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Bridging Theory and Practice: A Case Study in Engineering Design Education

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Abstract

This paper discusses the student preference with respect to learning material and modality of instruction in an upper-level engineering course. This project was conducted by assessing the course curriculum from a pedagogical perspective, surveying students on usage of course resources, and determining VARK modalities of each student. The concept of learning styles has been widely debated in the academic community. This project aimed to observe the connection between student VARK type and their preference of learning material offered through the course. Since the course contained both theory and design components, observations with regards to synthesis of theory and its application in design by students through learning material offered were made. The primary conclusion is that while students may not strictly fit into singular learning modalities, as classified by the VARK types, understanding the relationship between learning style, teaching materials, and modality of instruction allows for a robust pedagogical approach to designing engineering curricula. Considering the diverse demands of engineering design education, this project aims to provide insight into student preferences, demographics, challenges, and success in a multi-disciplinary classroom environment.

Introduction

Engineering education typically comprises of a combination of theory and design [1]. A sound theoretical foundation is essential for practical application [2, 3]. One of the primary purposes of engineering education is to equip students with the ability to synthesize theory and transform it into practical design solutions. In doing so, students must be trained to define and solve problems with the constraints of cost, time, and performance [4, 5]. While there may exist theoretical solutions that are state of the art, practical application demands an understanding for translation into adoptable technologies. Additionally, engineering is a very multi-disciplinary field, and the combination of knowledge from various domains is typical for arriving at a feasible and desirable solution [4, 6, 7].

In most universities, engineering education is split into eight semesters. The former semesters train students with fundamental domain principles, while the latter semesters are used to hone the expertise of students in specific areas. Students are also encouraged to gain practical training through internships and projects, with many universities specifying it as a mandatory degree requirement. While designing curricula for a course containing both theoretical and design components, pedagogical methods should be employed in determining the modality of instruction, delivery of content, grading scheme employed, and learning outcomes.

The primary consideration when designing course curricula is the learners themselves. With increasing diversity in classrooms today and learners coming from varying demographic backgrounds, educators are tasked with ensuring that the course design is adequate in equipping learners to achieve the desired learning outcomes [4, 8, 9]. In the current rapidly evolving dynamic engineering educational landscape, some factors of which are highlighted in Figure 1, there is much debate about traditional teaching practices. The introduction of accessible AI tools further tasks educators with ensuring that their course design is adequate to equip learners to meet the specified learning outcomes. The challenge currently lies in understanding the connection between pedagogical approaches to curriculum design and its relationship to student learning styles and preferences. Thus, engineering education and educators face the unique challenge of integrating several teaching methods, accounting for student learning styles across tasks, rooting course design in pedagogical foundations, and attempting to bridge theory and practice through synthesis of theoretical knowledge into applicatory design [6, 10].

Figure 1: The Evolving Educational Landscape

Learning Styles and VARK Types

The concept of Learning Styles [11] refers to the different methods through which individuals receive and synthesize information. Some models include Kolb's model of experiential learning, Honey and Mumford's model of the learning cycle, and Barbe's proposed learning modalities (VAK). Neil Fleming's VARK model [11] built upon Barbe's modalities and introduced the fourth formal learning modality. The commonly accepted paradigm thus classified learners into the four modalities-visual, auditory, reading and kinesthetic.

Based on the VARK Model, learners can be classified into either category depending on their preferred modality. There is also a classification for learners that may have a mixture of preferred modalities. Though this model may not encompass every facet of individual learning, traditionally, it has set a basis for the educational design paradigm.

The two key factors to note while utilizing this approach are:

- Most individuals are multi-modal learners.
- Learning can be facilitated by pairing the modality to the learning outcome.

Studies indicate that engineering students typically fall into the category of kinesthetic learners [12], however variations in modality are observed when tasks are modified. Another factor to note is that engineering education requires the holistic development of varied skill-sets, and a multi-disciplinary approach is essential to truly facilitate learning. Thus, the conclusion drawn here is that being mindful of student learning styles, understanding the modality that fits best with the learning component, and combining these factors through pedagogical theory and evidence-based teaching practices, allows for maximization of learning.

This concept thus implies that an individual is more likely to be successful in synthesizing information if the modality of its delivery matches their individual learning style. While the univariate classification of individuals based on learning styles remains a debated topic in pedagogical communities, there is evidence to suggest that the VARK modalities may be used as an aid to deliver learning outcome specific content in multi-disciplinary contexts, such as an engineering design classroom.

