2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33545

# Optimizing Design Experiences for Future Engineers in a Chemistry Laboratory

**Lorelie Imperial, University of Florida**

School of Teaching and Learning, College of Education, University of Florida

**Mr. Corey Payne**
**Dr. Kent J. Crippen, University of Florida**

Kent Crippen is a 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 scientist-teacher forms of professional development. Operating from a design-based research perspective, this work focuses on using innovative, iterative and theoretically grounded design for the dual purpose of addressing contemporary, complex, in situ learning problems while concurrently generating new theoretical insight related to the process of learning and the relationships among the people, tools and context of the problem space.

**Dr. Maria Korolev, University of Florida**

Maria Korolev is a Senior Lecturer in the Department of Chemistry at the University of Florida.

**Prof. Philip J. Brucat, University of Florida**

Department of Chemistry, University of Florida

**Prof. Chang-Yu Wu, University of Florida**

Professor Chang-Yu Wu received his BS from Mechanical Engineering Department at National Taiwan University and PhD from the Department of Civil & Environmental Engineering at the University of Cincinnati. His teaching and research interests range from air pollution control, aerosol science, environmental nanotechnology, dust control to engineering education. He has published more than 150 refereed journal articles and given 300+ conference presentations and 70+ invited lectures. His research has resulted in 6 US patents and 3 pending applications. He has received several awards recognizing his accomplishments in education, research and service.

**Optimizing Design Experiences for Future Engineers in Chemistry Laboratory**


## Abstract

Our approach to general chemistry laboratory for engineers in our NSF-funded IUSE project (DUE-1625378) involves the use of design challenges (DCs), an innovation that uses authentic context and practice to transform traditional tasks. These challenges are scaled-down engineering problems related to the NAE Grand Challenges that engage students in collaborative, team-based problem solving via the modeling process. With features aligned with professional engineering practice, DCs are hypothesized to support student motivation for the task as well as for the profession. As an evaluation of our curriculum design, we use Expectancy Value Theory to test our hypotheses by investigating the association between students' value beliefs and confidence with experiences of the DC and student characteristics (i.e., gender and URM status). Using linear regression analysis, we reveal that students find value in completing a DC when they feel like an engineer, are satisfied, perceive the task as collaborative, are provided help by TAs and the tasks are not too difficult. Students report feeling confident under similar conditions. We highlight that although female and URM students feel less confident, their perceptions of collaboration and sense of belongingness to engineering supported their confidence. Given the lack of representation for certain groups in engineering, this study suggests that specially designed curriculum interventions can afford a more inclusive learning experience.

# Optimizing Design Experiences for Future Engineers in Chemistry Laboratory

Retaining undergraduate engineering students is a critical issue, particularly those who identify as female or as members of an underrepresented ethnic minority (URM) [1]–[3]. Our local circumstance parallels that of the nation, an unacceptably low-level of student retention, which is particularly prevalent for freshman students in general chemistry. This situation is complicated by the nature of introductory science and mathematics courses, which are notoriously challenging and intimidating [4]–[6]. Targeted curriculum interventions may be one potential way to address this issue and our NSF-funded IUSE project (DUE-1625378) has produced one such example as a career-forward, project-based approach to laboratory for general chemistry.

Our curriculum involves teams of students working on Design Challenges (DCs) (Figure 1), which are scaled-down, developmentally appropriate versions of the National Academy of Engineering's Grand Challenges [7]. For example, students are tasked with recommending a substance, concentration and volume for sequestering 5.0 gigatonnes (GtC) of $CO_2$ for a reservoir that Pacific Gas & Electric would submerge beneath the ocean floor. Using a chemical system composed of $CO_2$ from breath and alkaline solutions, they use a probe to measure the $CO_2$, consider potential precipitation products, and use these results coupled with physical constraints to recommend viable components. The curriculum is designed to build and maintain student interest and motivation by helping them to understand the professional practice of engineers during their initial time on campus when they are completing their prerequisite science courses [8], [9]. Building their personal value beliefs as an explicit relationship with their career goal is hypothesized to support confidence and professional identity development, which should aid persistence [10]–[12].

