

Developing a Graduate Class on Synthetic Cells at a Minority Serving Institution: Lessons from the University of New Mexico

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Abstract

This article describes the development, methodology, enrollment and outcomes of a graduate technical elective course on synthetic cells and organelles offered at the University of New Mexico, a minority-majority institution, in Fall 2022. The course had a significant ethics component and took advantage of readily available, low cost and no-cost teaching materials that are available online. The course was effective in attracting a diverse enrollment of graduate students and senior undergraduates, some of whom participated in a survey of their background and motivations after the course was over. The article also provides results from this survey. Courses such as the one described have the potential to increase access and participation into emerging fields of research and technology such as synthetic cells.

Introduction

The assembly of particulate materials with cell-like functional characteristics (synthetic cells) from inanimate components is a current grand challenge in science and engineering that is being pursued world-wide.¹ Like traditional and emerging synthetic biology approaches, synthetic cells have potential to enable both basic research and the addressing of pressing societal problems in diverse endeavors, such as healthcare, environmental sustainability, energy production, food production and manufacturing.² This potential has been recognized by research funding agencies around the world and several significant research consortia have emerged to tackle this grand challenge, including, for example, the NSF-funded Build-A-Cell Research Collaboration Network in the U.S., BASyC Consortium in the Netherlands, and Max Planck Matter-to-Life School in Germany. The success of such research efforts will depend on the availability of a diverse and well-trained human resource pool. Likewise, the general acceptance of synthetic cell technologies will benefit by presence of an educated populace who can help demystify the field's approaches and applications. There is thus a significant need for formal educational activities in, and awareness by society in general of, synthetic cells.

Like many other emerging areas of scientific research, opportunities for participation in cutting edge research into synthetic cells is by and large limited to large research universities, leaving large swaths of the populace without accessibility to this exciting field. Such accessibility is important precisely because of the potential of such research to address looming societal problems, to which members of under-represented groups bring unique context. An unexpected consequence of the COVID-19 pandemic is that forums for scientific discourse on

synthetic cells, and most research areas in general, migrated to online virtual platforms, in some cases significantly increasing their accessibility to interested and potential participants worldwide. An example of this was the International Conference on Engineering Synthetic Cells and Organelles (SynCell20XX for short). Because of the pandemic, the first in this symposium series, SynCell2020, which was originally planned as a somewhat exclusive (limited to 150 registrants) activity, was held as a virtual conference, with over 700 participants from across 6 continents.¹ Subsequent SynCell conferences during the pandemic were virtual (SynCell2021) or had significant virtual components (SynCell2022). These virtual offerings as well as regular webinars that have been offered by the Build-A-Cell Network³ and the Max Planck School Matter-to-Life⁴ have further increased accessibility to the field of synthetic cell research.

At the University of New Mexico (UNM), we have taken significant advantage of this increased accessibility to online seminars by the world's leading researchers in synthetic cell technology. Starting from SynCell2021, we organized a formal seminar class (1 credit hour) that relied on technical content offered by the conference or the other online seminar series mentioned above. Enrolled students viewed recorded seminars at their convenience and the seminar class met once a week for organized discussion. This seminar attracted a diverse enrollment of 14 graduate and senior undergraduate students as well as several faculty-level researchers who routinely participated in the discussion.

The success of the seminar course was highlighted in NSF proposals and reports as a valuable mechanism by which to “broaden impact” of funded projects associated with projects aligned with the NSF’s Big Idea to “Understand the Rules of Life”.⁵ A significant concern of NSF programs funded to develop synthetic cell technology (e.g., “Designer Cells”) funded under the

auspices of “Understanding the Rules of Life” was that participants become aware of ethical implications of research into, and applications of, synthetic cells. As a result, a subsequent technical elective course (3 credit hours) was offered by the authors (López and Gannon) that again relied heavily on virtual content provided by leaders in the field through the Build-a-Cell webinar series, and that also had a significant component of discussion of ethical implications of synthetic cell research (led by Gannon). This technical elective is the subject of this paper.

UNM is a majority-minority, Carnegie-designated R1 institution and an Hispanic Serving Institution. A 2017 report from the Brookings Institution entitled “Ladders, Labs and Laggards: Which Public Universities Contribute Most?” identified UNM as one of the nation’s leaders in equal access to higher education, ranking 8th in universities with the most low-income students.⁶ This paper provides a description of a graduate / senior undergraduate technical elective course in synthetic cells that can be implemented with minimal resources. It takes advantage of free online course content, (YouTube™, TedX™ videos) in the form of weekly webinars by experts in the field, that is regularly updated. Implementation in minority serving institutions and other universities / colleges where students yearn for contemporary science and engineering offerings, but where instructors may lack time to develop such new courses, may significantly enhance accessibility to the field as well as provide diverse human resources to enable its development.