Overview of Research Objectives and Methodology

The broad aim of this project was to understand the relationship between individual student learning style and the study habits employed and course materials used by them to synthesize theory taught and apply it to their design project. In doing so, the goal was to observe if univariate classifications into the four modalities hold up, or if the model and method of instruction and supplemental learning materials holds greater weight in student success in the context of an engineering design course. Another factor intended to be observed was if students can truly be classified into a single modality of learning style, and if this had an effect on their preference for the learning materials offered in the course. Thus the two key research questions were:

- What are the study habits employed and course materials used by students in the environmental engineering course 'CHEE 476 576: Wastewater Treatment Design System' to learn and synthesize the theory taught, and apply it in practice to their design project?
- What is the observed relationship between individual student VARK types and their preferences with respect to learning material and modality of instruction?

The project was conducted in a 3-credit in-person upper-level (400/500) environmental engineering course titled 'CHEE 476 576: Wastewater Treatment Design System', which focused on the theory and practical design of wastewater systems. The course was divided into ten weeks of theory followed by five weeks of design using BioWin software. The final project was a software-based design, with no physical components required. The course used evidence-based teaching practices with nine pre-defined learning outcomes and specifications grading, complement to mastery learning. The pedagogical validity of each learning resource was ascertained, through analysis of factors such as modality, content type, and underlying theory. The sample was a total of 22 students (16 undergraduate, 6 graduate), which is representative of the population distribution found in upper-level engineering classes. Learners were full-time students, and classes were conducted in-person, with lecture recordings available on the learning management system (LMS).

The project was diagnostic and conducted in three Phases. Phase I was divided into two segments - observation of teaching and analysis of course design. Phase II consisted of surveying students to obtain demographic information & learning resource utilization data. In Phase III, students were classified into their VARK type through the VARK Questionnaire (Version 8.01).

Students were then divided into four focus groups (based on demographics) to answer the following questions regarding resource utilization during midterm preparation and final project design. Upon classification to their VARK type, and qualitative correlation between their preferred resources and VARK types was studied. Finally, student success through quantified grades was mapped to resource usage, to draw conclusions on effectiveness in utilizing specific learning resources to translate theory into design. Thus, the overall research objective aimed to observe the relationship between student learning style, learning resources and tools, and method of delivery and its effect on student learning.

Course Overview and Student Demographics

Learning Outcomes: This course, offered by the department of chemical and environmental engineering focused on the application of theory and engineering experience to the design of unit operations for the treatment of wastewater. It covered characteristics of wastewater; wastewater regulations; primary, secondary & tertiary treatment processes; selected topics on advanced treatment and resource recovery; sludge disposal; and design of water and wastewater treatment plants. The aim was to equip students with a working knowledge of the wastewater industry and have the skills to perform a preliminary design of a treatment plant. The nine learning outcomes specified by the instructor were as follows:

On successful completion of this course students will be able to:

1. Discuss wastewater quality data.
2. Identify specific pollution problems associated with wastewater discharge and sludge disposal.
3. Describe the main physical, chemical and biological unit operations applied in municipal and industrial wastewater treatment systems.
4. Identify laws and regulations that apply to water and/or wastewater treatment.
5. Explain the principles of wastewater treatment, understand the main design criteria and operational parameters for wastewater treatment processes, and apply the knowledge in the process design.
6. Understand the principles of excess sludge treatment and apply the knowledge in the process design.
7. Formulate a preliminary design of a wastewater treatment plant.
8. Reflect on the importance of practical wastewater design considerations as well as sustainability issues.
9. Use BioWin software to model wastewater treatment plants.

Grading System: The grading system employed was specifications grading. Specifications grading is a complement to mastery learning because grades are structured on competencies achieved rather than on points earned, meaning that mastery is the key to success. The goals for the usage of specifications grading as identified by the course instructor included the following:

- Uphold high academic standards,
- Reflect student learning outcomes,
- Motivate students to learn,
- Motivate students to excel,

- Discourage cheating,
- Reduce student stress,
- Make students feel responsible for their grades,
- Minimize conflict between faculty and students,
- Save faculty time,
- Give students feedback they will use,
- Make expectations clear,
- Foster higher-order cognitive development and creativity,
- Assess authentically,
- Achieve high interrater agreement,
- Be simple

The primary aim of specifications grading is to determine if a task has been completed successfully or not. In real-world engineering environments, this pass/ fail metric of measurement is typically employed to gauge project and individual success. By measuring student output in terms of success in completing the task at hand through the metric of specifications grading, it allows for students to disengage from the typically employed ‘rubric’ with rigid numeric partitions and instead focus on holistic task completion. The scale for the specifications grading is given in Table 1.

