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Essentials of the Nurse + Engineer: Chemical Engineers and Healthcare Devices

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Essentials of the Nurse+Engineer: Chemical Engineering Devices

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Abstract

Increasingly, nurses and engineers are working together in teams in the classroom, in research, and in practice to improve health for patients – including individuals, families, and communities. To support the integration of engineering and nursing, a series of three interconnected laboratory modules were used to introduce interprofessional co-design of chemical engineering processes and devices. These modules are part of an existing graduate class teaching biological principles of environmental engineering, which is available to meet the degree requirements of graduate students in chemical engineering, environmental engineering, as well as nursing (via distance education). Results of end-of-semester summative evaluations suggest that interprofessional (graduate) students generally appreciate the opportunity to work together at the interface of diverse disciplines to solve problems through a convergent approach. As described previously, the nurse+engineer is an emerging V-shaped professional who shows potential to build a better future. The results of this study highlight the importance of interprofessional co-design as an essential skill of the nurse+engineer.

Introduction

According to the American Institute of Chemical Engineers (AIChE) – the lead society for ABET accreditation of chemical engineering and similarly named programs – chemical engineers help people live longer, healthier, and more productive lives through advancements in biomedicine, including the development of diagnostic devices (i.e., for measuring illness) as well as therapeutic devices (i.e., for curing illness). In support of this professional objective, the ABET program criteria for training students enrolled in chemical and similarly named programs states that, "…Programs with biochemical, biomolecular, or similar modifiers in their titles must also include **biologically based engineering applications** [emphasis added] in their curriculum…" [1]. Thus, students of chemical engineering who pursue "biomedicine" must be trained in applications of biology in healthcare.

One way to accomplish this training is through the formation of interprofessional teams of chemical engineers and healthcare professionals working to translate technology from the laboratory to the field (i.e., clinical bedside, home, or community) where it may support patient health [2]. While students of chemical engineering may be trained in partnership with physicians, there are multiple benefits to training with nurses including linking theory and practice [3], identifying new theory [4], working on common goals [5], working in communities [6], and sharing professional approaches [7].

Nursing represents the single largest healthcare profession, and nurses invest substantial time caring for and educating patients in self-care (i.e., including the proper use of devices). Nurses define “patient” more broadly than physicians; a nursing patient could be an individual, a family, a population, or a community. Thus, interprofessional training with nurses provides an opportunity for students of chemical engineering to consider a broad definition of the ethical obligation to protect the health, safety, and welfare of the public. Partnering students at a similar level of educational attainment may facilitate successful team interactions. For example undergraduate students of chemical engineering teamed with undergraduate students of nursing may be a more appropriate as compared to partnering undergraduate students of chemical engineering with physicians already in professional practice. Individuals with similar educational attainment (and perhaps similar ages) may be better suited to partner together as co-inventors.

Interprofessional collaboration among nurses and engineers has been described extensively in the literature [8, 9, 10 11]. In particular, a strong case has been made that nursing should be considered as a part of STEM, or science, technology, engineering, and math [12, 13, 14, 15]. A recent systematic review of the literature identified more than 50 peer-reviewed publications describing teams of engineers and nurses working together [16]. Approaches to cross-training nurses and engineers have been described [17], and conceptual frameworks explaining the benefits of nursing and engineering collaboration have been proposed [18, 19].

Previously, we reported on educational innovations to teach students of engineering about devices with biomedical applications [20, 21, 22]. These teaching efforts included the development of devices in the laboratory [23], the deployment of these devices to the field (in this case, the community environment) [24], and the ongoing improvement of devices to promote human health [25]. These efforts incorporated high school teachers as well as historically underrepresented student populations to learn about and become involved in device development [26]. These prior efforts targeted long-standing problems of sustainable development including secure access to safe supplies of food and water [27, 28, 29, 30], the alleviation of poverty from participation in the information economy [31], and access to insurance to protect capital against loss associated with changing patterns of extreme weather [32].

Over the past decade, we have promoted intentional engagement among interprofessional teams of students of engineering and students of nursing working from the bedside and into the community, local to global [33, 34]. These efforts have included promoting sustainable development [35] to leave no one behind [36] as well as the role of nursing to provide empathy as part of STEMpathy – or the integration of caring into the STEM professions [37, 38].