The Course

The technical elective course “Synthetic Cells and Organelles: Research and Implications” was developed and taught in Fall 2022 by the authors. The goal of the course was

to cover (i) recent efforts to construct synthetic cells (including minimal cells) and organelles from components, (ii) methods and technologies that enable (i), (iii) applications of synthetic cells and organelles, and (iv) ethical implications of synthetic cells, their applications and synthetic biology in general. Specific learning objectives were (i) to provide students with an advanced awareness of the technologies associated with creating synthetic cells and organelles, and (ii) to provide students with knowledge and understanding necessary to form informed opinions on the ethical, environmental and societal implications of synthetic cells and synthetic biology in general. An abbreviated syllabus for this course is provided as Supporting Information. Prerequisites included basic knowledge of biochemistry, cellular and molecular biology, and standing as a senior or graduate student in a relevant technical field (or instructor permission). The course was cross-listed and attracted students from graduate and undergraduate sections in chemical and biological engineering, biomedical engineering, nanoscience and microsystems engineering, and biology. The grading rubric for the class weighted 30% for homework, 30% for an in-class presentation, and 40% on class participation; the latter dictating that attendance was important in determining the grade.

Learning resources for the course included a textbook, selected readings available through the UNM library,^{7,8,9,10,11} free online videos, and lectures prepared by the instructors. We did not find a textbook devoted specifically to synthetic cells for our course, and so chose an excellent, affordable book on synthetic biology as an introductory reference: *Synthetic Biology, A Primer* (Revised Edition, by Baldwin et al., 2016).¹² This easy to read book provided an excellent way to establish a uniform level of basic understanding of technical concepts throughout the course. Table 1 provides a list of the free online videos assigned in the class.

Typically, viewing of the video was assigned prior to a class period where it was discussed in detail, by all students, who either voluntarily provided comments or questions or were called upon to do so.

Table 1: Online videos assigned for discussion.

Topic/Title	Speaker, Affiliation	Link
iBiology: Synthetic Cells: Building Life to Understand It	Kate Adamala, Univ. of Minnesota	https://www.youtube.com/watch?v=07KVJZUAs3U
Max Planck School Matter to Life		https://www.youtube.com/watch?v=WWvuAE5GCK
Build-a-Cell Seminar: Building Functional Biomimetic Membranes	Patricia Bassereau , Univ. of Colorado	https://www.youtube.com/watch?v=TKe1idqbM7U&list=PLb2LmjoxZO-gKWXXZadcko8tHHkPuEeJT&index=13
Build-a-Cell Seminar: Design, Construction and Analysis of a Synthetic Minimal Bacterial Cell	John Glass, J. Craig Venter Institute	https://www.youtube.com/watch?v=Qzv6j0HcNFo
TEDxBerlin: Ethics in the age of technology	Juan Enriquez, Biotechnomy	https://www.youtube.com/watch?v=iiAirfn-IBI
Build-a-Cell Seminar: Unravelling the physical chemical principles of life	Dora Tang, MPI-Molecular Cell Biology and Genetics	https://www.youtube.com/watch?v=5qnmh7paiB0
Build-a-Cell Seminar: Freeze-Dried Cell-Free Synthetic Biology	Peter Nguyen, Harvard Univ.	https://www.youtube.com/watch?v=DTJX2aOtZ9c
Life in the Universe	Interview with Carlos Mariscal (Univ. Nevada /Reno)	https://www.youtube.com/watch?v=dQoWvj4JKQk
Synthetic Biology: What is it? What challenges does it pose for ethics and public policy?	Thomas H. Murry, The Hastings Center	https://www.youtube.com/watch?v=1y4jt7oDrZI
TEDxCambridge: Supporting Underrepresented Students in Higher Ed	Éireann Attridge, Elephant Group	https://www.youtube.com/watch?v=s4mcQNmNOhs
TEDxCambridge: On Diversity: Access Ain't Inclusion	Anthony Jack, Harvard Univ.	https://www.youtube.com/watch?v=i7w2Gv7ueOc

Homework assignments throughout the semester focused on research and preparation for in-class presentation each student was to deliver toward the end of the course. Descriptions of each such assignment are presented as Supporting Information. Presentations were focused on innovations and applications of synthetic cell technology and required a design component and a discussion of ethical implications, either positive or negative, or both. Homework leading up to the presentations included submission of a research topic, an annotated bibliography, an outline, an abstract and finally, the slides for the presentation. These assignments ensured that students worked on their presentation throughout the semester and feedback from the instructors provided guidance to ensure that students were on the right track. To incorporate design components into their presentations, students were encouraged, as necessary, to try to link disparate, yet relevant, innovations in synthetic cell research described in the literature to enable a solution to a particular technological problem. Table 2 lists selected presentations delivered by the students.