Pass Items Earned	**Percentage Equivalent**	**Comments**
1	90-100%	work is done, excellent, with possibly a few minor errors
0.75	60-89.9%	done, but needs a bit of work to reach the full credit standard
0	<59.9%	done, but with major errors or not done at all. View this as not meeting appropriate standards

Table 1: Scale of Specifications Grading

Course Components: The course consisted of pre-class readings, homework assignments, two midterm examinations, character growth assignments, the final design project and a term paper for graduate students, the highlights of which are provided in Figure 2.

Figure 2: Course Components of CHEE 476 576 – Wastewater Treatment Design System

Student Demographics: There were 22 students in the Spring 2024 cohort, of which 16 were undergraduate students and 6 were graduate students. The language of instruction was English. Learners were full-time students and class was conducted in-person, with lecture recordings available for subsequent viewings on the LMS. Figure 3 show the distribution of students according to their education level and major.

Figure 3: Demographic Distribution of Students

The majority of students were pursing undergraduate or graduate degrees in Environmental Engineering. Other degree majors included Chemical Engineering and Civil Engineering. Most undergraduate students were juniors, with a few seniors too. Graduate students however were evenly divided between master's students and doctoral students.

This cohort was a good example of a diverse engineering classroom environment. The multidisciplinary nature of the course aims to teach students both theoretical aspects as well as application through design, and followed a very hands on approach.

Project Methodology

Since the course was diagnostic in nature, it consisted of observation of the class, analysis of the course design, and obtaining both quantitative and qualitative data from the students. The goal was to answer the TAR question of what course materials were used the most by students to retain and reference theory, and apply it to their final project design. A combination of methods like passive observation, surveys, and focus groups were employed to collect data. This data was then analyzed to draw both qualitative and quantitative inferences. Figure 4 shows the project timeline in combination with the course timeline.

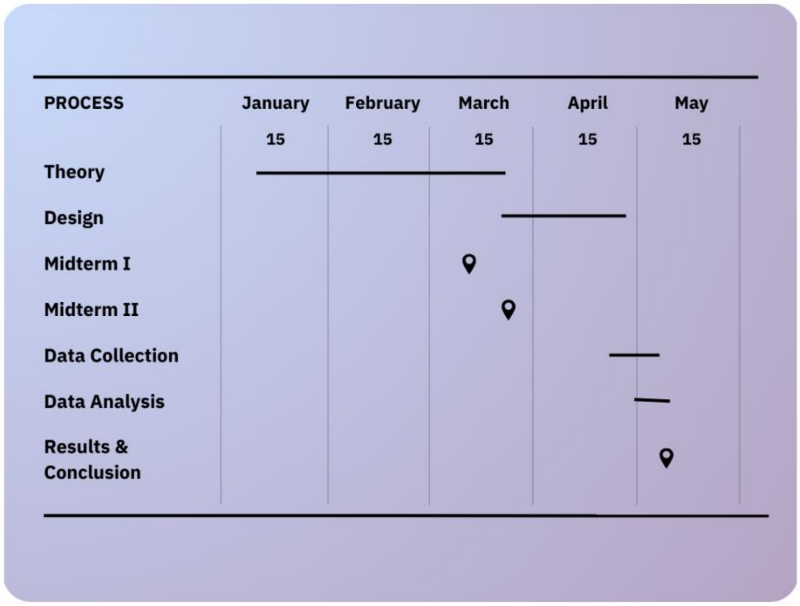

Figure 4: Project and Course Timeline

Phase I

Observation of Teaching: Observation of teaching was done on 3 separate occasions. Since the course was split into the theory portion (10 weeks) and the design portion (5 weeks), teaching practices were observed for each segment. Additionally, observation of teaching was conducted with a view to gauge the classroom environment and the interaction of the students with each other, as well as with the instructor. Inspection of the students as they asked questions regarding the homework and worked through in class-activities on BioWin was critical to understand their receptiveness to the course.

Analysis of Course Design: The other component of analysis was the course design. Reading through the syllabus and understanding the grading structure allowed for an understanding of the expectations for students. The resources available to students, like in-person lectures & recordings, online modality, office hours, readings, tutorials for BioWin, and supplemental practice materials were also studied. These resources, combined with the methods of implementation, set the background for answering the specified research questions.

