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Work-In-Progress: Reinforcing connections and creating efficiency in a 2nd year curriculum - a systematic approach to identify opportunities for integration

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Introduction

Engineering students often struggle to see connections between concepts taught in different courses, making it difficult to develop a cohesive understanding of their discipline. This disconnect can lead to fragmented learning, where knowledge integration occurs only in advanced years or during professional practice. Additionally, overlapping content across courses can create confusion or excessive workload, detracting from learning rather than reinforcing it. To address these challenges, integrating curricula to showcase the connections between course content may help students connect key concepts and foster deeper understanding. Our work aims to (1) highlight connections between courses in the undergraduate Chemical and Biological Engineering (CHBE) program, and explore if integrated assessments can cultivate stronger perceptions of connectedness, and (2) explore if a streamlined Y2 curriculum with integrated course content can enhance student learning by reinforcing key concepts throughout the program. This paper describes a systematic approach to assessing the curriculum for integration opportunities and reviews an integrated assignment designed to bridge two core courses as an initial step towards the first goal.

Our motivation stems from a wide body of literature on curriculum integration including a number of examples from our own institution that span (i) transdisciplinary approaches that integrate engineering and non-engineering program elements (e.g., Climate Emergency Transdisciplinary PhD); (ii) integrated engineering degree programs that span multiple engineering disciplines (e.g., IGEN), (iii) single-year integration within an engineering program where topics are taught outside of traditional course structures (e.g., MECH2), and (iv) integrated experiences that aim to connect topics across two or more courses. These examples demonstrate how integrating curricula can improve efficiency, reduce redundancy, and deepen student learning.

This work focuses on the last of these approaches, with guidance from previous studies on the potential benefits of horizontal integration. Farmer and Wilkinson [1] implemented a cross-course project at the University of Toronto, combining communication and laboratory courses to develop critical thinking and communication skills. While students reported skill gains and demonstrated slight performance improvements, challenges in fostering creativity highlighted the complexity of designing effective integrated curricula. Specifically, students demonstrated higher technical performance, but communication outcomes were not as strong. Zhan et al. [2] demonstrated horizontal and vertical integration in an Electronic Engineering Technology program by using a common project platform across multiple courses. Surveys revealed that students appreciated the efficiency of a familiar platform, though some learners expressed a need for exposure to diverse tools to broaden their skill set. Barrella and Watson [3] analyzed the conceptual sustainability knowledge of students at James Madison University (JMU) and The Citadel, which differ in their approaches to integrating sustainability into their curricula. JMU employs horizontal integration by weaving sustainability across a variety of classes, while The Citadel uses a vertically-integrated model with a single sustainability-focused course. By analyzing concept maps produced by the students in both programs, the authors determined that horizontal integration led to deeper, and more interconnected knowledge, demonstration of systems thinking, and greater representation of the social dimension of sustainability. These studies underscore the potential of horizontal integration to enhance learning outcomes while highlighting the need for careful design to balance efficiency, skill development, and engagement. Building on these findings, our initiative aims to identify opportunities for such integration within the CHBE Y2 curriculum and assess the effectiveness of an initial cross-course assignment.

Methodology

To achieve this goal, we start by breaking each course in the Y2 curriculum into its core topics. This was done through a process of compiling and organizing class notes from each course chronologically and aligning them with class days over the thirteen weeks of each term in the academic year. For each course, we systematically listed the concepts covered in each day and then overlaid these on the standard timetable of each term. This enabled us to see what topics students were learning in different classes on a given day or across a given week. Each topic was colour-coded to more efficiently identify overlap or repetition in different courses and throughout the term. Instances of repeated topics could then be investigated to assess if a topic was being progressed, reinforced or unnecessarily overtaught. While learning outcomes provide a broad framework for course goals, examining content topics allowed us to pinpoint concrete opportunities for connecting concepts. This granular focus was intended to enable the design of assignments that highlighted the connections between courses. Future work could expand this analysis to include explicit mapping of learning outcomes to ensure alignment with course goals and broader program objectives.

Orbitals and Hybridization	Sterochemistry	Alkenes	Coordination Chemistry
Bonding & Structures	Acids and Bases	Unimolecular Mechanisms	Coordinate Systems & Vectors
Polarity and Charges	Hydrocarbons & Radicals	Bimolecular Reactions	Equations of 3D Spaces
Resonance	Root Finding	Oxidation and reduction	Gradients and Tangents
Aromaticity	Entropy	Periodic Table	Derivatives
Processes and mass balance	Equations of state	Fluids & Forces	Ordinary Differential Equations
Economics	Control Systems	Taylor Series & Approximations	Partial Differential Equations
Reaction Kinetics & Equilibrium	Safety	Separation Methods	Solving systems of equations
Gas-Liquid Systems & Phase changes	Written/Visual Communication	Biology & Engineering	Periodic signals
Energy Balances	Laboratory methods	Teamwork & Time Management	Integrals
Units & Measurements	Fitting Data	Mixture Composition	Pressure