In the current article, we share the results of a teaching module where “introduction to engineering a molecular biology procedure” is included as part of a graduate-level elective course, which is available to meet the degree requirements of graduate students in chemical engineering, environmental engineering, as well as nursing (via distance education). The course that includes the teaching module is hosted by the Missouri University of Science and Technology (S&T), a large, public, Midwestern university, and available via distance to students enrolled at three additional campuses of the University of Missouri System, including the University of Missouri Columbia (aka, Mizzou), the University of Missouri Kansas City (UMKC), and the University of Missouri St. Louis (UMSL). This article includes a description of the course modules, representative student feedback on end of semester course evaluations, and views on how educators of chemical engineering may pursue collaboration with nursing educators to facilitate interprofessional teams of students to learn from the co-creation process. The results of this study highlight the importance of interprofessional co-design as an essential skill of the nurse+engineer.

Methods

Institutional context. Established in 1870 as the Missouri School of Mines and Metallurgy, today's S&T is a comprehensive public research university located in Rolla, Missouri. The undergraduate enrollment is approximately 5,500 students and the graduate enrollment is approximately 1,500 students. Currently characterized as Carnegie R2, a doctoral university with high research activity, S&T provides approximately 100 degree programs, which span from computing and engineering to arts, sciences, business, and education. For the purposes of this article, it is important to note that the College of Engineering and Computing (CEC) includes a Department of Chemical and Biochemical Engineering (CBE), which offers a Baccalaureate degree in Chemical Engineering, a Baccalaureate degree in Biomedical Engineering (starting Autumn 2024), a master's degree in chemical engineering, a PhD in Chemical Engineering, as well as a Graduate Certificate in Carbon Management Engineering or Chemical Process Engineering.

Course description. The modules described in this article are included as part of 6601, "Biological Principles in Environmental Engineering Systems," which, "covers the fundamental biological principles and biochemical processes involved in natural and engineered biological systems." Hosted by the Department of Civil, Architectural, and Environmental Engineering (CArE), 6601 includes two semester credit hours of lecture (two contact hours per week for 15 weeks) and one semester credit hour of laboratory (three contact hours per week for 15 weeks). As described previously, the course is offered using a blended, flipped, modified mastery format where mixed content (digital and non-digital) is reviewed by students prior to meeting with the instructor [39, 40]. Before meeting with the instructor, students complete required assignments focused on low-level Bloom's taxonomy (i.e., remembering, understanding, and applying). In class, the lecture-discussion format is open-ended, problem-based, and focused on mid-level Blooms' taxonomy (i.e., analyzing and evaluating). As part of modified mastery learning, students may complete optional assignments to earn academic credit that counts towards a grade of "B" or "A". These optional assessments are focused on high-level Bloom's taxonomy (i.e., creating). Enrollment in this course is optional to complete degree requirements for an existing master's degree in environmental engineering, and the course is open to graduate students in CBE as well as graduate students from the University of Missouri System, including students from the Sinclair School of Nursing at Mizzou.

Course content. As a textbook, CArE 6601, employs the most up to date version of "Brock: Biology of Microorganisms," which is currently in the 16th edition and most recently updated in 2020.

Modules descriptions. A total of six laboratory modules are included as part of CArE 6601. These include: 1) construction of Winogradsky columns; 2) delivering a Pecha Kucha presentation on the life and work of Professor Carl Woese; and 3) evaluating qualitative microbial risk assessment (QMRA) on a situation selected by each student. The remaining three laboratory modules are integrated to offer students an opportunity to link lecture learning with field learning/application, and these three modules are the subject of the current article. These three modules include: 4) DNA sequence comparison and oligonucleotide probe design; 5) application of 16S rRNA-phylogenetic analysis to identify, enumerate, and localize bacterial populations in wastewater treatment or recreational waterways; and 6) performing the full-cycle 16S rRNA-approach on a sample selected by the students. A detailed description of each of these three modules are included as Appendix A, B, and C, respectively.

As part of the overall learning objectives of CArE 6601, these three lab modules – DNA sequence comparison, application of 16S rRNA, and performing full-cycle 16S rRNA approach – is intended to support the following course learning:

a) linking microbial biochemistry – stoichiometry and kinetics – with reactor design and operation (e.g., sewage treatment system, human gastrointestinal tract, and recreational waterways);
b) exploring how the full cycle 16S rRNA approach is used to identify, enumerate, locate, and assess the metabolic (anabolic plus catabolic) activity of phylogenetically defined bacterial populations; and
c) coupling the function of microbial populations with the structure of the microbial community using devices developed in the laboratory and deployed in the field (e.g., to monitor environmental and clinical applications).

