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INTEGRATION OF AN AGAR ART TO A RESEARCH-ORIENTED MICROBIOLOGY LABORATORY SYLLABUS

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Abstract. Microbiology laboratory courses at universities are traditionally conducted by having students follow instructions to perform the experiments strictly. Such an approach, called a “cookbook” method, is perceived as tedious by students, although it is widely used in research-based universities with condensed curricula. It is not only seen as tedious by science-major students due to the lack of clear connections between learned methods, but they also experience difficulties in their practical applications. To address this issue, we successfully introduced artistic creativity that represents a unique creation in a Petri dish using living microorganisms. Here, we present our method of integrating Agar art into the microbiology laboratory course syllabus, being the first of its kind in Central Asia. Throughout the course, students characterized an unknown bacterium to the species level and designed colorful pieces of Agar art. This pilot project was non-graded, yet students enthusiastically participated in presenting their work as poster presentations. Collectively, Agar art integration exposed students to working collaboratively, enhancing their scientific communication skills, and better understanding lab topics

of the condensed research-focused lab syllabus with a further perspective to engage non-major/major microbiology students in taking the lab course.

Keywords: course-based undergraduate research experience, Agar art, microbiology, laboratory

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АГАР АРТ-ты МИКРОБИОЛОГИЯНЫ ЗЕРТТЕУГЕ БАҒЫТТАЛҒАН ЗЕРТХАНАЛЫҚ СИЛЛАБУСҚА ЕНГІЗУ

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Аннотация. Университеттердегі микробиология бойынша зертханалық сабақтар дәстүрлі түрде студенттер эксперимент жүргізу нұсқауларын қатаң сақтайтындай етіп өткізіледі. «Аспаздық кітап» деп аталатын бұл әдіс тығыз оқу бағдарламалары бар зерттеу университеттерінде кеңінен қолданылғанымен, студенттерге жалықтырғыш ретінде қабылданады. Жаратылыстану ғылымының студенттері үйренген әдіс-тәсілдердің арасында анық байланыстың жоқтығы жалықтырып қана қоймайды, сонымен қатар осы әдіс-тәсілдердің нақты тәжірибелерде қолдану қиынға соғады. Бұл мәселені шешу үшін біз тірі микроағзаларды қолданатын Петри табақшасында бірегей туынды болып табылатын «көркем шығармашылықты» сәтті енгіздік. Мұнда біз осы Агар арт шығармашылығын микробиология зертханасының оқу бағдарламасына Орталық Азияда бірінші болып енгізу әдісімізді ұсынып отырмыз. Курс бойы студенттер белгісіз бактерияны түр деңгейіне дейін сипаттап, Агар арттың түрлі-түсті туындыларын жасады. Бұл пилоттық жоба болғандықтан студенттерді бағалау жүйесін қамтымады, бірақ студенттер өз жұмыстарын постерлік презентация негізінде көрсетуге бар ынтасымен қатысты. Тұтастай алғанда, Агар арт студенттерге бірлесіп жұмыс істеуге, ғылыми коммуникация дағдыларын жақсартуға және зертханалық бағдарламаның тақырыптарын жақсы түсінуге мүмкіндік берді. Бұл әдіс келешекте микробиология және

микробиологиядан тыс оқитын студенттерді зертханалық курсты өтуге тарту үшін енгізілді.

Түйін сөздер: бакалавриат деңгейіндегі зерттеу тәжірибесі, Агар арт, микробиология, зертхана.

