronics Concepts (MTE 100)” to create room for hands-on engineering activities. This paper discusses an activity involving a small fuel cell car that was developed to integrate chemistry (ChE 102) and programming (GenE 121) into a hands-on mechatronics engineering application within the concepts course (MTE 100).

1.2 Opportunities with Chemistry

A chemistry course is taken by all engineering students. A common complaint is, “Why do we need to take chemistry?” The responses to three questions from an exit survey of the graduating students in years 2011 and 2012 are given in Table 1, and clearly show that the students did not see the relevance of the course. As is true of most of the foundation courses, there is a significant overlap between the topics in the course and those listed in the

Ontario Curriculum for Science, Grades 11 and 12 [1], which contributes to the disillusionment with regards to the course.

Table 1 : Program Weaknesses Identified by Fourth-Year Mechatronic Engineering Students

Graduating year and year of survey	2011	2012
Number of respondents (% of graduating class)	51 (58%)	62 (74%)
Which aspect did you least enjoy?	1. Material is irrelevant or not used in curriculum (59%) 2. Poor quality of teaching (18%)	1. Material is irrelevant or not used in curriculum (50%) 2. Poor quality of teaching (16%)
Which university course was least important?	1. ChE102 (43%) 2. MTE100 (8%) 3. MTE111 (8%)	1. ChE102 (24%) 2. SyDe 351 (19%) 3. ME 351 (5%)
What aspect of the program least met your expectations?	1. Curriculum issues (55%) 2. Labs and facilities (10%)	1. Curriculum issues (47%) 2. Teaching quality (15%)

In focus group discussions with upper-year MTE students, students made comments stating that ChE 102 was a “missed opportunity”, that it “should link more with materials science”, and that “it is not even remotely tied to upper-year materials science”. Students referred to it as a “necessary evil”, and some questioned as to whether its sole purpose in the curriculum was to help meet the required number of natural science academic units defined by the Canadian Engineering Accreditation Board (CEAB). Students indicated that they felt that another physics course would be preferable to the chemistry course, because they could see the need for a greater background in areas such as optics.

The MTE curriculum contains several key topics which rely on knowledge of chemistry. These topics include materials science, green energy, which is of increasing importance within the discipline, and the operation of electrical sensors. However, neither the first-year students nor the graduating students relate these important areas with the material learned in ChE 102. Much of the curriculum at UW is considered to be what [2] described

as being “received”, meaning that the curriculum is organized with the belief that there is a “given” body of knowledge to be taught that is predominantly non-negotiable. Heywood states that this is typical for engineering curricula, and further concludes that significant change is primarily driven by external forces from outside agencies. Changes to the course were (and continue to be) very difficult to implement: the chemistry course is team taught to most engineering disciplines, with eleven sections being taught the same material including identical midterm and final exams.

However, in 2011, there was an opportunity to try and address some of the issues with ChE 102. The CEAB is driving change with its Outcome Based Assessment initiative [3]. As part of this initiative, program committees are looking at new ways to monitor and improve undergraduate engineering programs. In addition, in the previous year, instructors for two first-year mechatronics engineering courses (the introductory concepts course MTE 100 and the programming course GenE 121) had begun to explore whether greater course integration would be beneficial to the students [4]. Within the Faculty of Engineering, a model of integrating engineering clinic activities was being introduced, which represented a smaller scale version of the engineering clinic pioneered at Harvey Mudd College [5]. While there had been some issues with the introduction of common activities, most notably to do with the instructors underestimating the amount of communication needed and the resources required, students had felt that even this amount of limited course integration was an improvement. So for the fall 2011 term, the instructors of the chemistry course, the programming course, and the introductory concepts course decided to include joint activities based on using a small inexpensive fuel cell car.