Together with associated lectures, these three labs provide an "introduction to engineering a molecular biology procedure" as part of an interdisciplinary team focused on co-creation.

<u>Instructor evaluation.</u> An online, end-of-semester student evaluation of instructor teaching is performed by S&T, and anonymized results are shared with the instructor for self-improvement and institutional administration as data for faculty annual evaluation. A Likert-scale from 0.0 to 4.0 is used to assess the question, "This instructor was an effective teacher," (i.e., 0.0 – not effective at all; and 4.0 – highly effective). In addition to Likert-scaling, a series of open-ended questions invite student feedback. These questions include, "With regard to teaching, what are the strengths of this instructor?"; "What suggestions do you have for improving the quality of instruction?"; and "What are the strengths and weaknesses of the instructor?"

Results

The course, CArE 6601, is offered every autumn semester to students on-campus at S&T as well as via distance to students attending remotely. Laboratory exercises include a combination of work that may be performed using a "kitchen lab approach" (i.e., the construction of Winogradsky columns may be performed using a variety of readily available household materials). For the more "equipment intensive" laboratory exercises, teams of students – including distance combined with students on-campus – complete assignments together sharing data. This format, student-teaming, helps to facilitate the interprofessional collaboration among students from different degree programs.

The course, CArE 6601, has been offered since autumn 2015. As shown in Table 1, enrollment from autumn 2015 through autumn 2023 included a total of 83 graduate students. The smallest enrollment included five students in autumn 2015 and autumn 2016, and the largest enrollment included 17 students in autumn 2023. Given the small number of students, all results are presented in aggregate to eliminate the possibility of inadvertent identification of any specific student.

Table 1. Total enrollment of students in CArE 6601, average end-of-semester evaluations of teacher effectiveness, and selected student comments provided on open-ended questions used to gauge strengths and weaknesses of the instructor and course.

Year[a]	#[b]	Score[c]	Comments[d]
2015	5	4.00	a) Strength: Develops understanding of biological process of microbial communities and applies those concepts to real world situations through the lab.
2016	5	3.50	No comments.
2017	14	3.75	b) Weakness: Why is there even a lab for this class? We pay lab fees, but it seems like it's all integrated into one big lab. Offer more hands on activities.
2018	6	4.00	c) Strength: Very good application to engineering compared to other such course I have taken, because often microbiology courses turn into pure microbiology and lose sight of the application.
2019	7	4.00	No comments.
2020	9	3.75	d) Strength: Good change from typical plug-and-chug engineering course because of the application in collaboration with health.
2021	12	3.75	e) Strength: Lab report format was clear and did not waste time on formatting and other clerical issues – lab material went perfectly with lecture allowing students to learn in a different format. f) Weakness: I wanted more real-time lab experiments and less combination working in lab and thinking of lab outside of the laboratory.
2022	8	4.00	g) Strength: Instructor knows how to thoroughly explain content, connection between concepts, and application to real world including health.
2023	17	3.75	h) Strength: The lab exercises are good for understanding what we are learning from the lectures, and we had a flexible schedule to complete our lab assignments. i) Mixed: More work than most classes, but instructor was extremely well organized and content was well connected, which motivated students to learn in lab. j) Weakness: More focus on engineering and less focus on health would be helpful to my career.

a. CArE 6601 was offered in the Autumn semester, annually
b. Number of enrolled students
c. Average instructor effectiveness (scale of 0.0 to 4.0)
d. Representative student comments

Table 1 includes a numeric score of instructor effectiveness and can range from a minimum of 0.0 to a maximum of 4.0. Typically, the average for all faculty at S&T is approximately 3.25 and the average for all faculty in the CArE department is similar (i.e., 3.25). Typically, the instructor of CArE 6601 scores an overall average for all courses offered of approximately 3.5 every semester, including a combination of required undergraduate course instruction, upper level electives, and graduate-only instruction. The instructor's score specific for offering CArE 6601 varied from a low of 3.5 on the second offering and included four of nine offerings with a perfect score of 4.0. It is important to note that student evaluations of faculty teaching often include bias, which can be related to the scheduled course time, instructor gender, age, and nationality, as well as other sources of bias related to the demographics of the students. Thus, what should be gleaned from these scores is that the instructor is viewed favorably by the students enrolled in this course.

