A Pilot Study of Project-Based Learning in General Chemistry for Engineers

Dr. Kent J. Crippen, University of Florida

Kent Crippen is an Associate Professor of STEM education in the School of Teaching and Learning at the University of Florida and a Fellow of the American Association for the Advancement of Science. His research involves the design, development, and evaluation of STEM cyberlearning environments as well as K-12 teacher professional development. In addition to NSF and NIH-funded research involving the translation of science into materials for K12 schools, Crippen has served as PI on multiple state-funded PD projects for STEM teachers.

Dr. Chang-Yu Wu, University of Florida

Dr. Chang-Yu Wu is Professor and Head of the Department of Environmental Engineering Sciences at the University of Florida. His teaching and research interests are in air pollution control, aerosol, incineration and engineering education. He has published more than 130 refereed journal articles, given more than 260 conference presentations and delivered 70+ invited speeches. He has received numerous recognizing his achievements in research and education, including the Lyman A. Ripperton Environmental Educator Award from Air & Waste Management Association in 2015 and the New Teacher Award from SE Section of American Society for Engineering Education in 2001.

Prof. Treavor Boyer, University of Florida
Trisha de Torres
Dr. Maria Korolev, University of Florida
Dr. Philip J. Brucat, Department of Chemistry / University of Florida

A Pilot Study of Project-Based Learning in General Chemistry for Engineers

Abstract

Engineering education cannot expect to meet the demands of a global, diverse, and knowledge-based society without addressing the well-established issue of student retention. Change Chem is a curriculum reform model created to address this issue for freshman, in particular, traditionally underrepresented student groups. This paper reports on a pilot study of Change Chem, which uses collaborative problem-based learning with model-eliciting activities to transform the discussion section of general chemistry so as to better retain freshman who are engineering majors. The study involved a quasi-experimental design with a treatment (i.e. reformed curriculum) and comparison condition (i.e. business as usual) that was completed over a two-semester sequence. Across the two courses, 530 students consented to participation. Participant outcomes were compared at the course level (treatment group vs. comparison group). In addition, female students and students who were classified as underrepresented ethnic minorities were identified as a single group (i.e. target group) so that their outcomes could be compared across the courses (treatment vs. comparison). After the first course, all groups gained in their perception of learning, but students in the comparison condition had higher grades. Self-efficacy and professional persistence decreased for students using Change Chem. After the second course, Change Chem performed equal to or better than the comparison on all variables. In fact, the Change Chem group increased in three key variables: perception of learning, confidence in their math and science abilities and exposure to project-based learning. This may suggest a treatment effect that requires a longer duration. These results indicate that Change Chem supports learning and motivation for all students, important elements for long-term retention. Plans for additional re-design of the model and further study are discussed.

Introduction

The current number of engineering students is not adequate for meeting the needs of the projected workforce and research suggests that the profession is not attracting a diverse student population[1]. In the U.S., the dropout rate has been reported to be in the range of 40%[2]. Two attributes characterize engineering majors: (1) they are disproportionately male, and (2) those that graduate are more than likely to have declared engineering as their major when they matriculated to college (i.e. students are not likely to change their majors to engineering).

Undergraduate engineering in the U.S. is in need of reform that addresses the retention of a diverse population of students. Indicators suggest that lower-level engineering curriculum is overly prescriptive and not based upon the authentic practice of engineers[2]. During pre-engineering courses, students report prescriptive forms of inquiry and algorithmic methods of problem solving[3]. The authentic experiences of teamwork, open-ended problem solving and collecting original data only occur toward the end of their programs. For certain student populations, the experience has been characterized as *chilly*, suggesting a cold and harsh setting that requires protection for survival[4]. Thus, reform needs to equally attend to the makeup of the student body as well as the quality of their experience.

Change Chem is a curriculum model that is designed to address the issue of retention, in particular, the retention of underrepresented student groups. Change Chem emanates from a situated perspective on learning and involves the application of cognitive apprenticeship as the theoretical framework. It uses collaborative problem-based learning with model-eliciting activities to transform the discussion section of general chemistry to better retain students who are engineering majors. It is theorized that the rich context of everyday engineering will help students to see themselves, their interests and those of others in their learning activities. By better identifying with the practice of an engineer, persistence with difficult coursework is more likely and intentional. Building on a successful field trial[5], this paper describes the results of an initial pilot study that evaluated the design of Change Chem against a comparison condition (i.e. business as usual).