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ИНТЕГРАЦИЯ АГАР АРТ В СИЛЛАБУС В ИССЛЕДОВАТЕЛЬСКО-ОРИЕНТИРОВАННЫЕ ЛАБОРАТОРНЫЕ ЗАНЯТИЯ ПО МИКРОБИОЛОГИИ

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Аннотация. Лабораторные курсы по микробиологии в университетах традиционно проводятся таким образом, что студенты строго следуют инструкциям по проведению экспериментов. Такой подход, называемый методом «кулинарной книги», воспринимается студентами как скучный, хотя он широко используется в исследовательских университетах с сжатыми учебными программами. Студенты естественных наук не только считают это скучным из-за отсутствия четких связей между изученными методами, но и испытывают трудности при их практическом применении. Чтобы решить эту проблему, мы успешно внедрили «художественное творчество», или Агар Арт, которое представляет собой уникальное творение в чашке Петри с использованием живых микроорганизмов. Здесь мы представляем наш метод интеграции данного творчества Агар арт в учебную программу микробиологической лаборатории, который является первым в своем роде в Центральной Азии. На протяжении всего курса студенты описывали неизвестную бактерию до видового уровня и создавали красочные произведения Агар арт. Этот пилотный проект не вовлекал оценочной системы, однако студенты с энтузиазмом участвовали в представлении своих работ в виде постер презентаций. В целом интеграция Агар арт позволила студентам работать совместно, улучшить свои навыки научной коммуникации, и лучше понять лабораторные темы

сжатой исследовательско-фокусированной лабораторной программы с дальнейшей перспективой привлечения студентов, не специализирующихся на микробиологии, к прохождению лабораторного курса.

Ключевые слова: опыт исследовательской работы на уровне бакалавриата, Агар арт, микробиология, лаборатория.

Introduction. Microbiology methods have been taught in universities through protocol-based instructions, where students strictly follow a step-by-step guide. This approach allows little room for student-driven hypothesis creation and testing, making it challenging for many universities to deliver the course and achieve the intended learning outcomes. However, some universities in the United States have developed an exciting alternative by incorporating Agar art into their microbiology courses, where it has gained popularity for teaching foundational concepts of microbes (Adkins, et al., 2018; Adkins-Jablonsky, et al., 2021; Danna, 2017; Smith, 2022).

The Agar art contest, launched by the American Society for Microbiology (ASM) in 2015, has generated tremendous public interest in the colorful and diverse world of microorganisms (Chan-Laddaran, 2015; ASM, 2017). These tiny organisms produce various pigments or unusual colors when grown on specific media, with the Petri dish serving as a canvas for microbial art (Charkoudian, et al., 2010). This initiative has been well-received in high schools (Lontok, 2019; Wu, et al., 2018) and universities (Adkins-Jablonsky, et al., 2021), where microbiology syllabi are not solely research-oriented and mainly cover essential concepts about microorganisms. Its goal is to illustrate the strong connection between art and science in historical discoveries. Art is inseparable from STEM (Science, Technology, Engineering, and Mathematics) subjects today, as artistic training enhances scientific inquiry by promoting imagination and developing observational skills (Adkins, et al., 2018). A prime example is Sir Alexander Fleming, a self-taught artist who often painted bacteria on agar plates and discovered penicillin, saving countless lives. His ability to observe bacterial growth aesthetically allowed him to notice fungi inhibiting bacteria, which others overlooked (Dunn, 2010). Therefore, creative activities in practical settings, such as lab courses, can enhance students' attention to detail, nurture creative thinking, and encourage enjoyment as they express their individuality in experiments. This involvement leads to a more significant personal investment in the outcomes of their work (Adkins, et al., 2018) and invites open-ended discussions about unexpected results (American Association for the Advancement of Science., 2009).