Figure 1: Example of Colour-coded Topic Categories

Integrated Assignment

One opportunity that arose through this analysis was related to the teaching of material balances and chemical reactions, both of which are core topics in CHBE 241 Material and Energy

Balances, and also integral to experiments conducted in CHBE 263 Introduction to Chemical Engineering Laboratory Practice (see colour-coded cells for each course in Figure 2). However, the data analysis methods in CHBE 263 and theoretical frameworks taught in CHBE 241 were previously misaligned, leading to confusion and missed opportunities for reinforcement. The mapping process provided a foundation for designing an integrated assignment to address this issue.

WEEK 6	10/10/2022 Mon	10/11/2022 Tue	10/12/2022 Wed	10/13/2022 Thur	10/14/2022 Fri
8:00		CHBE 220 Measuring pressure Phase diagrams		CHBE 220 Intro to Phase Transitions Gibbs Phase rule - DOF Equations of state	
9:00	CHEM 260 Nucleo/Electrophiles Electron movement Homo/heterocyclic fission		CHEM 260 Gibbs Free Energy Enthalpy Entropy		CHEM 260 Rate Determining Step Rate Equation Catalysts
10:00	CHBE 241 Fractional Conversion Reaction Extent		CHBE 241 Equilibrium Constant Equilibrium Composition		CHBE 241 Multiple Reaction Yield & Selectivity
11:00	MATH 253 Partial Derivatives	CHEM 250 Al and Group 13	MATH 253 Several Variable Chain Rule	CHEM 250 Transition Metals Coordinate bonds, Ligands	MATH 253 Applications of Partial Derivatives
12:00		CHBE 201 Peer review technical memo Receive feedback on technical memo			
13:00			CHBE 263 Banana Oil Synthesis Catalysts	CHBE 241 Tutorial TUTORIAL	
14:00				CHBE 201 Letter of engagement for project Technical memo on separation process	

Figure 2: Week 6 CHBE Y2 Timetable with Colour-Coded Topics. Cells with the same colour indicate related topics covered in multiple courses in this week – particularly CHBE 241 and CHBE 263, which prompted the integrated assignment.

The integrated assignment combines experimental procedures, data collection, and reporting from CHBE 263 with material balance calculations taught in CHBE 241. Students conduct a banana oil (isopentyl acetate) synthesis laboratory experiment in CHBE 263 through an esterification reaction between acetic acid and isopentyl alcohol with a sulfuric acid catalyst. The reaction takes place in a small reactor on a hot plate. Students then use liquid-liquid extraction to separate the banana oil and determine the yield and purity using gas chromatography. The "Production of Banana Oil" assignment was conducted in CHBE 241 and integrates with CHBE 263 by requiring students to apply theoretical concepts to their experimental findings, using skills learned in both courses to analyze the feasibility of constructing a plant to manufacture 50,000 kg/year of banana oil. Students use experimental data from CHBE 263, such as reactor conversion and product composition, to perform detailed material balance calculations. The assignment includes designing a preliminary process with key unit operations, such as a reactor, liquid-liquid extractor, and distillation column, while considering recycling streams, chemical losses, and reaction selectivity. Students also assess economic feasibility by estimating gross profit, incorporating costs for feed, separations, and recycle streams. In addition to building connections between courses, the goal for this assignment was for students to engage with realworld, ill-defined problems, develop tolerance for uncertainty, and explore the impact of process parameters on gross profit. Importantly, this integration does not affect how the lab is conducted. The experimental process remains open-ended, allowing students to develop important practical skills which are not taught in lecture. Instead, integration happens through how the data is used, connecting it to lecture-based analysis without standardizing or restricting the lab experience. By bridging theoretical and experimental components of chemical engineering, we hoped to foster a deeper understanding of process design and economic evaluation.

Preliminary Survey Results

To assess the effectiveness of the integrated assignment, a survey was administered to students enrolled in both courses. Students were asked two questions. Question 1 (blue, in Figure 3) asked students on a scale of 1 (not at all) to 5 (very much) to rate how much using data from their experiment in an assignment helped them recognize the connections between concepts taught in both courses. The majority of students rated the integration as moderately effective (31.7% for a rating of 3), with 30.0% assigning a rating of 4, indicating a positive but not overwhelming connection between the two courses. Lower ratings (1 and 2) accounted for 26.7% of responses, suggesting room for improvement. Question 2 (red) asked to what extent using lab data from their experiment for mass balance calculations helped improve their understanding of concepts taught in CHBE 241. The ratings are concentrated around 3 (40.0%), indicating moderate improvement in understanding. However, 33.3% of responses fell in the lower range (ratings of 1 and 2), showing that for a significant portion of students, the activity was less impactful. Higher ratings (4 and 5) were chosen by only 26.7%. The survey results reveal a generally moderate effectiveness, suggesting that while there was minor success in demonstrating connections between the two courses, the integrated assignment did not significantly improve or reinforce understanding of concepts.