Theoretical Framework

Situated learning is based upon the premise that knowledge cannot be separated from the context of its origin[6]. Thus learning is a process of apprenticeship, whereby social interaction supports problem solving, imitation and engagement in authentic activity[7]. Herein, learning opportunities are dependent upon context, use of available resources and emphasize social processes and participation over transmission and receipt of knowledge. For Change Chem, the work activities of a real-world engineer represent the sociocultural context and authenticity is defined by the degree to which activities represent this tradition. Learning is viewed as a transformation along a continuum from student to full professional member in the community of practicing engineers.

Change Chem targets the retention of students by focusing their work on authentic collaboration and learning in context, which is theorized to leverage interest in order to build personal identity with being an engineer[8] as well as the necessary efficacy for persisting with challenging coursework[9]. The use of collaboration, in lieu of competition or individualized learning is a documented strategy for supporting social interdependence and achievement[10] and has proven effective for supporting women in engineering[11]. Team-based collaborative learning has also been shown to support the retention of women in chemistry[12].

A model-eliciting activity (MEA) is a proven form of learning task that involves collaborative, model-based learning in authentic STEM contexts[13]. MEAs are "open-ended, realistic, client-driven problems that require the creation or adaptation of a mathematical model for a given situation"(p. 17). Created by applying six design principles, an MEA requires students to create, test and refine a model for a realistic situation, then present their findings as a deliverable to a potential client. For Change Chem, these models take the form of flow diagrams that describe a process or system. Zawojewski and colleagues[14] have developed a rich history and research program of using MEA's in undergraduate engineering courses as a means for supporting diverse students. Change Chem builds on this work by expanding the scope to include general chemistry courses, those that are prerequisite for an engineering major. In doing so, the content focus is maintained while refining the curriculum so as to better retain all students who are pursuing an engineering major.

The Design of Change Chem

Change Chem involves re-envisioning the discussion (i.e. recitation) component of the sequence of *General Chemistry for Engineers* to focus on three design projects per course (Table 1). These 3-credit hour courses are offered as special sections for engineering majors that are taught in an engineering case-study context.

Table 1. Overview of all six mini-projects across the two-course sequence.

	First Semester Course			**Second Semester Course**		
Project	*1*	*2*	*3*	*4*	*5*	*6*
Topic	Stoichiometry	Enthalpy Calorimetry	Gases	Acids & Bases	Thermo-dynamics	Electro-chemistry
Activity	Assessment of fuel storage and transport options for electricity generation.	Fuel combustion and energy generation	Assess options for Power Plant: a) oxy-combustion, and b) alt fuels.	Environmental Impacts of Energy Generation	Assess an upgrade of air pollution control devices for power plant.	Innovations in Energy Generation and Use

Change Chem is restricted to the discussion component of the course with the lecture serving as a complement. A team of graduate teaching assistants (TAs) from engineering and chemistry teach the discussion sections. The emphasis on the discussion is based upon the results of previous work demonstrating that the discussion and laboratory components of courses tend to be overly competitive and not collaborative[14].

The projects involve collaborative, team-based problem solving with socially relevant problems, which require multiple perspectives and values the forms of practical knowledge that students can bring to a team[15]. The projects are constructed to be MEAs and sequenced to emphasize the context in which an engineer understands chemistry, to require the use of collaboration and to scaffold the process of design[16].

The projects are conveyed in a three-phase format: Inquiry, Problem Solving and a Deliverable. During Inquiry, students are presented with the task as a memo from the hypothetical company CEO requiring them to produce a deliverable for a local client. Using this memo, the TAs guide students to: (1) construct lists of things they know and don't know, (2) brainstorm sources for information, (3) define parameters, (4) construct a flow diagram for the process, and (5) connect their approach to the ideas presented in the lecture. In the MEA format, the flow diagram is the model. During Problem Solving, a follow-up memo includes a more defined form of the task, including parameters and chemical equations. This focuses students on applying their flow diagram to a more structured form of chemistry problem solving. For the Deliverable, students construct an executive summary, a mainstay of engineering practice.

Study Design

A quasi-experimental, initial pilot study of Change Chem, involving a treatment (i.e. reformed curriculum) and comparison condition (i.e. business as usual) was completed over a two-semester sequence with the outcomes assessed across each course. Change Chem was assessed in relation to its design goal of supporting student learning, with a special emphasis on females and students from traditionally underrepresented ethnic minorities. As an evaluation of the second phase of design and development, the following research questions were addressed: What influence does Change Chem have on: 1) performance and perceptions of learning chemistry?, 2) self-efficacy and motivation for learning engineering?, and 3) use of metacognition during problem solving?

