TLEF Project – Final Report

Report Completion Date: (2022/05/30)

1. PROJECT OVERVIEW

1.1. General Information

Project Title:	Math Doesn't Need to Be Hard: Integrating Experiential Learning and Interactive Online Resources for Chemical Engineering		
Principal Investigator:	Bhushan Gopaluni, Professor – Chemical and Biological Engineering (CHBE), Associate Dean, Education and Professional Development – Faculty of Applied Science		
Report Submitted By:	Jonathan Verrett, Associate Professor of Teaching – Chemical and Biological Engineering (CHBE)		
Project Initiation Date:	May 1, 2018	**Project Completion Date:**	May 1, 2022 (extended 1 extra year due to Covid)
Project Type:	☐ Large Transformation ☒ Small Innovation ☐ Flexible Learning ☐ Other: [please specify]		

1.2. Project Focus Areas – *Please select all the areas that describe your project.*

☒ Resource development (e.g. learning materials, media)

☒ Infrastructure development (e.g. management tools, repositories, learning spaces)

☒ Pedagogies for student learning and/or engagement (e.g. active learning)

☐ Innovative assessments (e.g. two-stage exams, student peer-assessment)

☐ Teaching roles and training (e.g. teaching practice development, TA roles)

☐ Curriculum (e.g. program development/implementation, learning communities)

☐ Student experience outside the classroom (e.g. wellbeing, social inclusion)

☐ Experiential and work-integrated learning (e.g. co-op, community service learning)

☐ Indigenous-focused curricula and ways of knowing

☐ Diversity and inclusion in teaching and learning contexts

☒ Open educational resources

☐ Other: [please specify]

1.3. Final Project Summary

Two of the most computationally intensive courses in chemical engineering are reactor design (CHBE 355) and process control (CHBE 356). Undergraduates with limited mathematical knowledge have difficulty understanding core concepts in these courses. The design and implementation of modern, real-world process systems require programming skills and problem-solving proficiency. Graduates with only spreadsheet skills and limited programming abilities are uncompetitive in the job market. To address these issues, we propose creating open-source and interactive course content using Jupyter Notebooks and implementing a final design project. The online notebooks will integrate text, equations, and code in a productive, visual environment that supports active learning. Tight integration of Python programming in these courses will simultaneously teach students modern software tools and programming practices in solving engineering problems. The design project will implement concepts from CHBE 355 and CHBE 356 in the design of a functional reactor and integrated reactor control systems.

1.4. Team Members – *Please fill in the following table and include **students**, undergraduate and/or graduate, who participated in your project.*

Name	Title/Affiliation	Responsibilities/Roles
Bhushan Gopaluni	Professor – Chemical and Biological Engineering (CHBE), Associate Dean, Education and Professional Development – Faculty of Applied Science	Instructor of process control (CHBE 356)
Jonathan Verrett	Associate Professor of Teaching – Chemical and Biological Engineering (CHBE)	Instructors focusing on undergraduate design
Vikramaditya Yadav	Associate Professor – Chemical and Biological Engineering (CHBE)	Instructor of reaction engineering (CHBE 355)
Yankai Cao	Assistant Professor – Chemical and Biological Engineering (CHBE)	Instructor of process control (CHBE 356)

1.5. Courses Reached – *Please fill in the following table with* ***past***, ***current***, *and* ***future*** *courses and sections (e.g. HIST 101, 002, 2017/2018, Sep) that have been/will be reached by your project, including courses not included in your original proposal (you may adapt this section to the context of your project as necessary).*

Course	Section	Academic Year	Term (Summer/Fall/Winter)
CHBE 355	101	2018/2019	January
CHBE 356	101	2018/2019	January
CHBE 344	101	2018/2019	September
CHBE 550	101	2018/2019	September
CHBE 355	101	2019/2020	January
CHBE 356	101	2019/2020	January
CHBE 344	101	2019/2020	September
CHBE 550	101	2019/2020	September
CHBE 355	101	2020/2021	January
CHBE 356	101	2020/2021	January
CHBE 355	101	2021/2022	January
CHBE 356	101	2021/2022	January
CHBE 355	101	Future course iterations	January
CHBE 356	101	Future course iterations	January

2. OUTPUTS AND/OR PRODUCTS

2.1. *Please **list** project outputs and/or products (e.g. resources, infrastructure, new courses/programs). Indicate the current location of such products and provide a URL if applicable.*