Table 1 incudes representative comments provided by students in response to open-ended questions regarding strengths, weakness, and opportunities for improvement of instruction. As participation in providing comments was optional, there is no way to ensure data saturation, and therefore, the qualitative nature of the comments and the limitations of the instrument are important to recall when considering each comment individually as well as collectively.

From the comments, some students felt that the laboratory content and the lecture content were mutually reinforcing (i.e., Table 1, comment h) and that the laboratory content connected to "real world applications" (i.e., Table 1, comment a). At least two students were dissatisfied with the "integrated" nature of the labs (i.e., Table 1, comments b and f), and at least one student was dissatisfied with the interprofessional approach to engineering plus health (i.e., Table 1, comment j). Overall, the generally positive nature of the comments and the generally satisfactory Likert-scale scores suggest that the students enjoyed both the course content and the approach integrating engineering and health as part of linked laboratory exercises.

Discussion

The ABET program criteria for chemical, biochemical, biomolecular and similarly named engineering programs specify that the curriculum must include, "engineering applications of these sciences to the design, analysis, and control of **processes** [emphasis added]…" [1]. The ABET program criteria for bioengineering and biomedical and similarly named programs specify that the curriculum must include, "experience in analyzing, modeling, designing, and realizing bio/biomedical engineering **devices, systems, components, or processes** [emphasis added]…" [1]. This subtle difference means that a curriculum that teaches students about "process" is acceptable both to chemical as well as to biomedical program criteria, whereas an exclusive focus on a "device" would satisfy biomedical (but perhaps not satisfy chemical) program criteria. The integrated laboratory sequence included in CArE 6601 is designed with intentionality to include a link between process engineering, microbial ecology, and the use of molecular biology-based techniques to provide measures of bacteria, which may be integrated into conceptual and mathematical process models [41, 42, 43, 44, 45, 46]. The "chemical engineering device" that is co-designed in CArE 6601 is more an overall "process" and less a "physical device". None the less, the molecular biology-based techniques included in the laboratory employ a variety of "physical devices", which are subject to the opportunity for continuous improvement and better integration.

Recently, co-authored articles including nurses and engineers have highlighted the benefits of collaborations among interprofessional teams [47]. It is argued that one of the benefits of such an approach is to facilitate innovation at the interface of the disciplines [48]. There are emerging examples of biomedical engineers cross-training in nursing for the purpose of building the necessary bridges among the disciplines for the explicit purpose of improving health outcomes for patients [49], and faculty are being encouraged to promote the nurse+engineer partnership in the classroom, in research, and in practice [50]. Table 2 provides a partial list of readily available, on-line resources that the reader may use to learn more about the emergence of the nurse+engineer partnership.

Table 2. Partial list of available resources for the nurse+engineer.

Item	Details
1	https://nurseengineer.com maintained by Kelly Landsman
2	Duquesne University dual BS in biomedical engineering and BS in nursing, [Online] Available: https://www.duq.edu/academics/colleges-and-schools/nursing/undergraduate-programs/bme/bsn-dual-degree/index.php
3	Elaine Marieb Center for Nursing and Engineering Innovation, [Online] Available: https://www.umass.edu/engineering/organizations/marieb-center-nursing-and-engineering
4	Florida Atlantic University BS in nursing and MS in biomedical engineering, [Online] Available: https://nursing.fau.edu/admissions/bachelor-of-science-nursing-program/freshman-direct-admit/bsn-bio-eng/
5	University of Connecticut Nursing and Engineering Innovation Center, [Online] Available: https://nursing-engineering-innovation.center.uconn.edu
6	Johns Hopkins University graduate study in Healthcare Systems Engineering, [Online] Available: https://e-catalogue.jhu.edu/engineering/engineering-professionals/healthcare-systems-engineering/

While the current article highlights the benefits of chemical engineering students partnering with the profession of nursing with an eye towards device development for diagnostics and therapeutics, the essentials of the nurse+engineer include convergence among the disciplines with an eye towards tackling grand challenges for humanity and the planet that remain unsolved in the twenty-first century [5]. For example, nurses and engineers may promote an improved understanding of finance and economics, which has a benefit to practitioners in each discipline as well as the patients – individuals, families, and communities – served by both professions [51, 52, 53]. Lessons learned during the first few years of the COVID-19 endemic highlighted ways that engineers and nurses should work together to promote effective risk communication [54], encourage proper hygiene when using face masks [55], promote resilience to future health threats by centering individual patients [56], and achieve a global response network through science diplomacy [57]. And recently, nurses and engineers have speculated on the opportunity to empower and support individual decision making as a way to achieve improvements in population and community health leveraging the simple example of fluoridation of drinking water and proper oral hygiene [58].