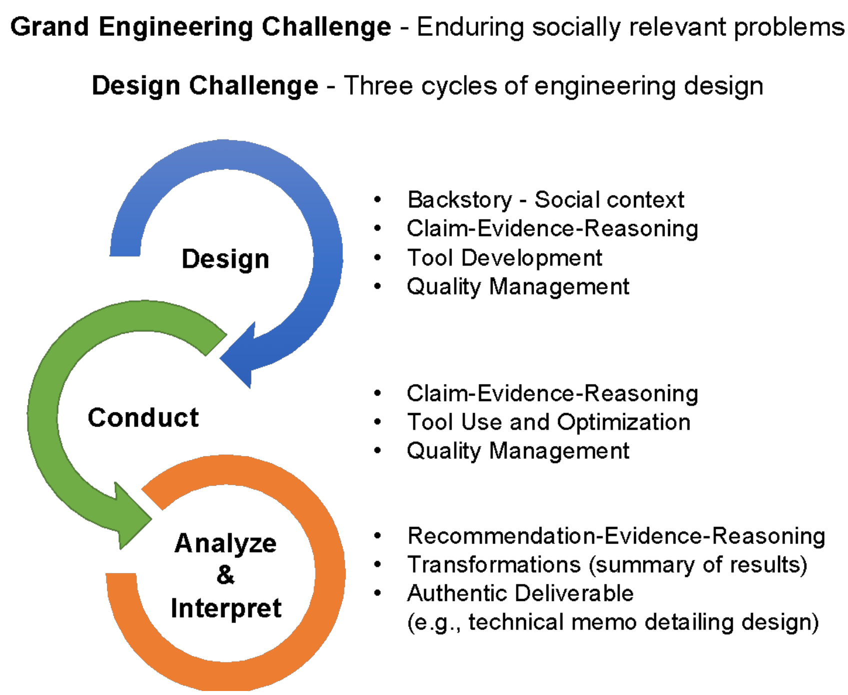


**Figure 1.** Framework for a Design Challenge.

As an evaluation of this hypothesis for the case of our curriculum, we use Expectancy Value Theory to investigate the associations between student value beliefs and confidence with experiences of the DC based upon student characteristics (i.e., gender and URM status).

## Theoretical Framework

Expectancy Value Theory proposes that an individual's motivation for a task involves a combination of their expectations of success (i.e., expectancy beliefs) and their beliefs about the value of completing the task (i.e., task value beliefs) [13], [14]. Both components include specific facets, but this study only involved subjective task value as a compilation of intrinsic, attainment, and utility value beliefs. Intrinsic value is the perception of enjoyment or interest. Attainment value is the perception of importance to the individual's self-concept and utility value is the perceived usefulness for the individual's short- and long-term goals. These facets were assessed as a single factor, subjective task value. Value beliefs are based upon interests and how the task relates to personal goals. In this case, that goal is recognized as a declared major in engineering. Students who place higher value on learning tasks are more motivated to complete the task regardless of context [15], [16].

Self-confidence is a major factor in retaining underrepresented students [17]. Confidence refers to an individual's internal judgements for a task regarding how well they will perform currently as well as in the future [13]. The value that a student perceives translates to achievement as well as to the decisions for taking additional courses [18], [19]. Interest and success build self-efficacy, an expectancy belief, that is defined as "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" [20]. Self-efficacy has been shown to be one of the strongest predictors of academic achievement for undergraduates [21].

## Methodology

This study employed a causal-comparative, single group research design. A purposeful sample of 281 participants taking the first semester general chemistry laboratory course for engineers were consented as participants. Demographics were determined based upon an initial survey where participants indicated their major, gender identity and ethnicity. URM status was defined as either of the following: African Americans, American Indians/Alaska Natives, and Hispanic, which are those formally recognized by NSF [22].

At the end of every laboratory period, participants completed a 10-item survey composed of six experience-related items asking level of difficulty, degree of effort, satisfaction, degree of collaboration, frequency of help from teaching assistants and the degree to which the participants felt like an engineer while completing the DC. The final four-items included a three-item scale for subjective task value and a single-item on confidence.

Based on our hypothesis that the student experience would relate positively to motivation for a DC, we used the experience-related items as independent variables and subjective task value and confidence as dependent variables. We first conducted a correlational analysis using Pearson's coefficient to identify which independent variables related to the dependent variables, then a stepwise multiple regression to test the strength of each independent variable in predicting both task value and confidence.