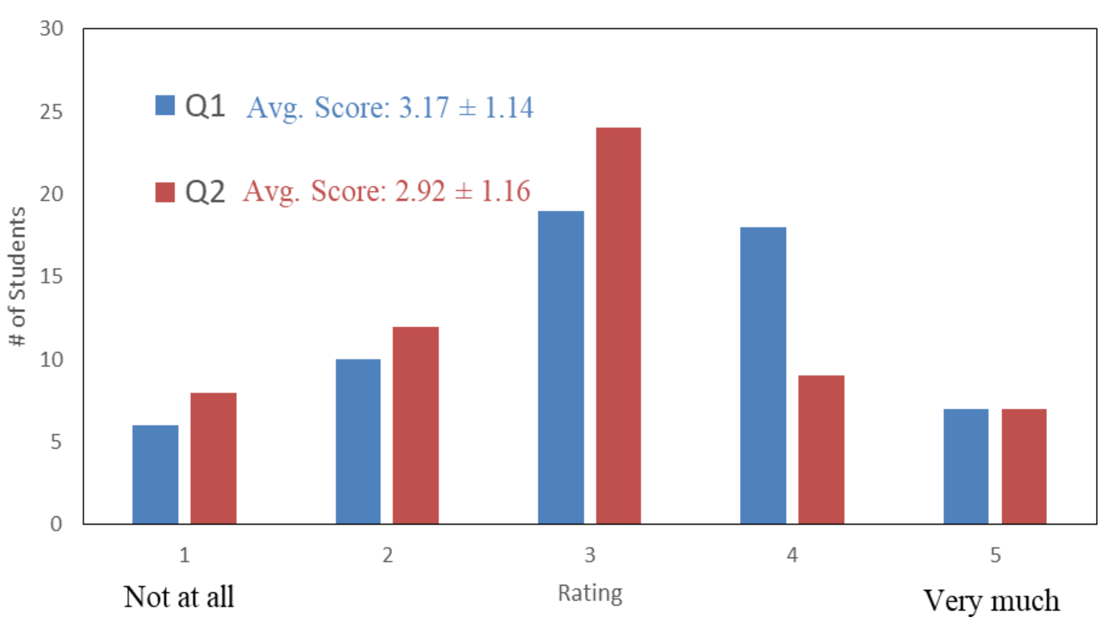

Figure 3: Survey results indicate moderate impact of the initial integrated assignment

Because the data was based solely on self-reported measures, it does not fully capture retention or depth of learning. Future iterations should include quantitative feedback such as post-course concept assessments. For example, higher-level courses could begin with concept checks to evaluate long-term retention of foundational material. Expanding this approach could provide a clearer picture of actual student learning over time.

Conclusion and Next Steps

The systematic curriculum review proved valuable in identifying opportunities for integrating concepts across CHBE 263 and CHBE 241. Identifying shared topics across courses can reveal immediate opportunities for integration that might not otherwise be evident, and testing integrated assignments in one course, as we did with CHBE 241, offers a manageable starting point to evaluate feasibility and effectiveness. However, the findings highlight the need for a more deliberate and systematic approach to developing and implementing integration. While the assignment was thoughtfully designed, its introduction solely in CHBE 241 limited its potential to fully reinforce the desired learning outcomes across both courses. Future efforts should focus on embedding the assignment into both courses' instructional strategies, with explicit emphasis on the interconnection of concepts. This approach could ensure more effective reinforcement of the learning objectives and promote a deeper understanding of how core chemical engineering principles apply across different contexts.

Future work will focus on revising the implementation of this assignment and expanding integration to additional courses in the Year 2 CHBE curriculum. Additionally, refinements to the survey design and assessment methods will provide deeper insights into the impact of integration on student outcomes. Finally, collaboration between instructors will be prioritized to ensure alignment in teaching approaches and expectations. Workshops or regular meetings may be implemented to facilitate this process. This also points to a key challenge in a symbiotic approach to curriculum integration: developing and maintaining integrated assignments requires significant coordination between instructors and alignment of course schedules, which can be time- and resource-intensive when being initiated. As this initiative evolves, we hope it will contribute to a broader understanding of how curriculum integration can improve efficiency, reduce student workload, and foster meaningful learning in engineering education.

References

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