Product(s)/Achievement(s):	Location:
All resources we have developed (specifics below)	Available in the OpenChemE GitHub repository: https://github.com/OpenChemE
Introductory tutorial notebooks Topics included: - Basics of Python programming language, Jupyter notebooks and interactive programming - Solving algebraic equations - Solving Ordinary Differential Equations (ODEs) and systems of ODEs - Linear and non-linear regression - Solving Partial Differential Equations (PDEs) - Symbolical computation in Python - Applying numerical methods for solving Chemical Engineering Reactor design challenges - Using the Pandas library (a common library) to manipulate data - The Laplace Transform - Using the Control library to model and simulate Transfer Functions (TF)	Openly available on Github under a creative commons license: https://github.com/OpenChemE/Tutorials-2018W2
Kinetic and reactor design notebooks Topics include: - Batch and CSTR reactor modelling in Python - Data fitting for reactor design - Systems of reaction ODEs - Diffusion - A 1-month long design project using simulation of the Belousov-Zhabotinsky (BZ) reaction - One take home and one in-class quiz	Openly available on Github under a creative commons license: https://github.com/OpenChemE/CHBE355
Process control notebooks Topics include: - Modelling Chemical Processes - Transfer Functions - Feedback control - Stability Analysis - Advanced Process Control	Openly available on Github under a creative commons license: https://github.com/OpenChemE/CHBE356

2.2. Item(s) Not Met – *Please list intended project outputs and/or products that were not attained and the reason(s) for this.*

Item(s) Not Met:	Reason:
None – all expected outcomes met	

3. PROJECT IMPACT

3.1. Project Impact Areas – *Please select all the areas where your project made an impact.*

☒ Student learning and knowledge

☐ Student engagement and attitudes

☒ Instructional team-teaching practice and satisfaction

☐ Student wellbeing, social inclusion

☐ Awareness and capacity around strategic areas (indigenous, equity and diversity)

☐ Unit operations and processes

☐ Other: [please specify]

3.2. What were you hoping to change or where were you hoping to see an impact with this project? – *Please describe the intended benefits of the project for students, TAs, instructors and/or community members.*

With this project we had intended to benefit students, TAs and instructors in the following ways:

Students – the project has allowed them to apply their numerical method and programming abilities to solve mathematically complex problems in an applied setting. The notebooks have also allowed them to work at their own pace, while also structuring their study in tutorials where TAs and instructors can assist them.

TAs – The use of notebooks and structured examples has assisted TAs in providing better support to students during course tutorials.

Instructors – The use of notebooks has helped to structure learning activities and make them easy to disseminate and update.

3.3. Were these changes/impacts achieved? How do you know they occurred? – *How did you measure changes/impacts? (e.g. collected survey data, conducted focus groups/interviews, learning analytics, etc.) Describe what was learned from this process. You are encouraged to include copies of data collection tools (e.g. surveys and interview protocols) as well as graphical representations of data and/or scenarios or quotes to represent and illustrate key themes.*

The changes described were achieved. Student feedback collected through course evaluations noted the positive impact of the tutorial structure on their learning. Students commented that these materials assisted them to see the connection between mathematical methods and larger scale design problems. Feedback from TAs and course instructors noted that these materials helped to better structure student learning in tutorials. The ease of updating and maintaining these materials was also noted.

3.4. Dissemination – *Please provide a list of **past** and **upcoming** scholarly activities (e.g. publications, presentations, invited talks, etc.) in which you or anyone from your team have shared information regarding this project. Be sure to include author names, presentation title, date, and presentation forum (e.g., journal, conference name, event).*

The project has been disseminated through open sharing on GitHub. This has also been highlighted through a presentation at the Computer Aids in Chemical Engineering (CAChE) 50th Anniversary Conference in 2019 (citation below) as well as a journal article in Chemical Engineering Education (citation below).

Jonathan Verrett "Educational Innovation Using Open Educational Resources", Computer Aids in Chemical Engineering (CAChE) 50th Anniversary Conference, Breckenridge, Colorado (July 19-20, 2019)

J Verrett, A Dowling, F Boukavala, Z Ulissi, V Zavala (2020). Computational notebooks in chemical engineering curricula. Chemical Engineering Education. 54(3), 143-153. http://orcid.org/0000-0003-4709-6276

4. TEACHING PRACTICES – *Please indicate if **your** teaching practices or those of **others** have changed as a result of your project. If so, in what ways. Do you see these changes as sustainable over time? Why or why not?*

Teaching practices in both of the principal courses (CHEB 355, 356) have changed. Instructors have integrated design examples and the use of Jupyter notebook and python into their tutorials for analyzing reactor design and control systems. These resources will continue to be used in these courses and built upon. These changes are sustainable as the Jupyter notebooks provide a good framework for transferring knowledge and skills to students. They are also easily replicable and can be copied by the students. This allows for them to be easily updated and used year to year. The notebooks provide a useful guide for teaching assistants in these courses as well who assist students in tutorials.

5. PROJECT SUSTAINMENT – *Please describe the sustainment strategy for the project components. How will this be sustained and potentially expanded (e.g. over the next five years). What challenges do you foresee for achieving the expected long-term impacts listed above?*

The main sustainment strategy will be continued use of these notebooks in the reactor design (CHBE 355) and process control (CHBE 356) courses). The numerical methods course students in the chemical and chemical and biological engineering program2 take in 2nd year has also moved to use Python and Jupyter notebooks and this has also helped to improve student experience and applied programming skills. Barring a significant shift these technologies will likely continue to be used. The examples in the notebooks can be updated as time progresses or added to as needed based on the needs of the course instructors. They are also reasonably robust as they are not tied to the content management system (Canvas) and are openly available in GitHub.