As described in Section 2, the initial integration focused on providing space within the concepts course for the fuel cell car activity, and the fuel cell car project served as the topic for many of the writing and communication assignments. Informal feedback from the students in fall 2011 and 2012 was positive and so the project was expanded to include a microcontroller, and thus programming practice, into the activity. In spite of issues with reliability of the fuel cell cars, the students were very positive about the changes introduced to the course. First year mechatronics students are indicating a more positive attitude towards ChE 102 in comparison to their mechanical engineering counterparts that do not complete the fuel cell car activity. The teaching team is optimistic that further improvements to the fuel cell car will increase the utility of the activity, and they are also exploring whether the activity can be expanded to include other disciplines within engineering.

2. INITIAL FUEL CELL CAR ACTIVITY

The fuel cell car activity was introduced in the fall 2011 term, and was repeated in fall 2012. A small “intelligent” fuel cell car available online was selected as the base platform [6] (Fig. 1). The car has gas storage cylinders, the fuel cell, a motor with limited gearing, and a small amount of electronics mounted on a plastic base. Students use electrolysis to generate hydrogen and oxygen from water, and then use the gases to power the motor and electronics. When connected, the car moves forward until it encounters an obstacle. When stuck on an obstacle, the electronics detect the increase in current from the stalled motor, and then briefly reverse direction of the motor. As the motor unit is able to swivel, the net effect is that the car turns.

Fig. 1. Original Fuel Cell Car used in 2011/12 [6]

During the term, the students were able to explore the operation of a mini-fuel cell, and practice their communication skills by writing reports on it. At end of term, a fun competition was introduced whereby students competed to see how long they could get the fuel cells to run, and how well the cars could navigate a set of mazes.

The fuel cell project involved making connections between the concepts covered in the ChE 102 chemistry course with environmental implications of new technologies, practicing engineering communication skills in an applied setting (not just random busy work - [7]), and engineering design. Students were randomly assigned into groups of 4, with the leadership rotating weekly, and completed 4 mini-reports and a fuel cell car redesign with this group. While the ChE 102 instructor led the fuel cell car project, the student contact time exists in the MTE 100 (the concepts course) lecture time and the marks for the fuel cell project were part of MTE 100, with a small exception of 5% going into ChE 102 for the chemistry content (starting in 2012). This division of marks is due to constraints with the team taught ChE 102 and inflexibility of the course content and schedule. No new ChE 102 material was introduced during these lectures but the students were introduced to the connections between their chemistry course and mechatronics engineering. During the first week of term, students are introduced to the services available at the library. For many students these are abstract concepts, and it is hoped that early exposure will promote their use.

Fig. 2. Examples of student fuel cell car projects

Each mini-report was included in the next report that was submitted. This use of “telescoping reports” was introduced as part of the project aim to address the engineering communication portion of the MTE 100 goals. The reports were due approximately one week after the in-class portion and feedback was provided to the groups approximately one week later, to allow the students time to learn from their mistakes and make adjustments before the next deliverable is due. This feedback loop is key [8].

The first two-page report asked the students to study the fuel cell car based on the instruction manual and their experiences in class, determine the top 3 safety, health, and environmental risks they identify with the car and suggest ways to mitigate these risks. One page of the report was a mini-research project where the students must find at least 3 references, 2 of which cannot be websites, describing an alternate way of producing hydrogen gas that could have been used to generate H_2 at the site of the Vancouver 2010 Olympics.

If the students in a group have completed their WHMIS training and have passed report 1 (identified and mitigated key risks, such as safely working with the H_2 and O_2 gases generated by the fuel cell car), each group then received their own car. The focus of the second report was on stoichiometry and estimating the mols of gas generated by the fuel cell and assumptions in the ideal gas law. These are concepts taught in ChE 102 but students struggle about the assumptions needed to apply them to the “real world” application in the fuel cell. Students learned how to perform calculations and explain their work in an

engineering report, instead of just copying an Excel printout into the appendix, for example.

Report 3 was due after midterms, once students have been working with the fuel cell car and were starting to propose design modifications so that the car can perform better in the maze on the last day. Design modifications are proposed, based on a design process and analysis taught in the MTE 100 course. The second part of the report focused on gas solubility, a tricky concept in ChE 102. Students must gather data from suitable sources to perform the calculations and estimate the percent loss of their valuable H_2 fuel as a result of the storage method used on the cars.