Phase II

Student Demographics

Section 1: This section of the survey was to collect information about student demographics like education level, major, minor, engineering design experience, and prerequisite knowledge (CHEE 377). This was done to understand the background of the learners in this course, and the existing knowledge they possessed coming into it. It was also essential to gauge student expertise in design, as the analysis of efficiency of teaching methods was dependent on the existing baseline of experience.

Section 2: The next section of the survey gathered information on each students' preferred mode of receiving information, performing tasks, and learning certain concepts. This section was tailored specifically to this course, so students were able to select the course resources they utilized for specific tasks. Students were also asked for their feedback on the instruction of the course, the resources available to them, their opinion on in-class group activities, & difficulty level of examinations.

Phase III

VARK Style Survey: The VARK Questionnaire (Version 8.01) was distributed to each student. Based on their answers, each student was attributed a learning style corresponding to each of the VARK modalities. The purpose of this survey was to test the general claim in the literature of engineering students being primarily kinesthetic learners. Another purpose of this survey was to map individual student learning style to the initial course feedback received, and resources utilized by students. This combination was done to contextualize the use of student learning styles in engineering course design.

Focus Groups: Once the course was over and the surveys were answered, in-person group interviews with students were conducted to obtain feedback and understand their experience in their own words. Students were divided into 4 focus groups. The two questions posed to the students were:

Q1: While studying for the mid-term exams and completing homework assignments, what resources did you find helped you the best?

Q2: During the design portion, what resources did you use to reference theory & to troubleshoot in BioWin?

Findings

The following are the results of the Course Feedback & Resources Survey. Each question was rated using a Likert Scale ranging from 1 to 5, with 1 corresponding to 'Strongly Agree' and 5 corresponding to 'Strongly Disagree'. This survey had an 86% response, with 19 students of 22 from the cohort filling it.

Mode of Instruction: The preferred mode of instruction was in-person, with most students preferring to work with their peers during class to solve problems as opposed to solving them alone. This also highlights the importance of teamwork in an engineering classroom, which is reflective of an engineering work environment. Engineering often demands a collaborative environment, and fostering cooperation at an early educational level is a good recipe to set students up for success. It is also essential to note that while in-person attendance was mandatory, lectures were recorded for subsequent viewings. Additionally, students were granted a percentage of excused absences. If additional absences were required, students were allowed to make up for them by providing a commentary on the material taught within a stipulated time period. Figure 5 shows the distribution of student preferences with respect to mode of instruction.

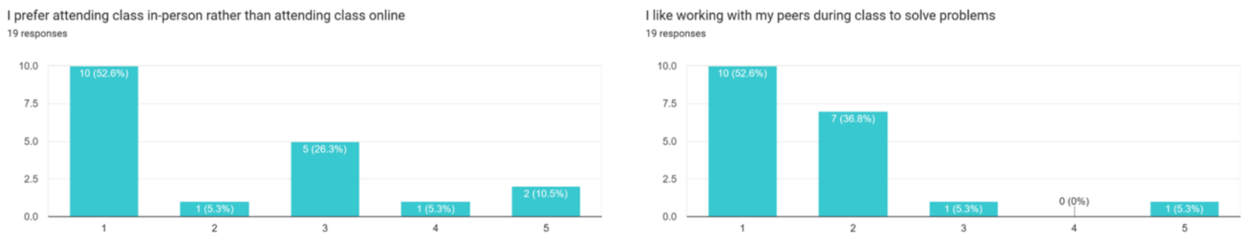

Figure 5: Mode of Instruction Preferences

Course Content Organization: Having a well-organized LMS reduces the cognitive load placed on students while accessing course resources. Additionally, it allows students to fully utilize resources if they have no trouble finding what they are looking at. Another factor for consideration is the mental models arising out of the organization of content and the sequence of delivery. Figure 6 shows the course content organization satisfaction of students. There is shown to be higher retention when students are able to link the readings, in-class lectures and activities, homework, and design assignments. This allows for smooth flow and increases possibility of connection and synthesis.