The analysis of data involved a quasi-experimental nonequivalent groups design. Students in *General Chemistry for Engineers I & II* were exposed to the new curriculum and are identified as the treatment group, while students in *General Chemistry* (offered for all other majors) served as the comparison group. The same instructor, a member of our design team, taught the lecture sections for both courses. In addition, female students and students who were classified as underrepresented ethnic minorities were classified *a posteriori* as the target group, a subgrouping of the whole. This method afforded an assessment of the performance of all students in the treatment group against a comparison group and secondarily, an assessment of students in the target population against similar students in the comparison group. Following a description of the research instruments, the results are presented accordingly, semester by semester, first comparing all students, and then comparing students in the target group across conditions.

Instrumentation

Student performance was assessed at posttest using the final course grade, which was a compilation of all the course requirements. Perception of learning was assessed pre/post with two different forms of a researcher-constructed version of the Student Assessment of Learning Gains (SALG)[17]. The two forms of this instrument were necessitated by the different content foci of each course. Students rated their understanding of chemistry content on a Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). Example items included: 1) How to apply the principles of stoichiometry (first semester) and 2) How to determine the equilibrium constant for a given chemical reaction (second semester).

Self-efficacy[18], defined as "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (p. 3), was assessed pre/post with the 8-item self-efficacy subscale from the Motivated Strategies for Learning Questionnaire (MSLQ)[19]. Students rated the degree to which each item were true for them on a scale from 1 (not at all true of me) to 7 (very true of me). Example items included: 1) I can master the skills being taught in this class and 2) I'm certain I can understand the most difficult material presented in the readings for this course.

Motivation for learning engineering was assessed using 11 of the 16 scales related to motivation, skills, and perceptions of the learning environment from the Academic Pathways for People Learning Engineering Survey (APPLES). APPLES is a research tool used by the Academic Pathways Study, a study of national scope that was designed to better understand the undergraduate engineering experience and the transition from school to work[20].

Metacognition[21]—"the skills that enable learners to understand and monitor their cognitive processes" (p. 112) was assessed pre/post with the knowledge of cognition (11-items) and regulation of cognition (9-items) scales developed by Faber et al[22] that are specific to engineering problem solving. Students used the same 5-pt. Likert-type scale to rate their agreement with items such as: 1) I consider several ways to solve the problem before I answer and 2) I know how well I did after solving the problem.

Results

Across the two courses, 530 students consented to participation and served as our research sample. In addressing the research questions, comparisons of changes within-subjects from pre to posttest were assessed via paired t-test. Between groups comparisons involved an analysis of covariance (ANCOVA) with the pretest values for each measure as the covariate.

For the first semester course, the treatment group had initially higher levels of self-efficacy, confidence in their math and science abilities, prior exposure to project-based learning and metacognition—knowledge of cognition. This suggests some unique characteristics for this group of freshman engineering students. For the target group, this difference was only found for their confidence in their math and science abilities and metacognition—knowledge of cognition. Indicating that the group characteristics were not entirely homogeneous across the group.

Table 2: Comparison of results for Final Course Grades.

Condition	N	M	SD
Comparison I	74	84.8^{*}	11.6
Intervention I	159	81.0	11.2
Comparison I Target	53	82.9	12.0
Intervention I Target	93	79.1	11.1
Comparison II	217	85.2	10.3
Intervention II	80	84.6	10.0
Comparison II Target	159	85.3	10.8
Intervention II Target	59	82.9	9.9

Note: $^{*}p<0.05$

Table 3: Comparison of results for Perceptions of Learning.

	Pretest			Posttest		
Condition	**N**	**M**	**SD**	**N**	**M**	**SD**
Comparison I	74	81.4	17.0	74	95.1	19.4
Intervention I	161	81.5	17.5	161	95.7	18.2
Comparison I Target	53	81.6	18.4	53	91.9	21.2
Intervention I Target	94	80.3	17.4	94	96.1	18.0
Comparison II	219	48.0	9.9	217	59.6	11.5
Intervention II	79	47.7	12.4	80	63.6*	10.3
Comparison II Target	160	48.1	9.7	159	59.0	12.3
Intervention II Target	59	47.5	13.2	59	63.6*	7.2

Note: $^{*}p<0.05$

At the end of the course, the comparison group had statistically higher grades (84.8% vs. 81.0%), but this was not the case for the target group who performed equally as well as their peers (Table 2). All groups reported significant gains in their perception of learning (Table 3). However, self-efficacy for the treatment and target groups decreased ($F(2,148) = 11.018$, $p = .001$, partial $\eta^2 = .071$; $F(2,106) = 11.771$, $p = .048$, partial $\eta^2 = .037$) (Table 4) and this pattern was the same for the variable of Professional Persistence—their intent to practice engineering for at least three years after graduation ($F(2,60) = 6.548$, $p = .013$, partial $\eta^2 = .103$; $F(2,34) = 6.046$, $p = .02$, partial $\eta^2 = .163$)(Table 5).