This article shares details of laboratory modules where "introduction to engineering a molecular biology procedure" is included as part of a graduate-level elective course. Although limited, the results presented in this article strongly support the conclusion that interprofessional (graduate) students generally appreciate the opportunity to work together at the interface of diverse disciplines to solve problems through a convergent approach. Chemical engineering educators are encouraged to look for ways to collaborate with nursing educators to build interprofessional teams co-designing devices and processes. The results presented in this article are similar to prior results, which show that effective training of chemical engineers in applications of biology in healthcare includes interprofessional teaming with nurses to translate technology from the laboratory to the field where it may support patient health [2].

Conclusion

While engineering and nursing are acknowledged to be different in practice and in education [7], the opportunity for interprofessional teaming to improve outcomes for human health offer a compelling reason to collaborate to build a better future for everyone [34]. Consistent with prior reports, the results presented in this article strongly support the conclusion that interprofessional (graduate) students generally appreciate the opportunity to work together at the interface of diverse disciplines to solve problems through a convergent approach. The results of this study highlight the importance of interprofessional co-design as an essential skill of the nurse+engineer.

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Appendix A.

Course: CArE 6601
Lab: 4 DNA Sequence Alignment and Construction of Taxonomic Tree
Document: Instructions

The objective of this unit is to learn sequence alignment and the construction of a taxonomic trees through a hands-on exercise. The results will be used to learn how to design an oligonucleotide probe targeting a specific clade.

By the end of this units, students should:

1. Recall how to use automated systems (i.e., BLAST) to align sequences
2. Describe the process for calculating distance matrices
3. Apply proper sequence alignment and distance matric calculation to construct a taxonomic tree (i.e., using neighbor joining)
4. Differentiate the quality among taxonomic trees using primary, secondary, tertiary, and quaternary sequence data
5. Create a tree
6. Defend the tree you created to peers

Suggested resources include:

1. Khan Academy available at: https://www.khanacademy.org/science/ap-biology/natural-selection/phylogeny/a/building-an-evolutionary-tree
2. A. Harrison, Tender is the Byte [Blog] available at: https://www.tenderisthebyte.com/blog/2022/08/31/neighbor-joining-trees/
3. Oxford Academy (YouTube) available at: https://youtu.be/09eD4A_HxVQ

Exercise:
Sequences to consider:

```
Seq A UUCGU CUGUA GGUUU CCACC AA
Seq B ACAUU CGUGU AUAGG UUUCC ACUAA
Seq C ACAUU CGUGU AGAGG UUUCC AC
Seq D AAGUU CGCUA GGUUU CCACG AA
Seq E CGUGA GAUCC AGGUA UCCAC A
```

1) Align The Sequences
    a. Recall, the starting and ending of the sequences may be different
    b. Recall, there may be insertions/deletions internal to the sequences
2) Create A Distance Matrix Using Identical Positions
    a. Count the fraction identical nucleotides at each common position
3) Assign Relationships Based Upon Distance Matrix
    a. The easiest approach is the "neighbor-joining method" which simply begins with the two most common sequences; collapses these into a single node; and then proceeds to include the next most common sequence. With each step, the number of sequences to consider for the Distance Matrix becomes fewer and fewer.

Submit a copy of your final tree along with your calculated distance matrices and your sequence alignment.

Together, we will discuss these in lecture and use these data as input in our process to design an oligonucleotide probe targeting a specific clade.

Appendix B.

Course: CArE 6601
Lab: 5 Kinetics and Stoichiometry Applied to Built- and Natural-Systems
Document: Instructions

The objective of this unit is to connect the concepts of microbial metabolism (anabolism and catabolism) with concepts of mass balance and reactor configuration.