Furthermore, creating paintings on Agar plates with differently pigmented bacteria promotes scientific communication through visual arts. Previous studies have demonstrated the effectiveness of an Agar art curriculum in boosting student engagement, helping them feel like real scientists as they formulate new hypotheses, thus creating a course-based undergraduate research experience (CURE) from an introductory lab with minimal investment from the university (Adkins, et al., 2018). Additionally, out of three CURE activities, including Agar art, experimental design, or poster presentations used to assess student engagement and understanding of the

nature of science (scientific thinking, experimental design competence, and academic performance), Agar art achieved the highest student engagement and outcomes linked to the nature of science, where interviewed students described the activity as enjoyable and as a way to apply knowledge in practice, thereby connecting research to classroom learning (Adkins-Jablonsky, et al., 2021). Another application of microbial painting in the microbiology curriculum conducted in Bulgaria, where students grew pigmented microorganisms on nutrient media, interpreting the resulting color patterns using an international standard system for color coordinates, the CIELab system. This marked a first for the numerical presentation and discrimination of microbial pigment coloration through spectrophotometric measurements (Todorova, et al., 2015). It also enabled the exploration of how nutrient medium composition, pH, and the type of carbon source influence pigment coloration. Agar art painting was also used as an extension to a transformation protocol in a high school microbiology class, where competent *Escherichia coli* cells were transformed with commercially available plasmids yielding fluorescent proteins, selecting and painting transformed colonies on agar plates, then visualizing the art under UV light. Students appreciated the project's outcome because microbial art offered them a real-world application of genetics, allowing them to gain hands-on experience with bacteria while understanding the replication of bacteria and inheritance of the genes for fluorescent proteins (Wu, et al., 2018). Kansas State University utilized *E. coli* in its undergraduate teaching in the food microbiology laboratory by incorporating three engagement strategies. Agar art served as a method for identifying foodborne pathogens by isolating and confirming them on differential media. Student engagement increased when all three strategic tools were applied (Mendez, et al., 2020) compared to years when few or no tools were utilized, consistent with findings from the University of Alabama (Morris & Adkins, 2018). Agar art also played a key role in the upper-level biochemistry course, where students engaged in active learning by working with specific plasmids that displayed distinct colors while experimenting with various antibiotics and inducers to implement their artwork successfully. The authors aimed to integrate art into the class to foster creative learning and deepen understanding of gene expression using inducible promoters with UV-light or blue-LED excited fluorescent proteins (Jefferies, et al., 2022). As can be seen, this activity has been gaining popularity in recent years not only for aesthetic enjoyment but also for learning more about the microbial world, including their role in food science and the study of inducible promoters.

Finally, Agar art led to mastering artistic practice among introductory and advanced art students to recreate famous artists' paintings or their own concepts after learning safe bacterial handling and culturing. As a result of this activity, students enhanced their confidence in handling microorganisms and aesthetically creating microbial art. Furthermore, some students even became finalists in the ASM's Agar art contest, thereby validating the success of the interdisciplinary project between the biology and art departments (Torruellas Garcia, et al., 2022). Table 1 summarizes the use of Agar art in educational settings. It is evident from the table that Agar art has been extensively employed in North America, but no Central Asian countries have yet integrated it into their course curriculum.

Country	Study conducted, years	University (-ies)	Outcome achieved	Parameters evaluated	No. of students participated	Ref.
Bulgaria	2015	Razgrad Branch of University of Ruse "Angel Kanchev"	The possibility of microbial pigments' color measurement and discrimination using the CIELab system was revealed.	Not available	Not available	(Todorova et al., 2015)
USA	2016 - 2017	University of Alabama at Birmingham	Identification of unknown microorganisms in control and active groups from labstock culture and nearby park, respectively	Concept mastery, attitudes toward science, student demographic characteristic in control and active groups before and end of semester	15 out of 30 students (control group); 33 out of 48 students (active group)	(Adkins et al., 2018)
USA	2018- 2020	Fred Hutchinson Cancer Research Center, Science Education Partnership; Center School, Seattle Public Schools; Eastside Preparatory School, Kirkland	Use of bacteria as paint promoted their understanding of bacterial genetics, employment of plasmids as a molecular tool, as well as reinforced creative and critical thinking in class	Lack of cross-contamination, expression of transformed plasmids with fluorescent proteins, color visualization under normal and UV light	3 respondents; unknown number of class participants	(Wu et al., 2018)
USA	2016- 2018	Kansas State University	Creative engagement activities, including Agar art, outbreak case studies and a research group project improve students' learning outcomes and engagement in food microbiology and food safety.	1. Learning outcomes for the Food microbiology class (quizzes, exams, lab notebooks, in-class participation evaluation scores) compared across student groups with/without creative activities implemented; 2. Students engagement (through pre- and post-questionnaires)	173	(Mendez N et al., 2020)