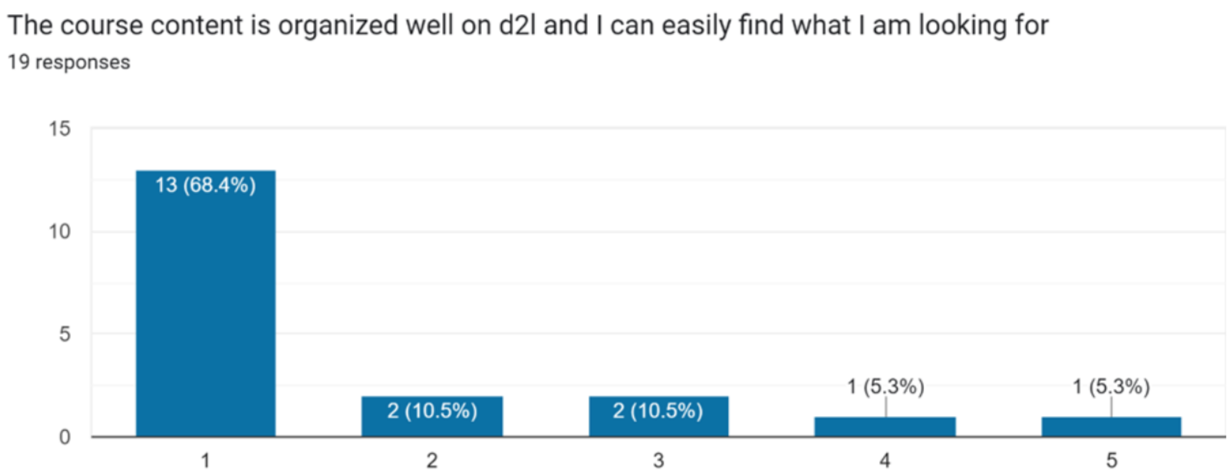

Figure 6: Course Content Organization Satisfaction

Student Learning Styles: This section of the survey contained generalized questions aimed at understanding student preferences with respect to receiving information, as well as specific examples to gauge student preferences within offered course resources. Through answers, it was clear that most students preferred complex problems, such as those found in engineering education. Additionally, methods like note taking, and rewatching lectures as opposed to reading theoretical material were preferred by most students.

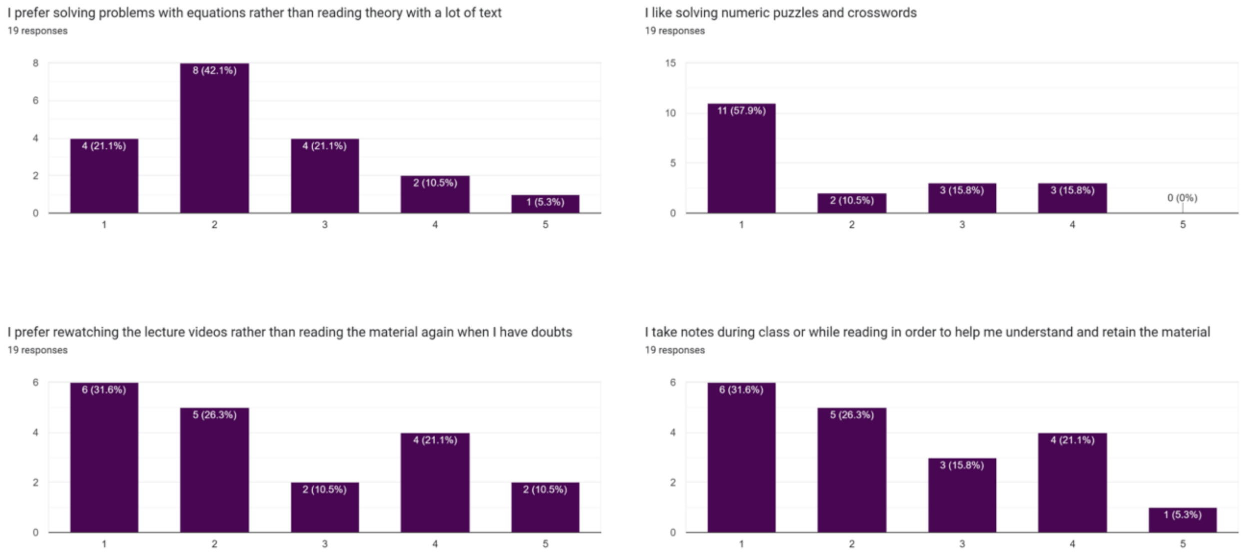

Figure 7: Student Learning Preferences

Student Course Feedback: These questions aimed to gauge the way students felt about the course. The hypothesis this project was based on was that the course design was robust and sufficient, and the resources provided were sufficient to allow students to mee the learning outcomes. This was validated by the answers received, and demonstrated in Figure 8. Most students felt comfortable completing the readings before class, and that the resources provided to them to be successful in the midterm exams and BioWin project, were sufficient. Though students may have preferred certain resources to others, this exercise in validation demonstrates the sufficiency of the course material provided.