The fourth report got the students in an electronics lab with their fuel cells, where they used a multimeter to measure the voltage and current produced by their fuel cell and observed how both change over time. This is an important learning opportunity as many have been experiencing the limits of the fuel cell as they've tried to optimize their car design. Also, it is their first introduction to using industrial-quality electrical measuring equipment, which could prove to be a valuable asset in their first work-term in the subsequent semester. The first part of this final report asked for the final design of the fuel cell car, which will be used the week following in a maze-navigating time trial. The second part of the two-page report asked the students to apply ChE 102 concepts to predict how temperature changes might affect the voltage of the fuel cell.

With the submission of each of the fuel cell reports and following the maze trial, each group member submitted a short (100 word) personal reflection. The subject matter was loosely based on how the group work is going, what it is like to be leader or not be leader (since it changes every week), and any surprising lessons learned from that week's assignments. Some students gave short "everything's going great" type answers, which prompted further feedback from the TAs reviewing the input. Any problem areas such as group friction were addressed at that time. This feedback also serves to adjust final marks if one group member is consistently not contributing.

3. IMPACT ON STUDENT LEARNING

At the end of each term, the mechatronics engineering students are surveyed about their experiences with the course integration, and other aspects of their 1A term. In fall 2011, there was a 0.5 mark bonus for completing the survey, which resulted in responses from 125 of the 137 students. When the survey was repeated in fall 2012, it was entirely voluntary with no incentive, we received 53 responses out of 145. The results for the two fuel cell-related questions are shown in Table 2 (the percentages may not add to 100% due to rounding). Of the students

enrolled in chemistry and the concepts course, in fall 2011, over 67% were positive about the fuel cell project, while in fall 2012, nearly 60% were positive. Over half of the students surveyed felt that the exercise of writing the reports had improved their skills in this area.

In fall 2011, practicing technical writing was a clearly defined objective of the fuel cell car project. In fall 2012, this objective was emphasized less with the students, which could explain the increase in students disagreeing that the fuel cell reports helped improve their technical writing.

In addition, when given open-ended questions with regards to the courses, students did not highlight the relevance of chemistry and communication skills as a problem area. In past terms, typical feedback received by the chemistry instructor was, "I believe this course is so distant from the other courses." After the introduction of the fuel cell project, students had a greater understanding of the role of chemistry in the overall curriculum. One student commented on the survey, "Connecting CHEM 102 to the other courses was helpful, since it seems to be an odd course for tron. Seeing the connections to other parts of engineering helped me realize that it is a good course to have."

Table 2 : Student Responses to the Fuel Cell Project

Term	1	2	3	4	5	N/A
Do you agree that the fuel cell project is a good way to bring chemistry and mechatronics together (Where 1 is definitely no, and 5 is definitely yes)?						
2011	6%	13%	12%	38%	25%	6%
2012	10%	17%	13%	51%	6%	4%
Did the MTE-ChE 102 fuel cell project reports help improve your technical writing skills?						
2011	4%	13%	16%	42%	18%	6%
2012	17%	17%	11%	34%	17%	4%

Student performance in chemistry, and overall performance in terms of term averages and failure rates was analyzed, comparing performance before (prior to 2010) and after the initiative was launched. The results do not show any clear trends. Some factors, such as who taught the course and the admission averages for students were determined to be the same for both groups of students.

Other confounding factors such as changes in the style of exam questions and changes in the term promotion rules, combined with the fact that mechatronics students are a

resilient group who already had a low failure rate, may be obscuring any improvement in course grades.

4. PROGRAMMABLE FUEL CELL CAR ACTIVITY

While the fuel cell car activity was well-received in 2011 and 2012, students were frustrated by the limits of the original car. When they ran the car through the maze, the result depended to a small degree on initial placement of the car, and to a large extent on luck. Also, the topics taught in the programming course were still not integrated into the project in any meaningful way. To address these issues an improved version of the fuel cell car was developed.