USA	2018- 2021	University of Alabama at Birmingham and Jefferson State Community College, Alabama	Participation in the CURE improved both research university and community college students' course engagement, scientific thinking capabilities, experimental design competence, and overall academic outcomes. Agar art was found to be the most engaging among three creative activities tested	1. Course engagement Nature of science (NOS) questions evaluated on a Likert scale: 2. Scientific thinking 3. Experimental design competence 4. Academic performance	82 (25 community college students, 57 research university students)	(Adkins-Jablonsky et al., 2021)
USA	2020- 2021	U.S. Air Force Academy Department of Chemistry	Understanding biochemical concepts (cloning, antibiotic use, protein fluorescence); incorporation of scientific concept visual art through Agar art	Pre-activity and post-activity quizzes; Understand differences between constitutive and inducible promoters antibiotic selection concept; emission of light by FP at different wavelengths		(Jefferies L, et al., 2022)
USA	2021- 2022	Halmos College of Arts and Sciences, Nova Southeastern University, Fort Lauderdale, Florida	To integrate fundamental microbiology laboratory techniques and utilize them as innovative tools for artistic expression among undergraduate Arts students	Aesthetic, conception, and technical proficiency in handling the bacteria among undergraduate Arts students	Introductory (n=17) and advanced art (n=33) students	(Torruellas Garcia et al., 2022)

Table 1. Agar art Application as a Course-Based Undergraduate Research Experience in Biology Undergraduate Students

Introduction to Microbiology Laboratory course is offered to undergraduate students at Nazarbayev University (NU), a research-based university established in Central Asia, Kazakhstan. The course syllabus primarily emphasizes research-oriented content with different lab topics encompassing various microbiological methods. After running the course for several years, students' feedback from previous years' class evaluations indicated a lack of innovative teaching methods, potentially leading to a lack of interest in the course and hindering its popularity among other students.

To address this issue, our undergraduate students were put into a routine microbiologist workflow where they could get a CURE. Therefore, the course is considered research-oriented due to its component of identifying and characterizing unknown bacteria, where students define their hypotheses and investigate pathogens to generate new knowledge. Moreover, we successfully integrated Agar art into the laboratory to understand the science behind developing artwork on a Petri dish. In the current paper, we aim to share our method of embedding Agar art into the research-oriented curriculum for the Introduction to Microbiology laboratory course for its further popularization to engage more students and create a learning environment where students use their artistic work to find discoveries.

Methods and materials.

This section aims to share a curricular approach to implementing the Agar art activity throughout the course syllabus, which contains 14 weeks with 12 weeks of wet labs. The first lab session was dedicated to microbiology lab safety, where students gained knowledge and training on aseptic techniques followed by appropriate handling, culturing, and disposal of microorganisms. They were given a task to identify and characterize an unknown bacterium (further referred to as Bacterium X) causing an infection. Instructors gave a bacterial mixture containing Bacterium X. Students spent one month identifying the Bacterium X.

Over one month, instructors ensured that the students received adequate safety training to handle procedures for interpreting results in the context of Bacterium X characterization as microbiologists. During this period, they learned to isolate a specific bacterium from a bacterial mixture. This process involved streaking from the mixture followed by its inoculation into an agar slant, allowing them to define the type and morphology of a bacterium (Figure S1). Furthermore, students were taught to conduct simple and differential staining methods (Figure S2).