Table 4: Comparison of results for Self-Efficacy.

	Pretest			Posttest		
Condition	**N**	**M**	**SD**	**N**	**M**	**SD**
Comparison I	74	42.9	9.7	74	41.8*	10.5
Intervention I	161	46.5	7.3	161	39.8	11.3
Comparison I Target	53	41.0	10.2	53	39.4*	10.9
Intervention I Target	94	45.8	8.1	94	37.5	11.9
Comparison II	219	43.5	8.1	217	43.4	9.8
Intervention II	79	45.9	8.0	80	46.7	8.8
Comparison II Target	160	43.1	8.4	159	43.1	10.4
Intervention II Target	59	44.6	8.2	59	45.7	8.7

Note: $^{*}p<0.05$

Table 6: Comparison of results for Professional Persistence.

	Pretest			Posttest		
Condition	**N**	**M**	**SD**	**N**	**M**	**SD**
Comparison I	33	20.5	3.5	29	21.0*	2.7
Intervention I	160	21.6	2.4	160	20.6	2.9
Comparison I Target	22	20.8	3.6	17	22.1*	2.6
Intervention I Target	94	21.6	2.3	93	20.5	2.8
Comparison II	56	18.9	2.9	37	19.6	3.8
Intervention II	78	21.2	2.1	79	21.1	2.7
Comparison II Target	35	19.3	3.2	24	19.7	4.5
Intervention II Target	58	21.1	2.0	59	21.2	2.9

Note: $^{*}p<0.05$

For the second semester course, the treatment group had initially higher levels of self-efficacy, intrinsic motivation, confidence in their math and science abilities, professional persistence, metacognition—knowledge of cognition and metacognition—regulation of cognition. For the target group, this difference was only found for their confidence in their math and science abilities, intrinsic motivation and professional persistence. Due to the greater than 50% carry over of students, this may be due to a carry over effect from the first semester course.

Table 7: Comparison of results for Intrinsic Motivation.

	Pretest			Posttest		
Condition	**N**	**M**	**SD**	**N**	**M**	**SD**
Comparison I	32	10.2	2.3	29	10.4	2.4
Intervention I	158	10.4	1.8	159	10.4	1.7
Comparison I Target	21	9.9	2.6	17	10.7	2.3
Intervention I Target	93	10.5	1.8	92	10.4	1.8
Comparison II	56	8.8	2.5	37	9.5	2.3
Intervention II	78	10.6	1.9	80	10.5	2.1
Comparison II Target	35	8.7	2.6	24	9.7	2.4
Intervention II Target	58	10.6	1.8	59	10.5	2.0

Note: $^{*}p<0.05$

Table 7: Comparison of results for Confidence in Mathematics and Science Ability.

	Pretest			Posttest		
Condition	**N**	**M**	**SD**	**N**	**M**	**SD**
Comparison I	74	11.1	2.4	74	11.4	2.5
Intervention I	158	11.9	2.0	158	12.0	2.0
Comparison I Target	53	10.9	2.4	53	11.0	2.5
Intervention I Target	92	11.6	1.9	92	11.6	2.0
Comparison II	215	11.4	2.0	213	11.4	1.8
Intervention II	78	12.3	1.7	79	12.5	1.8
Comparison II Target	157	11.3	2.0	155	11.4	1.8
Intervention II Target	58	11.9	1.7	59	12.3*	1.8

Note: *p<0.05

Table 8: Comparison of results for Metacognition—Knowledge of Cognition.

	Pretest			Posttest		
Condition	**N**	**M**	**SD**	**N**	**M**	**SD**
Comparison I	74	41.9	6.1	74	41.5	5.9
Intervention I	160	43.3	5.8	161	43.0	5.6
Comparison I Target	53	41.4	6.3	53	41.2	6.2
Intervention I Target	94	43.4	5.1	94	43.1	5.0
Comparison II	219	39.9	6.6	217	41.0	6.8
Intervention II	79	41.9	7.3	80	43.3	7.3
Comparison II Target	160	40.0	6.7	159	41.1	6.7
Intervention II Target	59	41.2	7.4	59	42.7	6.3