## Results & Take-Aways

### Correlational Analysis

Table 1. Correlations among experiences, task value and confidence.

| Measure | M | SD | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Task Difficulty | 2.480 | .960 | - | | | | | | | | |
| 2. Effort | 3.160 | .839 | .317** | - | | | | | | | |
| 3. Satisfaction | 3.840 | .917 | -.280** | .015 | - | | | | | | |
| 4. Collaboration | 4.170 | .756 | -.174** | .071** | .552** | - | | | | | |
| 5. Feel like engineer | 4.030 | .854 | -.124** | .112** | .532** | .621** | - | | | | |
| 6. Task Value | 11.942 | 2.396 | -.199** | .024 | .590** | .593** | .631** | - | | | |
| 7. Confidence | 4.30 | .784 | -.355** | -.088** | .419** | .416** | .393** | .463** | - | | |
| 8. Gender | .460 | .499 | .033 | -.007 | -.0100 | .019 | -.016 | .012 | -.107** | - | |
| 9. URM status | .290 | .456 | -.039 | .090** | .092** | .061** | .069** | .053** | -.027 | -.063** | - |

**Correlation is significant at the 0.01 level (2-tailed)

Note: The variables Task Difficulty, Effort, Satisfaction, Collaboration, TA Help and Feeling Like and Engineer were assessed in a continuous scale ranging from 1 to 5, with higher values indicative of more positive response. Binary codes were created for gender (Male = 0; Female = 1) and URM status (non-URM = 0; URM = 1).

**Take-Aways from Correlational Analysis**

- Students' view of self as engineers is strongly and positively correlated with task value (r = .631).
- Students' perceptions of satisfaction and collaboration are moderately and positively correlated with task value (r = .590; r = .593).
- Students' confidence for a DC is moderately correlated with satisfaction (r = .419), collaboration (r = .416) and view of selves as engineers (r = .393).
- Students' confidence for a DC is negatively correlated with task difficulty (r = -.355) and amount of effort expended (r = -.088).
- Students' perception of task difficulty is negatively correlated with task value (r = -.199).
- Female students are less likely to be confident in completing a DC (r = -.107).
- URM status has low correlations with effort (r = .090), satisfaction (r = .092), collaboration (r = .061), feel like engineering (r = .069) and task value (r = .053).

**Regression Analysis for Task Value**

Table 2. Regression model for task value.

| Variable | UnStandardized Coefficient, B | Standard Error | Standardized Coefficient, β | t | P | F | Degrees of Freedom | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| Task Value | | | | | | 534.960 | 5 | 0.524 |
| Overall | 1.510 | 0.310 | | 4.868 | 0.000 | | | |
| Feel like engineer | 0.936 | 0.053 | 0.334 | 17.792 | 0.000 | | | |
| Satisfaction | 0.692 | 0.047 | 0.265 | 14.661 | 0.000 | | | |
| Collaboration | 0.631 | 0.061 | 0.199 | 10.287 | 0.000 | | | |
| TA Help | 0.345 | 0.060 | 0.088 | 5.739 | 0.000 | | | |
| Difficulty | -0.104 | 0.036 | -0.042 | -2.864 | 0.004 | | | |

The model for task value is statistically significant (Table 2), $F(5,2430) = 534.960$, $p < .001$

**Take-Aways from Regression Analysis for Task Value**

Students place value in completing a DC when they:

- Feel like an engineer (0.334 unit increase in confidence for every unit increase in feel like engineer)
- Are satisfied (0.265 unit increase in confidence for every unit increase in satisfaction)
- Work collaboratively (0.199 unit increase in confidence for every unit increase collaboration)
- Are provided help by the TA (0.088 unit increase in confidence for every unit increase in TA help)

Students place lower value in completing a DC when they:

- Perceive the task as difficult (0.042 unit decrease in confidence for every unit increase in TA help)

**Regression Analysis for Confidence**

Table 3. Regression model for confidence.

| Variable | UnStandardized Coefficient, B | Standard Error | Standardized Coefficient, β | t | P | F | Degrees of Freedom | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| Confidence | | | | | | 154.861 | 8 | 0.338 |
| Overall | 2.360 | 0.124 | | 19.086 | 0.000 | | | |
| Satisfaction | 0.128 | 0.018 | 0.150 | 7.026 | 0.000 | | | |
| Difficulty | -0.199 | 0.015 | -0.243 | -13.306 | 0.000 | | | |
| Collaboration | 0.155 | 0.024 | 0.149 | 6.494 | 0.000 | | | |
| TA Help | 0.206 | 0.023 | 0.159 | 8.787 | 0.000 | | | |
| Feel like engineer | 0.135 | 0.020 | 0.147 | 6.659 | 0.000 | | | |
| Gender | -.166 | 0.026 | -0.106 | -6.423 | 0.000 | | | |
| URM Status | -.118 | -0.030 | -0.068 | -4.548 | 0.000 | | | |
| Effort | -0.034 | 0.017 | -0.036 | -2.022 | 0.043 | | | |