During the second month of the course, students were immersed in methodologies used in research, such as selecting different types of bacteria and differentiating closely related microorganisms using selective and differential media such as crystal violet (CV) agar, MacConkey agar (MCA), eosin methylene blue (EMB) agar, and mannitol salt agar (MSA) (Figure S3). Once selective and visually differentiated growth of the unknown pathogen was achieved, our students were assigned to determine the nature of the Bacterium X. Identifying an unknown bacterium allowed students to deeply understand each method outlined in the syllabus from weeks 2 to 5 and comprehend the methods' practical application.

Students employed sophisticated lab methods such as indole, methyl red, Voges Proskauer, citrate (IMViC) tests, nitrate reduction, and analytical profile index 20E (API 20E) to characterize it further. As per the syllabus, students learned widely used methods in antibiotics assay and analyzed spectrophotometer-obtained data to determine generation time for their bacterial growth curve. To continue, students had a lab session on the use of different extracellular and intracellular enzymatic activities of microorganisms (starch, gelatin, lipid hydrolysis, catalase, and oxidase assays) followed by determining hydrogen sulfide production and motility in the bacteria of interest (data not shown). At the same time, our students were investigating Bacterium X for the abovementioned biochemical activities, and these experiments further confirmed the correct identification of Bacterium X from week 5.

For each assay students were provided with a positive control to ensure quality of results comprised of the following strains: *E. coli* (Migula) Castellani and Chalmers (ATCC 23735), *Serratia marcescens* Bizio (ATCC 4003), *Bacillus cereus* (ATCC 14579), *Enterobacter aerogenes* (ATCC 13048, now available as *Klebsiella aerogenes*), and *Staphylococcus aureus subsp. aureus* Rosenbach (ATCC 25923).

The first half of the third month of the syllabus served as an introductory session for the food microbiology lab, an upper-level course offered as an elective one to identify coliform contamination in food samples. Enterobacteriaceae was differentiated by IMViC assay to differentiate *E. coli* from *E. aerogenes*. API 20E test revealed the enteric bacterium to the species level. Similarly, a Bacterium X was tested along with controls, and API 20E complemented the findings from the IMViC tests to confirm the Bacterium X to be an *E. coli* strain with a 99% match according to the APIWEBTM, an online bacteria and yeast database (https://apiweb.biomerieux.com/login) (Figure S4).

To finalize the biochemical part of the syllabus, students also learned to interpret the results of nitrate reduction assay and understand how bacteria employ nitrates to produce nitrite or nitrogenous gases. To further extend research-targeted methods conducted with bacteria, we included a lab experiment with bacteriophage culturing and their enumeration using double-layer and spot-phaging methods. Students also performed the immunological assay called a ring precipitation test, a qualitative test for the presence of an antibody-antigen complex (data not shown). The last week of labs was devoted to teaching students how to preserve the bacterial culture long-term in glycerol, an essential technique to be mastered by each microbiologist.

Integrating the Agar art into the course syllabus was made as smooth as possible: lab procedures for its preparation were broken into specific parts from mid-semester until the end by simultaneously performing research-based methodologies with the unknown Bacterium X as given in the course syllabus (Figure 1).

To upload their Agar artwork, our students used an online bulletin board called Padlet (https://padlet.com) to prepare a poster presentation to be defended during the final week of classes. All lab procedures were conducted by wearing personal protective equipment (i.e., lab coat, closed-toed shoes, gloves, and safety glasses).

Results.

The Introduction to Microbiology laboratory course is organized to include a

three-hour lab practicum once a week over 14 weeks (Figure 1). As presented, the syllabus is intensive and heavily packed with essential and sophisticated research-based lab methods for a student taking microbiology labs for the first time. We "softened" the course syllabus by incorporating creative agar artwork to alleviate the burden. Midway through the semester, students commenced their Agar art project, having already acquired essential techniques such as aseptic culturing of bacteria, simple and differential staining to observe bacterial morphology, preparation of culture media, and inoculation of bacteria on different selective/nutritive/differential media (see Procedure and Figure 1). Fifty undergraduate students participated for the first time in the history of NU. They had already acquired knowledge and practical experience on the characteristics of various bacteria used in the lab to decide which bacterium to choose for their Agar art project.