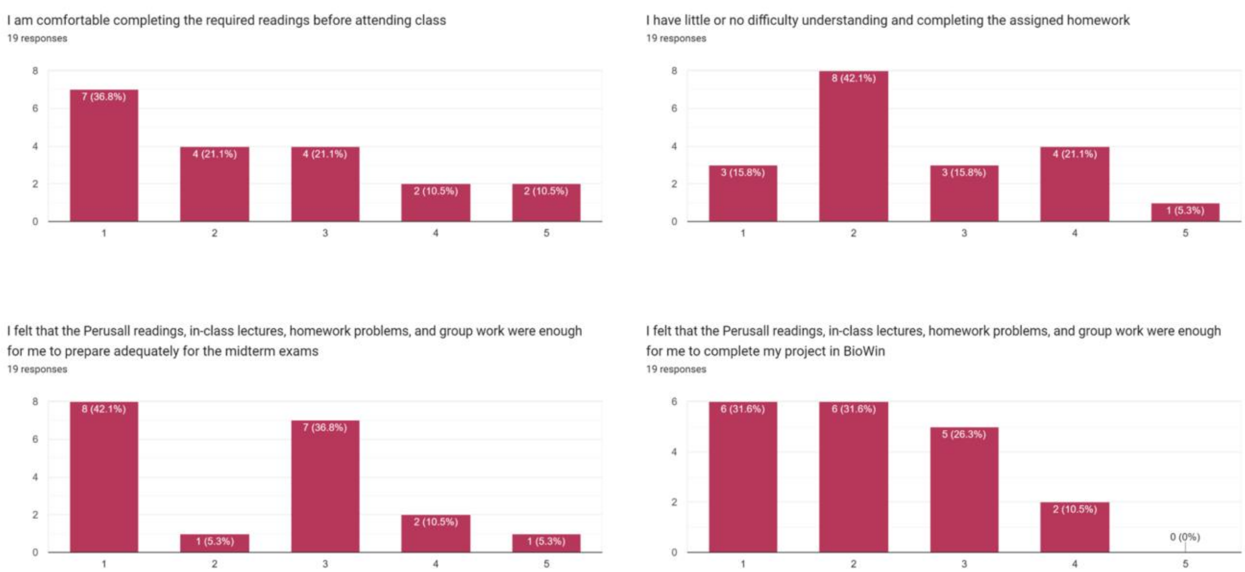

Figure 8: Student Course Feedback

Supporting Student Learning: The role of the educator is to equip students with the necessary tools for success. In a well-designed course, the instructor aids the students in their learning journey but does not spoon-feed them. The results in Figure 9 display the desire that students have to work on problems by themselves, and only if unsuccessful, approach their instructor. It is important to be available to students when they need it but also gives them room to try themselves.

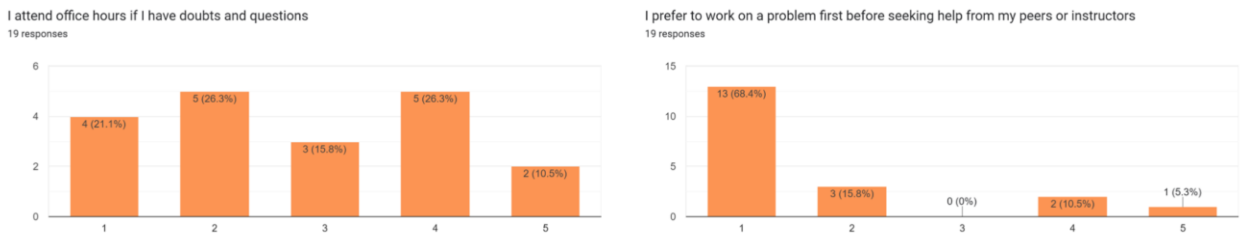

Figure 9: Feedback on Course Instructor by Students

VARK Style Survey: Each student was given version 8.01 of the survey, with a total of 16 multiple-choice questions. This survey had a 100% response, with all 22 students from the cohort filling it out. Each choice in each question corresponded to a learning modality (visual, auditory, reading/writing, & kinesthetic). A total score was provided to each modality, and the modality with the highest score was attributed to the corresponding respondent. Students with equal score in two or more modalities were classified as multimodal learners. The percentage classification of students according to learning modalities is catalogued in Figure 10 and Table 2 shows the distribution by numbers.