By the end of this units, students should:

7. Explain the concepts of
    a. Electron donor/Electron acceptor couple;
    b. Carbon source; Nitrogen source; Phosphorous source;
    c. Biomass production and production of Waste products as part of:
    d. an overall, balanced stoichiometric reaction of biomass growth and substrate consumption
8. Use your understanding of the concepts of 1 = fs + fd, where fs is the fraction of electrons to biomass synthesis and fd is the fraction of electrons to terminal electron acceptor (aka biomass yield, or Y), to link mass balance and microbial metabolism
9. Defend a reactor configuration using the concepts of competitive microbial growth rates where mumax and Ks strategies create selective advantages for the growth of different types of microorganisms

Suggested resources include:

4. D. Jenkins, M.G. Richard, and G.T. Daigger, *Manual on the Causes and Control of Activated Sludge Bulking, Foaming, and Other Solids Separation Problems, 3rd Ed*. Boca Raton, FL: CRC Press, 2003.
5. PDF entitled, "371hw09s," which begins, "Consider the design of a wastewater treatment plant (WWTP) for a community with average daily and peak hourly wastewater design flows of 2.0 MGD and 5.0 MGD. The raw sewage has an average of 230 mg/L BOD5 and 260 mg/L of suspended solids."
6. The appendix in Brock Biology of Microorganisms.

Exercise:
Consider ONE of the Selector Case Histories described in Jenkins et al beginning on page 120. Your assignment is to convert ONE of these case histories into a "good" final exam-type question testing the concepts of microbial energetics and kinetics studied during the accompanying course unit. An example of the type of question typically asked on a final exam is provided in the attached file entitled, "371hw909s.pdf". Please note: this example question is actually a "homework" problem, and therefore is "more involved" than a typical final exam question. There, use this template as "harder than" the type of question you should generate. Be sure that you link your questions to the learning content available in the appendix in Brock Biology of Microorganisms. After you have generated your question, you also need to create a solution.

Your assignment is to submit both the question and the solution.

Together, we'll solve these as a class and compare answers to the solution you provide.

Appendix C.

Course: CArE 6601
Lab: 6 Full-cycle 16S rRNA-approach on a bioreactor of your choice
Document: Instructions

The objective of this unit is to couple process engineering understanding, microbial ecology (structure/function), and molecular phylogenetics (tools to identify, enumerate, and locate targeted populations) to optimize bioreactor performance.

By the end of this units, students should:

1. Use 16S rRNA tools to:
    a. isolate DNA
    b. PCR amplify 16S rDNA genes
    c. clone, sequence, align and design a probe
    d. identify bacterial populations in a sample
2. Use process engineering understanding to create a schematic of a bioreactor operation
3. Defend why specific populations occur in the bioreactor

Suggested resources include:

1. S. Juretschko et al, "The Microbial Community Composition of a Nitrifying-Denitrifying Activated Sludge From an Industrial Sewage Treatment Plant Analyzed by the Full-Cycle rRNA Approach," *System. Appl. Microbiol.*, vol. 25, pp. 84-99, 2002.
2. M.P. Ginige et al, "Use of Stable-Isotope Probing, Full-Cycle rRNA Analysis, and Flourescence In Situ Hybridization-Microautoradiography to Study a Methanol-Fed Denitrifying Community," *Appl. Environ. Microbiol.*, vol. 70, pp. 577-596, 2004.
3. Y. Kong et al, "Structure and Function of the Microbial Community in a Full-Scale Enhanced Biological Phosphorous Removal Plant," *Microbiol.*, vol. 153, pp. 4061-4073, 2007.

Exercise:

Prepare a written report considering the following:

1. Providing a narrative of the overall problem – what's the problem you are studying, which type of treatment systems are susceptible, which type of microorganism is responsible. Be sure to include at least one reference from the literature that has examined this 'exact' problem.
2. Including details of typical sizes, configurations, operating conditions of the treatment system
3. Including details of the typical metabolism of the microorganism of interest
4. Including a pictorial representation of the overall system with explicit notation for reactor configuration, mixing, terminal electron donor and acceptor, micronutrients, and the identity of microorganisms through the system
5. Creating a mathematical representation of the energetics of the relevant microorganisms and the selection applied by the change in configuration of the treatment system
6. Describing how to use 16S rRNA full cycle approach to assess the presence and confirm the presence of specific microorganisms
7. Describing the lesson/s learned in the overall exercise

Submit a copy of your work.

You will be provided with a copy of a classmate's assignment. Following the prescribed grading rubric, you will grade their report, and they will grade your report. The grade from your classmate will serve as a baseline for a final grade to be assigned by the instructor after we meet together as a class to discuss all of the reports as part of a regularly scheduled lecture.