Table 2: Selected student presentation topics.

Development of Universal Tissue Therapeutic Through the Paracrine Effect of Artificial Pluripotent Stem Cells
Feasibility of developing a synthetically engineered vesicle with the ability to synthesize fully and correctly folded functional hemoglobin within the vesicle given general nutrients. A first step in engineering RBCs.
The process of inserting two different types of integral proteins into synthetic membranes, a receptor and ligand, in order to facilitate endosomal delivery of engineered organelles.
Investigate the viability of a bottom-up approach to developing, replicating, and characterizing a synthetic organelle that can allow non-photosynthetic microorganisms to directly convert solar energy into electricity.

The development of artificial beta cells (ABCs) that sense hyperglycemic conditions in diabetes patients and allow for the biosynthesis and secretion of insulin.

Feasibility of creating a chloroplast-mimic for rubisco-free photosynthesis.
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The course was set up so that students could consider the technological and scientific importance of synthetic cells along with ethical and social dimensions. We provided an emphasis on ethical considerations with each class period and required that students include the ethical context in their project presentations. As part of the content delivery, we delivered discreet lectures on ethics including “ethical implications of applications”, “biosafety”, and “accessibility”. These class periods covered obvious issues such as biosafety and the environment, biosecurity and biohacking, ownership, philosophical and theoretical considerations, public value and global inequity. A number of these issues are considered in the textbook, but were also supplemented with readings from literature.

The key messages delivered to students were that biosafety awareness and practices need to be transmitted across generational, cultural, and socio-economic gaps. Moreover, risks must be considered when doing this work: unintended and unanticipated detrimental effects on human health, other life, and the environment. During class, we posed key questions such as “Who should be responsible for setting standards or determining the safety of synthetic organisms (cells, organelles)?”, “Who should bear the burden of risk?”, “How much (money, time, space) should society spend on reducing risks (or potential risks) from synthetic cells to humans (or to all species for that matter) and environment?” The views of two renowned ethicists – Peter Singer and Arthur Caplan – were also presented and discussed.^{13,14} Class members seemed to enjoy considering these things especially the idea that this technology

does, in a way, “play God”, and also in considering whether “life” can be patented (e.g., the oncomouse).¹⁵

The Students

A total of 19 students took the technical elective course, ‘Synthetic Cells and Organelles: Research and Implications’ in Fall of 2022, including 13 graduate students and 6 undergraduates from biomedical engineering, chemical & biological engineering, biology and nanosystems and microsystems engineering. This is a healthy number for new technical elective graduate classes in engineering at UNM. When asked why they enrolled, most students indicated that they were engaged in research projects related to the subject matter. Some indicated that topical technical electives relevant to their research areas were not frequently offered.

At the end of the course, we were able to gather some basic data characterizing the student demographics along with a few comments on why they enrolled in the course and what they gained from the course. Of the graduate students who were enrolled, we received comments from 9. All respondents were US citizens, but only 3 (33%) were born locally in New Mexico. All were born in the US except for one student who was from the Philippines. There was variety in the number of years the respondents had been in graduate school. Two students indicated that Fall 2022 was their first semester and one student had been in their university program for 11 years. Most respondents had 2 – 6 years enrolled as a graduate student (n = 5).

English was the primary language for 8 of 9 respondents and gender was nearly evenly split at 5 males and 4 females. Only 1 described themselves as first of their family to go to

college, and the other 8 had parents and/or siblings who had attended and/or completed degrees including graduate degrees. Most had goals to apply their graduate degrees to medical fields, “impactful publications”, development and application of novel therapeutics, “run my own lab as a PI” and “help others find a passion for research”, be prominent in the fields of microbiology or synthetic biology or biotech; one stated this was a step for him, “to go to space and beyond”.

Ethnicity of respondents was 1 African-American, 1 American Indian/Native, 1 Asian and 4 identifying as white, with 5 as Hispanic/Latinx. Students were from several academic disciplines and described themselves as having come from biomechanical engineering, biology (n = 3), chemistry, biomedical engineering, nanoscience, chemical engineering, or general engineering.