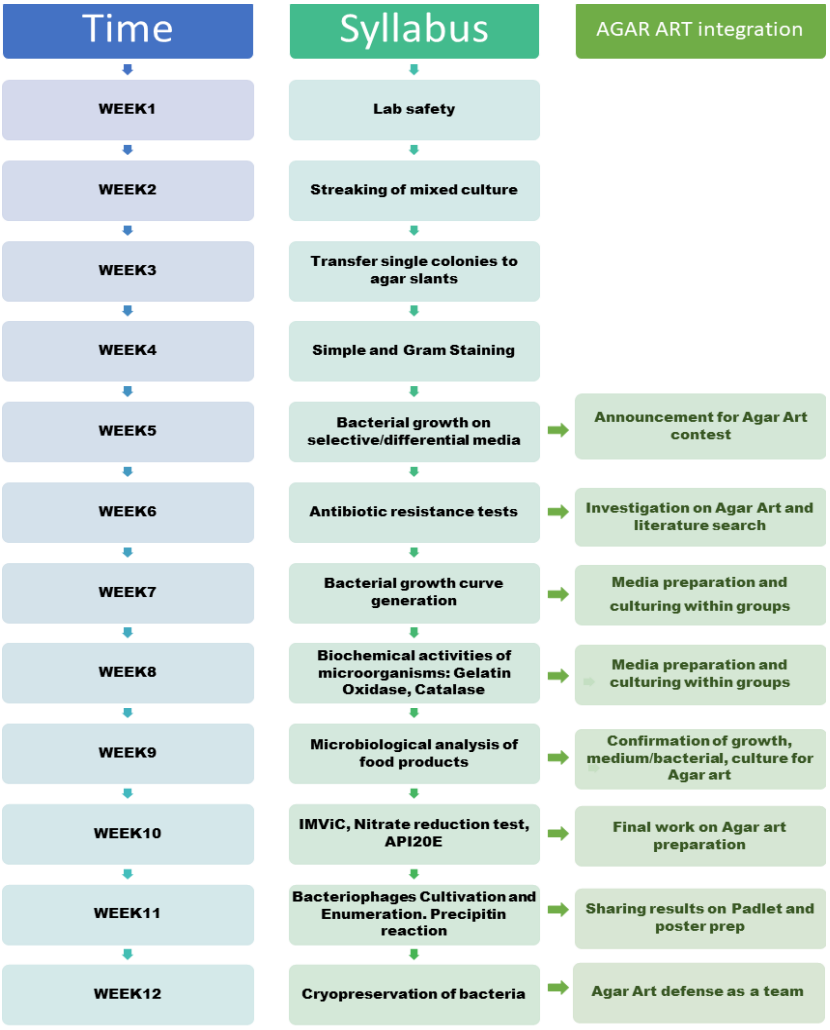
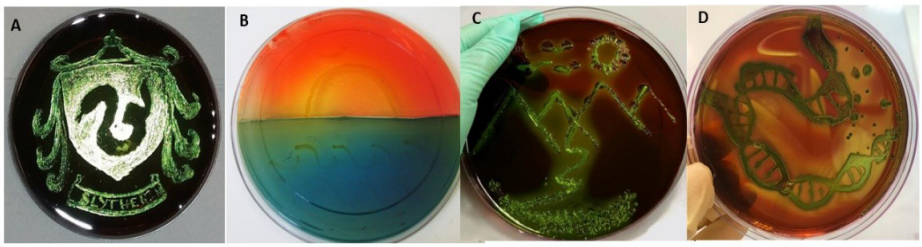


Figure 1. A flowchart on the integration of Agar art into the course syllabus.