Figure 10: Student VARK Learning Style Distribution Percentage

VARK Type	Number of Students
Visual	2
Auditory	0
Reading/ Writing	1
Kinesthetic	17
Multimodal	2

Table 2: Student VARK Learning Style Distribution

Focus Groups: All students in the cohort participated in the focus group sessions. Groups were demographically divided, and the interviews were conducted after both the theory and design portions were completed. The sessions were conducted on Reading Day, and the only remaining submission was the final design project. This allowed students to reflect on the course as a whole, and provide their feedback independent of final grades received.

The focus groups were divided as follows:

- Focus Group 1: 7 Undergraduate Students
- Focus Group 2: 7 Undergraduate Students
- Focus Group 3: 4 Graduate Students
- Focus Group 4: 4 Students (Asynchronous)

The main opinions shared were as follows:

- The majority of students seemed to like to mandatory attendance policy, as they believed it to motivate them to attend class and work with their peers. Since a majority believed that working with their peers allowed them to build on each others' competencies, this made a case for active learning and in-person involvement in engineering education.
- The grading of the course followed a pass/ fail system. Students agreed in unison that this grading system took the pressure of performing tasks for grade points, and allowed them to be immersed in the learning experience. However, opinions on this system specifically for the midterms were polarized, with some students in favor and others against. The ones in favor shared the opinion of the reduction in pressure to perform allowing them to do better in the test. The ones opposed to it added that while they favored the pass/ fail grades in all other course components, they wished the midterm had specific points so as to serve as motivators to push harder. This observation was interesting, because it allows for a clear display of the diversity in opinion.
- Students were generally appreciative of the readings assigned, as they believed it provided them with a basis for understanding the concepts. When it came to revising the material however, they mainly relied on lecture slides, in-class notes, and homework. Thus, this demonstrated the flow of method of instruction that students utilized.
- Something that stood out was the general consensus on 'Character Growth Assignments'. These assignments were optional and allowed students to make up for grades missed in other sections. Students seemed to unanimously agree that these assignments helped them reflect on themselves and their journey.
- As for their design project, most students felt equipped to design a wastewater treatment plant at this point in the semester. The resources that they relied on when in doubt was mainly the BioWin tutorials, lecture slides, and homework assignments. The BioWin tutorials covered individual portions of the WWTP and hence allowed students specific troubleshooting. In addition, the BioWin FAQ Guide provided them with quick solutions to any issues they may have with the software. Overall, students did not seem to struggle with the tool. As for integrating concepts, the majority felt that the in-class exercises and homework assignments involving problems allowed them to integrate multiple concepts, which is a crucial aspect of engineering design.

Resources Utilized by Students: With a combination of quantitative and qualitative data, as well as observations of teaching and learning, & analysis of course design, both research questions were studied. Figure 11 gives the distribution of preferences of students of the learning resources offered. The primary conclusion followed that the majority of were classified as kinesthetic learners, which demonstrated that rigid classification into univariate modalities is often not representative of a real-world multi-disciplinary engineering classroom environment. Additionally, the reliance on learning materials was found to be more dependent upon the factors of information conveyed and desired synthesis and translation than individual learning style classification. This is to say that it is more important to match the learning resource with the desired learning outcome than student learning style.