The initial focus of the design was to replicate the existing car, but with a microcontroller for intelligence, an additional motor to enable steering of the car, and sensors to provide feedback about the environment. However, the design was limited because of the low voltage that is produced by the fuel cells. An increase in voltage could have been achieved with an increase in the size of fuel cell, but the difficulties involved in working with greater amounts of flammable gas combined with the added expense meant that this idea was not feasible. Instead, the voltage was increased by connecting two fuel cells in series.

The microcontroller chosen was a low power (and inexpensive) Texas Instruments MSP430 [9]. This microcontroller allowed the students to practice their C++ (the language used in GenE 121) while working on the fuel cell project as well as giving them exposure to a commercial Integrated Development Environment (IDE). This project was the first chance for many of the mechatronics students to see a microcontroller, and was intentionally left visible in the design of the car. The microcontroller was coupled with a motor controller driver board that was capable of handling very low power motors (similar to those in a typical child's toy). This board proved to be very sensitive to noise and power levels for the electronics, and so the electronics are powered by a separate battery pack.

The car was designed to be as robust as possible, utilizing aluminum for the chassis as the car is quite heavy when loaded down with the electronics and the fuel cells (with the tanks necessary for storing the hydrogen and oxygen). To give the students more flexibility with the maze competition, the car is capable of being run in several different "power configurations" including running with 2 fuel cells in series, 2 fuel cells and a AAA battery in series, 1 fuel cell and a AAA battery in series, etc. with a "multiplier" assigned to each power arrangement based on the perceived difficulty at powering the car with each arrangement. The preliminary design,

given to the students in fall 2013 can be seen below in Fig. 3.

Fig. 3. Programmable Fuel Cell Car - Fall 2013

To give the students the ability to "sense" where they are in the maze, two reflectance sensors were mounted under the front of the chassis which can provide information on the relative darkness or brightness of the ground under the car. This necessitated the addition of some high contrast lines on the maze courses that are used for the competition. The car also has a switch mounted on the front of the car to provide feedback when it bumps into something. As the MSP430 has little in the way of feedback to the programmer (to aid in debugging program issues), an LED light bar was added to the car as an indicator.

As the complexity of the electronics on the car grew, there was concern about having the students make these electrical connections (and possibly damaging some of the electronics in the process), so a "daughter board" was designed and manufactured. This "daughter board" mounts directly on top of the MSP430 board, while still providing access to the two LEDs and two switches which are included on the original board. This board makes all of the connections to the microcontroller and provides a ribbon cable with color coded connectors which the students need to connect to sensors and other electronics on the rest of the car.

Unfortunately as development of this new programmable car was done on a condensed timetable, thorough testing was not able to be performed before the cars were given to the students in the fall 2013 term. This resulted in a large number of reliability issues relating to nearly every aspect of the car, forcing the students and teaching team to devote a large number of hours debugging hardware issues, which should be minimized as much as possible, so attention is spent on the teaching aspects of the project (mainly the chemistry).

5. CHALLENGES AND RESOURCES

The teaching team faced, and continues to face, several challenges in relation to this project. These include reliability/robustness issues with the cars, keeping the emphasis on chemistry, teaching too many topics to the students in a single semester, the reliance on support from the instructor of the chemistry course, and controlling use of resources (money and personnel). Some of these issues are being addressed already, others will need to be addressed as the project moves forward.

5.1 Challenges Faced

In MTE 100, one of the submissions that students must complete is a professional memo. As a topic for this memo, we had the students comment on the fuel cell car project, and list any issues they experienced throughout the project. The issues they experienced are summarized in Fig. 4.