Participation in this activity was voluntary and non-graded for all students in this course. The following weeks, 6-11, were devoted to preparation for the project. During week 6, the students were shown outstanding works of Agar art winners from previous years on the ASM website that motivated and demonstrated how colorful the bacterial world can be (ASM, 2017). By this time, a group of two or three students had formed to start this project. Moreover, trained teaching assistants and instructors closely monitored the progression of each step in the project by giving timely feedback. As the syllabus layout shows (Figure 1), students continued following lab course experiments and running their Agar art projects in parallel. In week 6, students were tasked with determining the media and bacterial culture types required for their work. To accomplish this, they conducted a literature overview on the growth of microorganisms in various selective and differential media. Some students used an isolated bacterial strain from a bacterial mixture given to them at the beginning of the labs. In contrast, others used another type of bacteria for their artwork creation. We allowed our students to use all available growth media in our lab, including those reserved for advanced elective lab courses.

Once students chose media and bacterial cultures, week 7 was devoted to media inoculation. Week 8 was busy observing the results of week 7's bacterial growth on students' media. We allowed the students to have it repeated, if necessary, in case of contamination or getting unexpected results. Week 9 was set as a concluding week to establish media and microorganisms of choice, having obtained results from weeks 7-8. Notably, the students prepared media independently and poured plates that served as a canvas for their Agar art. Students used week 10 lab to finalize their project by creating agar art on a Petri dish. In week 11, students uploaded Agar art results and artwork descriptions into the Padlet, where they observed each other's works. An example of a group result submitted to the Padlet is demonstrated in Figure S5 and available following the link: https://padlet.com/aigerim_soltabayeva/agar-art-3z9wuo068dcj. It was observed that sharing one team's work with others effectively increased interest in the task among peers, thereby enhancing student discussion. Week 12 culminated with a poster presentation where each group presented their Agar art, explaining the choice of media and "drawings" on a Petri plate (Figure 2).



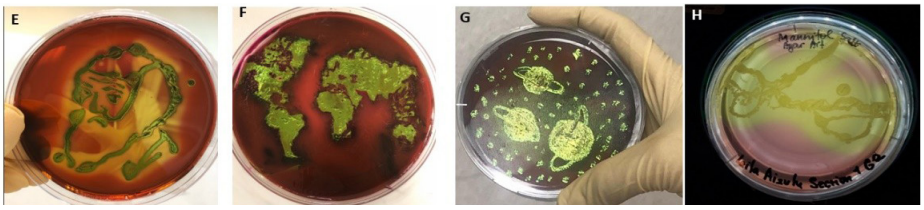


Figure 2. Agar artwork performed by students enrolled in the microbiology laboratory course in the Fall of 2019. The compositions are labeled as follows: Slytherin (A); Sunset Over the Ocean (B); Atameken (C); Egoism (D); Charles Darwin aka Father of Evolution (E); Save the Mother Earth (F); Universe of three planets: Saturn, Uranus, and LeRim (G); Sign (H).

The entire poster with all student groups' projects and descriptions is provided in Figure S6. Then, the students were invited to participate in an International Agar art competition organized by the ASM using Bacterium X in their art pieces. One group submitted their work to the ASM (Figure S7). We investigated the impact of integrating Agar art into the course on students' academic performance. To evaluate this, we compared two cohorts of students: one from 2018, when Agar art was not integrated into the curriculum, and one from 2019, when it was introduced. We found that, on average, the inclusion of Agar art stimulated better academic performance. Interestingly, the percentage of students with grades ranging from 90% to 94.99% was slightly higher with the inclusion of Agar art, although the number of students taking the lab course with Agar art was two times less in 2019 (n=50) compared to 2018 (n=105). As for the number of high-achievers, 30% of students had exceptional performance by gaining a grade between 95% and 100% compared to 21% with no Agar art when it was not integrated into the syllabus. Notably, there were no failing students in the class with agar art, in contrast to 2% of students who failed the lab in the previous year (Figure 3).