The model for confidence is statistically significant (Table 3), $F(8,2427) = 154.108$, $p < .001$

**Take-Aways from Regression Analysis for Confidence**

Students have confidence for completing a DC when they:

- Are satisfied (0.150 unit increase in confidence for every unit increase)
- Work collaboratively (0.149 unit increase in confidence for every unit increase)
- Are provided help by the TA (0.159 unit increase in confidence for every unit increase)
- Feel like an engineer (0.147 unit increase in confidence for every unit increase)

Students lose confidence for completing a DC when:

- The task is too difficult (-0.243 unit increase in confidence for every unit increase)
- A lot effort is required (-0.036 unit increase in confidence for every unit increase)

Demographic variables:

- Students who identify as female are less confident they can complete a DC (β = -0.106).
- Students who identify as URM are less confident they can complete a DC (β = -0.068).

## Conclusion

Given the lack of representation for certain groups in engineering, this study suggests that specially designed curriculum interventions can afford a more inclusive learning experience.

However, the process by which this happens may vary for different segments of the student population. For this case, success was promoted for URM students when they perceived a sense of collaboration and for female students when they felt more like an engineer. This has implications for our theoretical understanding of persistence as well as for further materials development activities that seek to support the success of all students.

## Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. (DUE-1625378). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of NSF.

## References

[1] E. Cech, B. Rubineau, S. Silbey, and C. Seron, "Professional role confidence and gendered persistence in engineering," *Am. Sociol. Rev.*, vol. 76, no. 5, pp. 641–666, Oct. 2011, doi: 10.1177/0003122411420815.

[2] K. A. Robinson, T. Perez, J. H. Carmel, and L. Linnenbrink-Garcia, "Science identity development trajectories in a gateway college chemistry course: Predictors and relations to achievement and STEM pursuit.," *Contemp. Educ. Psychol.*, vol. 56, pp. 180–192, Jan. 2019, doi: 10.1016/j.cedpsych.2019.01.004.

[3] K. A. Robinson, T. Perez, A. K. Nuttall, C. J. Roseth, and L. Linnenbrink-Garcia, "From science student to scientist: Predictors and outcomes of heterogeneous science identity trajectories in college.," *Dev. Psychol.*, vol. 54, no. 10, pp. 1977–1992, Oct. 2018, doi: 10.1037/dev0000567.

[4] J. A. Gasiewski, M. K. Eagan, G. A. Garcia, S. Hurtado, and M. J. Chang, "From gatekeeping to engagement: A multicontextual, mixed method study of student academic engagement in introductory STEM courses.," *Res. High. Educ.*, vol. 53, no. 2, pp. 229–261, Mar. 2012, doi: 10.1007/s11162-011-9247-y.

[5] R. M. Marra, K. A. Rodgers, D. Shen, and B. Bogue, "Leaving Engineering: A Multi-Year Single Institution Study," *J. Eng. Educ.*, vol. 101, no. 1, pp. 6–27, Jan. 2012, doi: 10.1002/j.2168-9830.2012.tb00039.x.

[6] T. Perez, J. G. Cromley, and A. Kaplan, "The role of identity development, values, and costs in college STEM retention.," *J. Educ. Psychol.*, vol. 106, no. 1, pp. 315–329, 2014, doi: 10.1037/a0034027.