Fig. 4. Technical Issues Reported by Students

From these responses, many students experienced mechanical and electrical connectivity issues which are unrelated to the teaching goals of the project. This steered their attention away from the topics of chemistry and programming, and while it taught them extremely valuable real-world debugging skills, as well as the troubles of developing a new platform, their attention needs to be steered back to the desired topics. Unfortunately, due to time constraints, the students ended up performing much of the quality control checking for the new cars, with the motors and gearbox (and the attached motor controller) being the largest source of these issues. A large percentage of these problems were due to assembly of the components, so as they were discovered, they were either corrected, or working units were swapped with the student's. As the teaching team continues to improve the execution of the fuel cell car, the number of issues relating to the motors/gearbox, motor controller and wiring should be reduced, and therefore, the student's attention can re-focus on the chemistry and programming practice of the project.

To address concerns about student work-load and whether they are learning too many different platforms, some changes are being discussed for how the project is delivered to students in the fall 2014 semester. One of the successes of this project is in identifying overlapping topics in student deliverables. Moving forward with this course integration, the teaching team needs to continue to identify areas where there is overlap in topics, and therefore reduce the number of deliverables that students are submitting and/or reduce the number of topics they are learning. One solution would be to go back to the original fuel cell car project, which required much less time on the part of the students. However, in the memo that the fall 2013 students submitted, they were asked whether they thought the fuel cell car project should remain, and their response was overwhelmingly positive about the project (their responses are summarized below in Fig. 5).

Fig. 5. Student Opinion on Fuel Cell Car Project

Rearranging time of deliverables to better match student schedules is another strategy that will be implemented in the fall 2014 semester. Currently in GenE 121/MTE 100, the students are asked to design, build and finally, write a report on a project of their choosing, implemented out of Lego (using the Lego Mindstorm platform to control the project). Moving the fuel cell competition earlier in the term, to create more distance between these two large projects should free the students from the need to multi-task on both simultaneously.

Finally, the teaching team needs to review which topics are key to student learning, and which activities are important to student success in these three courses and possibly remove topics/activities that no longer fit with the integrated set of courses.

5.2 Project Resources

The resources used in the execution of this project are summarized in Table 3.

For this project, the one-time costs, both financial and personnel-related, vastly outweigh the ongoing costs. The fuel cells, specifically, make up approximately 50% of the total cost of all components needed for the car. Also, the

time required in the initial design, construction and assembly was quite high for all parties involved. Keeping these costs under control moving forward is of paramount concern, and now that the project has been successfully executed once, keeping the ongoing costs down should be relatively easy.

Table 3: Resources Used for Fuel Cell Car Project

Financial		Personnel	
One-Time	Ongoing	One-Time	Ongoing
Material costs, machining time for chassis	Repair, Replace broken parts	Co-op student time used in designing chassis, "daughter board" (1 student for chassis, 1 student for "daughter board")	Software upgrades (staff/faculty)
Cost of Electronics	Storage of project materials	Co-op student time used in assembling cars (2 students)	Repairs, upgrades (co-op student and faculty/staff)
Cost of Additional Fuel Cells (some parts of original cars were used)		Staff/faculty time used in selecting components, designing project, writing software library	Additional time in MTE100 labs (staff/faculty)
Printed Circuit Board manufacture		Staff/faculty time to generate support documents for students	

6. IMPACT ON STUDENT LEARNING

6.1 Fuel Cell Car

Students enrolled in the three courses, chemistry, mechatronics engineering concepts, and programming were surveyed at the start and end of the Fall 2013 term. The survey was voluntary, although students were offered a 1% bonus on their concepts course grade for "submitting" the survey, and 62 of 145 completed the

survey. As a control group, one cohort of first year mechanical engineering (ME) students was also surveyed during the Winter 2014 term. Responses were voluntary and 36 of 115 students completed the survey. Table 4 shows the results for the question, "Why do you think a course in chemistry is included as part of the mechatronics / mechanical engineering curriculum?"