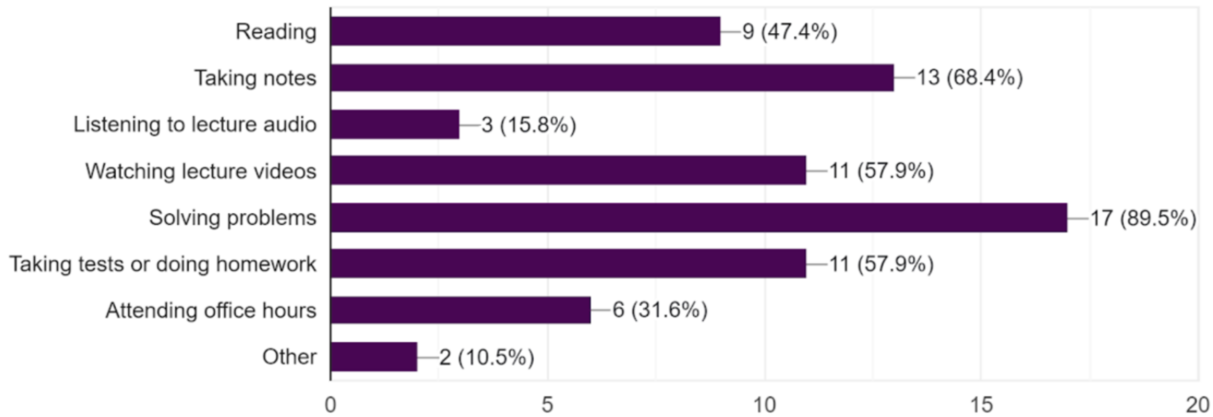

Figure 11: Course Resource Preference by Students

Discussion and Future Scope

The aim of this project is not to present data in a silo or claim the superiority of a single learning theory. Instead, the primary message is that context is key. The theory of individual learning styles on its own may be debated, but when combined with learning content and modes of instruction, it becomes a useful tool for course design. A merit of this theory is the inclusion of diverse perspectives. In this project, though the majority of students of the course were found to be kinesthetic learners, there were a few students that fit into other modalities as well. When aggregated, this formed a significant proportion of the population, at least in the context of an upper-level engineering classroom. By considering diverse perspectives, course design allows for inclusivity. Catering to different learning challenges requires a mixture of flexibility and rigidity.

Another significant observation was the importance of collaboration. Facilitating a collaborative environment in which students may explore problem spaces themselves & with their peers is essential for understanding and long-term retention. There is ample evidence in pedagogy of active learning being a direct contributor to student success. This, then, is an example of how student learning preferences, learning styles, and method of instruction is aggregated for success.

A key observation throughout the duration of this course was the role of the instructor. The course instructor was observed to be an outstanding support and resource to his students. His malleability and willingness to adapt to the needs of the students allowed him to be approachable and reliable. Further, the course design being rooted in experience based teaching methods and pedagogical foundations allowed to maximize potential learning and also adapt to the dynamic challenges of the classroom environment.

The final note is that reflection in individual teaching practices allows for a deeper understanding of what may have worked, what may have not, and what could be done better. Reflection not only makes us better instructors, but better people. When in doubt, the science of pedagogy may contain answers to building the classrooms of the future and instilling in students the lifelong gift of learning.

References

1. Litzinger, Thomas, et al. "Engineering education and the development of expertise." *Journal of engineering education* 100.1 (2011): 123-150.
2. Dym, Clive L. "Design, systems, and engineering education." *International Journal of Engineering Education* 20.3 (2004): 305-312.
3. Claris, Lionel, and Donna Riley. "Situation critical: critical theory and critical thinking in engineering education." *Engineering Studies* 4.2 (2012): 101-120.
4. Wymore, A. Wayne. "Systems movement: autobiographical retrospectives." (2004): 593-610.
5. Brunhaver, Samantha R., et al. "Bridging the gaps between engineering education and practice." *US engineering in a global economy*. University of Chicago Press, 2017. 129-163.
6. Crawley, Edward, et al. "Rethinking engineering education." *The CDIO approach* 302.2 (2007): 60-62.
7. Crawley, Edward, et al. "Rethinking engineering education." *The CDIO approach* 302.2 (2007): 60-62.
8. Davis, Kirsten A., Alejandro Salado, and Thomas A. McDermott. "Lessons learned from a first attempt to teach systems engineering as a studio art class." *2019 ASEE Annual Conference & Exposition*. 2019.
9. Gutierrez-Bucheli, Laura, Gillian Kidman, and Alan Reid. "Sustainability in engineering education: A review of learning outcomes." *Journal of Cleaner Production* 330 (2022): 129734.
10. Perrenet, Jacob C., Peter AJ Bouhuijs, and Jan GMM Smits. "The suitability of problem-based learning for engineering education: theory and practice." *Teaching in higher education* 5.3 (2000): 345-358.
11. Pritchard, Alan. Ways of Learning: Learning Theories and Learning Styles in the Classroom. United Kingdom, Taylor & Francis, 2013.
12. Prithishkumar, Ivan J., and Stelin Agnes Michael. "Understanding your student: using the VARK model." *Journal of postgraduate medicine* 60.2 (2014).