Hardships and barriers that students had to overcome were mostly financial. Student comments included, “no money as an undergrad - lots of loans”, “financing my education meant that I always had to juggle coursework with a job”. Another student added, “...but I have been able to do everything I needed to do to maintain my scholarships and support myself through my academic career.” One student mentioned the difficulty from having divorced parents/single-parent household. Another has primary responsibility as caregiver to grandmother with dementia. However, more personal issues arose including family and health, “...my journey has been made difficult due to family obligations”, “the pandemic as well as personal health issues” (made it more difficult). Some respondents mentioned disabilities as, “It is difficult for people to believe that a traumatic event can affect me so drastically, and it is even more difficult for myself to believe that others are accepting of my disabilities.” Other

issues were mentioned such as, “changing careers and going back to school”, or “obtaining a position in the lab with no experience” (has been difficult). A respondent said, “finding the right program/PI/location, understanding the limited amount of time we all have in our lives.”

When students were asked “What attracted you to synthetic cell research?”, responses fell into two categories, new field potential and how the technology mimics life. Specific comments surrounded the idea of the potential of this being a new field and it being an intriguing topic. They stated that they were, “fascinated by the idea that you could create and understand cell biology from a molecular point to macro level”, “The research is new and intriguing” with “parallels to molecular nanotechnology, mechanosynthesis, and nanorobotics.” The students indicated that the notion of creating a cell with the same function as a living cell only using artificial components is a challenge. “This research could do an extraordinary amount of good for the world.” (What attracted me was) “how new the field is and the potential it has in addressing difficult issues within science.” “Synthetic cells, I believe, will be key to solutions (for understanding how) cells that cannot regenerate or repair without scar tissue are key to the prolonging of life in individuals and solving difficult diseases.” There were comments about how these developments mimic life. “The field has unimagined application and making something can overcome natural barriers.” “I thought that it was an interesting topic to explore - to make 'cells' and cellular factories in order to accomplish various tasks. Very practical really.” In addition to their participation in our own custom survey, the results of which are described above, students were encouraged to take the university-administered course evaluation survey. Responses to selected questions from that survey are provided as Supporting Information and will be used to help improve our offering of this course in the future.

Results and Discussion

Offering the course arguably had beneficial outcomes to both students and UNM as an institution. Students were exposed to a variety of concepts and methodologies that they could directly implement in their research, thus making both them and UNM more competitive in research. Likewise, as instructors, we are able to describe this course as an innovative educational offering to enhance our competitiveness for grants that require creative means to address the research workforce and / or under-representation in STEM. Many institutions of higher learning and industries have pro-active agendas to recruit members of under-represented or minoritized groups, but often are faced with few or no applicants. The interest we encountered in the field of synthetic cells will lead us to consider new course offerings in this area. As we offer this course in future semesters, we will calibrate the content and structure to better interest and serve students based both on our first attempt and with respect to student responses and comments. We will also embellish the video and literature resources. Finally interacting with our colleagues in the Build-A-Cell Research Collaboration Network, BASyC Consortium, and Max Planck Matter-to-Life School through discussions of curricular and ethical content and other emerging issues in the synthetic cell community will enrich our knowledge base and ability to transmit that information to students. Because many colleges and universities are now well equipped for remote instruction, we will explore the possibility of inter-institutional courses. We are now establishing relationships with faculty members at tribal universities and other Hispanic-serving institutions in our state to do so.

We have presented a general plan for a graduate level technical elective that relies on readily accessible or free teaching resources. This course is a reasonable mechanism to introduce synthetic cell research and technology, and synthetic biology in general at universities such as UNM, and potentially even those in which faculty members face higher teaching loads. Implementation of such courses at minority-serving universities and those serving resource-poor communities is a way to increase accessibility to the field of synthetic cells and synthetic biology in general, to broaden participation, and to enhance the workforce for these important endeavors, and, finally, to generate understanding that can facilitate societal acceptance and governance of these emerging fields.

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Supporting Information

1. Abbreviated Course Syllabus. 2. Course Writing and Presentation Assignments. 3. Results from Selected Questions from University-Administered Course Evaluation.

Author Information

Author Contributions: GPL and WLG designed and taught the graduate course as co-instructors and both contributed to the design of this study, gathering and analyzing data, and the writing of this manuscript.

Conflict of Interest Statement: The authors declare no competing financial interests.

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