Table 4: Student Opinion on Chemistry as a Part of Their Curriculum

Chemistry	Start of First Term MTE	End of First Term MTE	End of Second Term ME
Don't include	2 (2.7%)	2 (3%)	8 (22%)
Don't know why taking this	6 (8%)	3 (4.8%)	7 (19%)
Important because we are asking this	3 (4%)	3 (4.8%)	1 (3%)
Can see relevance	53 (71%)	37 (60%)	19 (53%)
Surprised only one course	11 (14.7%)	17 (27%)	1 (3%)

There is a clear division between the two groups on their opinion of chemistry at end of term, as 87% of mechatronics students can see the relevance of the course compared to only 56% of the mechanical students (even after they have nearly completed a course in materials). However, the results are higher than expected, given that informal feedback from the students indicates that the mechatronics engineering students are no longer asking why they are taking the course, while mechanical engineering students clearly dislike ChE 102.

In further discussions with students, this appears to be an issue with the wording of the question. Students feel that chemistry itself is a useful and relevant area of study, while they dislike what is delivered in the chemistry course that they receive (ChE 102 itself). The fairly stable numbers between beginning and end of term for the mechatronics students could also be a result of the expectations that are set by the upper year students about the course and project. During orientation week and the first few weeks of semester, there is a lot of communication about course expectations between the upper year students and the incoming class. Another question on the end of term MTE survey asked students their opinion on the joint engineering clinic activities between the three courses. The responses are shown in Table 5.

They were also asked whether the fuel cell car activity met their learning style. A significant number of students agreed that it did. This data is summarized in Table 6 below.

Table 5: Student Opinion on Fuel Cell Car Activity

The fuel cell car project and the mechatronics course project were activities that are joint between two courses. How do you feel about this?	
It was a terrible idea.	2
There were problems and it didn't really work.	5
I am indifferent.	0
It was okay and helped me learn about mechatronics.	15
I think it was a great idea.	40

Table 6: Student Opinion on Fuel Cell Car Meeting Their Learning Style

Did the Fuel Cell Car activity meet your learning style?	
Agreed	47
Disagreed	4
Did not know	11

From the responses, the fuel cell car activity is increasing the relevance of the chemistry course to the first year MTE students.

6.2 Telescoping Reports

One of the challenges first year students face when given tasks such as “write a professional memo” is to come up with a topic to write on. With the addition of the fuel cell car project, and the integration happening between the three courses, we are able to draw on student experiences in ChE 102 for a report submitted in MTE 100. This has had the effect of reducing the workload on the students as the topic is one that is known to them, and they have formed strong opinions on the topic. The other major issue we face with first year students is getting them to read, and respond to, the feedback they are given on marked submissions. The telescoping reports require the students to re-submit old (and improved) reports with the new submission and therefore, the person evaluating the student's work is aware of the previous weaknesses.

6.3 Programming

Time in a programming course is spent in two broad areas. The first is on the programming “facts”, for example how a loop operates and on programming syntax. The second area is that students need sufficient time

practicing their programming skills to achieve a working ability with programming. It was this second area that was addressed with the fuel cell car project. As part of the project, the students gained exposure to a microcontroller (and its programming environment) that is used in the real-world. Their real-time programming skills, introduced as part of GenE 121 were exercised further as the students needed to program the car through the maze. In addition, they were presented with design decisions such as whether to program the motors to move at high speed, or whether to move slower and conserve the finite amount of gas available for the fuel cell. The students were able to transfer this additional practice for less than ideal conditions into a stronger set of end of term mechatronics programming projects.

7. CONCLUSIONS AND RECOMMENDATIONS

The outcome of the course integration activities, the fuel cell car project, and its telescoping reports, is best summarized by the stark difference in student opinion between the mechatronics engineering students and their counterparts in mechanical engineering. The mechatronics students saw enough value in their chemistry course to recommend a second course in chemistry, whereas their counterparts are still questioning the relevance of chemistry to engineering.

From the student perspective, for integration activities to succeed, overlap between course topics and activities needs to be recognized, and work load must not increase. Additionally, faculty members need to see value in the activities, as these activities can require a great deal of effort and time, especially in the first offering.

This project will continue to be used to integrate programming, chemistry and mechatronics concepts for first term mechatronics students. Data will continue to be collected in subsequent offerings to allow long term comparisons.

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