Note: *p<0.05

There were no differences in final course grade for any of the groups, they all performed equally well. All groups reported significant gains in their perception of learning. Unlike the first semester course, there were no decreases in any of the variables for any of the groups. In fact, quite the opposite, the variables either remained unchanged or increased (Tables 6-11). When controlling for pretest differences, the treatment group demonstrated significant increases in their perceptions of learning ($F(2,158) = 3.971$, $p = .048$, partial $\eta^2 = .025$), confidence in open-ended problem solving ($F(2,66) = 4.022$, $p = .049$, partial $\eta^2 = .06$) and exposure to project-based learning ($F(2,155) = 6.724$, $p = .01$, partial $\eta^2 = .042$). Notably, the comparison condition did not outperform the treatment group on any variable at posttest. For the target group, they demonstrated a greater perception of learning ($F(2,118) = 6.043$, $p = .015$, partial $\eta^2 = .05$), confidence in their math and science abilities ($F(2,117) = 3.936$, $p = .05$, partial $\eta^2 = .033$) and exposure to project-based learning ($F(2,117) = 23.585$, $p = .000$, partial $\eta^2 = .171$). All of these variables can be associated with the designed intent of the reformed curriculum and we view this positive change as encouraging.

Table 9: Comparison of results for Metacognition—Regulation of Cognition.

	Pretest			Posttest		
Condition	N	M	SD	N	M	SD
Comparison I	74	36.0	4.8	74	35.3	4.8
Intervention I	160	36.1	4.7	161	36.1	4.9
Comparison I Target	53	35.6	5.0	53	35.3	5.0
Intervention I Target	94	35.8	4.6	94	36.0	4.7
Comparison II	219	34.2	5.2	217	35.1	5.2
Intervention II	79	36.1	5.8	80	36.7	6.2
Comparison II Target	160	34.1	5.3	159	35.2	5.2
Intervention II Target	59	35.7	6.2	59	36.1	5.4

Note: $^{*}p<0.05$

Table 10: Comparison of results for Confidence in Open-Ended Problem Solving.

	Pretest			Posttest		
Condition	N	M	SD	N	M	SD
Comparison I	33	10.5	2.0	29	10.8	1.7
Intervention I	160	10.5	1.5	160	10.8	1.6
Comparison I Target	22	10.7	1.6	17	11.2	1.7
Intervention I Target	94	10.5	1.5	93	10.7	1.7
Comparison II	56	10.6	1.4	37	10.6	1.4
Intervention II	79	10.7	1.6	78	11.0^{*}	1.3
Comparison II Target	35	10.6	1.6	24	10.5	1.4
Intervention II Target	59	10.5	1.6	59	10.9	1.3

Note: $^{*}p<0.05$

Table 11: Comparison of results for Exposure to Project-based Learning.

	Pretest			Posttest		
Condition	N	M	SD	N	M	SD
Comparison I	73	5.9	2.6	74	6.0	2.5
Intervention I	156	7.0	2.0	160	7.1	1.8
Comparison I Target	52	6.0	2.6	53	5.9	2.6
Intervention I Target	93	6.8	1.9	93	7.2	1.8
Comparison II	216	6.5	2.4	213	6.2	2.5
Intervention II	78	7.2	1.6	80	7.5^{*}	2.1
Comparison II Target	159	6.7	2.3	155	6.3	2.5
Intervention II Target	58	6.9	1.6	59	7.6^{*}	2.1

Note: $^{*}p<0.05$

Discussion

These results indicate that Change Chem supports learning and motivation, important variables for long-term retention. This is especially significant for the target population, as these variables are critical for building identity, a critical construct for retention[8]. Though different and unique from the comparison group, the higher initial motivation of the engineering students is consistent with other reports of first year students[20]. While the decrease in self-efficacy and professional persistence in first semester course is somewhat discouraging, such a result is consistent with other research that has identified these variables as resilient to intervention[11,23]. For example, Driscoll et al[11] reported that in comparison to their male peers, women had a more positive perception of an MEA-reformed laboratory, but lower feelings of efficacy, felt less valued as team members and had a greater preference for working in groups. The results for the second semester course were much more encouraging and may suggest a treatment effect that requires a longer duration. These results are currently being explored further. Targeting improved motivation over the first semester course is a priority in our next round of re-design and is one of the driving forces behind our adoption of a safe-to-fail philosophy. This implies a gradual progression of responsibility and accountability for students across all of the projects. With this increase, the scaffolds and supports are faded. This is intended to keep interest and engagement high while building the necessary knowledge and skills over time. The specifics of these revisions as well as the plan for an additional study will be provided during the presentation.

Conclusion

This study makes an important contribution to the teaching and learning of science by improving the quality of STEM education through the application of a unique approach to transform the curriculum of undergraduate chemistry to a more contextually relevant and engaging experience for engineering students. This will allow researchers as well as practitioners to better design and develop STEM learning environments that equally attend to the makeup of the student body as well as the quality of their experience.