[7] National Academy of Engineering (NAE), "Grand Challenges - 14 Grand Challenges for Engineering," *http://www.engineeringchallenges.org/*, 2008. [Online]. Available: http://www.engineeringchallenges.org/challenges.aspx. [Accessed: 06-Jul-2020]

[8] K. J. Crippen, L. Imperial, C. Payne, M. Korolev, P. Brucat, and C. Y. Wu, "General Chemistry Laboratory as Situated Engineering Design," presented at the Annual Meeting of the American Society for Engineering Education (ASEE), Salt Lake City, UT, 2018 [Online]. Available: https://peer.asee.org/29965. [Accessed: 11-Apr-2021]

[9] C. A. Payne, K. J. Crippen, L. Imperial, C. Y. Wu, M. Korolev, and P. Brucat, "Persistence of First Year Engineering Majors with a Design-based Chemistry Laboratory Curriculum In- and Out-of-Sequence," presented at the Annual Meeting of the American Society for Engineering Education (ASEE), Tampa, FL, 2019 [Online]. Available: https://peer.asee.org/32326. [Accessed: 11-Apr-2021]

[10] D. Chachra, D. Kilgore, H. Loshbaugh, J. McCain, and H. L. Chen, “Being and becoming: Gender and identity formation of engineering students,” presented at the American Society of Engineering Education (ASEE) Annual Conference & Exposition, 2008, p. 13.250.1-13.250.20 [Online]. Available: https://peer.asee.org/3597. [Accessed: 23-Jan-2021]

[11] S. Chen *et al.*, “Am I a science person? A strong science identity bolsters minority students’ sense of belonging and performance in college.,” *Pers. Soc. Psychol. Bull.*, p. 146167220936480, Jul. 2020, doi: 10.1177/0146167220936480.

[12] J. W. Osborne and C. Walker, “Stereotype Threat, Identification with Academics, and Withdrawal from School: Why the most successful students of colour might be most likely to withdraw,” *Educational Psychology*, vol. 26, no. 4, pp. 563–577, Aug. 2006, doi: 10.1080/01443410500342518.

[13] J. S. Eccles and A. Wigfield, “In the Mind of the Actor: The Structure of Adolescents’ Achievement Task Values and Expectancy-Related Beliefs,” *Pers. Soc. Psychol. Bull.*, vol. 21, no. 3, pp. 215–225, Mar. 1995, doi: 10.1177/0146167295213003.

[14] A. Wigfield and J. S. Eccles, “Expectancy-Value Theory of Achievement Motivation.,” *Contemp. Educ. Psychol.*, vol. 25, no. 1, pp. 68–81, Jan. 2000, doi: 10.1006/ceps.1999.1015.

[15] M. E. Bathgate, C. D. Schunn, and R. Correnti, “Children’s motivation toward science across contexts, manner of interaction, and topic,” *Sci. Ed.*, vol. 98, no. 2, pp. 189–215, Mar. 2014, doi: 10.1002/sce.21095.

[16] H. Gaspard, A. Wigfield, Y. Jiang, B. Nagengast, U. Trautwein, and H. W. Marsh, “Dimensional comparisons: How academic track students’ achievements are related to their expectancy and value beliefs across multiple domains,” *Contemp. Educ. Psychol.*, vol. 52, pp. 1–14, Jan. 2018, doi: 10.1016/j.cedpsych.2017.10.003.

[17] I. Goodman and C. Cunningham, “Final Report of the Women’s Experiences in College Engineering (WECE) Project,” Goodman Research Group, https://eric.ed.gov/?id=ED507394, ED507394, 2002.

[18] K. P. Dabney *et al.*, “Out-of-School Time Science Activities and Their Association with Career Interest in STEM,” *International Journal of Science Education, Part B*, vol. 2, no. 1, pp. 63–79, Mar. 2012, doi: 10.1080/21548455.2011.629455.

[19] K. A. Renninger and S. Hidi, “Revisiting the conceptualization, measurement, and generation of interest,” *Educ. Psychol.*, vol. 46, no. 3, pp. 168–184, Jul. 2011, doi: 10.1080/00461520.2011.587723.

[20] A. Bandura, “Social foundations of thought and action,” in *The health psychology reader*, 1 Oliver’s Yard, 55 City Road, London EC1Y 1SP United Kingdom : SAGE Publications Ltd, 2002, pp. 94–106.

[21] M. Richardson, C. Abraham, and R. Bond, “Psychological correlates of university students’ academic performance: a systematic review and meta-analysis.,” *Psychol. Bull.*, vol. 138, no. 2, pp. 353–387, Mar. 2012, doi: 10.1037/a0026838.

[22] U. S. National Science Foundation, “NSF definition of groups underrepresented ,” *US NSF - MPS - DMR - Broadening Participation*. [Online]. Available: https://www.nsf.gov/mps/dmr/diversity.jsp. [Accessed: 07-Mar-2021]