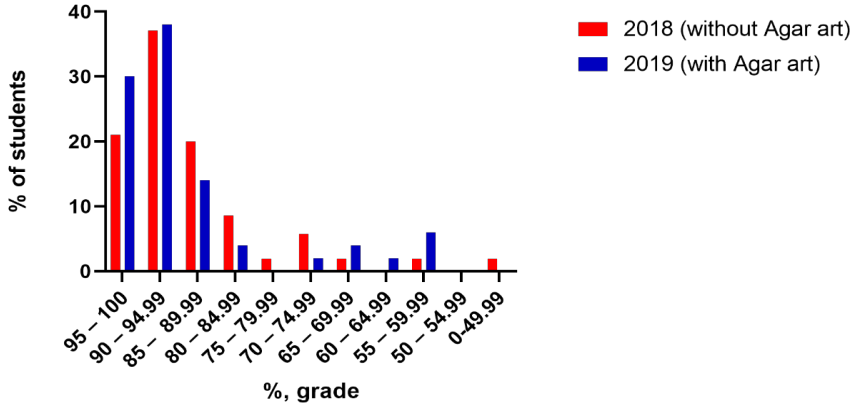


Figure 3. Distribution of students' grades in the Introduction to Microbiology course for two different years: 2018, when Agar art was not integrated (n = 105 students), and 2019, when it was integrated (n = 50 students).

Our observations were backed up with several comments from the course feedback survey, where students outlined what they most enjoyed while taking the course. As evidenced, students notably understood fundamental and applied lab techniques as they were implemented. More importantly, Agar art was considered one of the favorite parts that motivated students to perform well (data not provided). Due to the pandemic that commenced in the Spring semester of 2020, students switched to an online mode of learning, and, unfortunately, the Agar art project did not find further implementation.

Discussion.

The course goes through the annual monitoring assessment on the departmental and university levels, where we collect student feedback that serves as a basis for improvements and corresponding changes in the syllabus year by year. Previous years' course feedback demonstrated that students perceived the course as boring due to a lack of innovative teaching methods. With an attempt to bring a novel method of teaching the course and simultaneously show a practical link among the learned laboratory techniques, students were put into a routine day of a microbiologist who is involved in the identification and characterization of an infectious-causing pathogen named Bacterium X using different microbiological techniques which are outlined in the course syllabus. The course learning outcomes were achieved as the students learned research methods weekly encompassing major topics on bacterial staining, metabolic activities, antibiotics resistance, enumeration of bacteriophages, serological testing, differentiation of Enterobacteriaceae members, and bacterial count in food products as presented in Figure 1.

We aimed to keep the research component of the course and, at the same time, smoothen the syllabus by introducing Agar art to bring more creativity to the scientific module (Figure 1). Its smooth integration took place by applying the methods each week that permitted students to complete their projects in a non-stressful way. Since it was a pilot project, completion of the Agar art was optional to complete the course. However, all fifty enrolled students participated and successfully defended their project as teamwork by presenting a poster in class, where each team member explained the media/bacteria used for their microbial painting and the philosophy behind the artwork. All results were collected and broadcast on the university channel and put into a poster that further increased first-year students' interest in the world of microorganisms (Figure S6). Most notably, we could keep all the lab topics by having more engaged students with better academic performance (Figure 3). The Agar art was a culmination point of the course, where students could express their ideas using living microorganisms and creating beautiful color patterns of pigmented bacteria. Such an activity allowed students to develop critical thinking skills during results interpretation and teamwork skills to prepare the Agar art project. Our results also support the findings of Adkins-Jablonsky et al. (2021), who revealed that students selected Agar art as a curricular tool that is relevant and favored by students. Our students simultaneously had an experience of a typical

day of a microbiologist investigating the pathogen, thereby comprehending a link between diverse microbiological experiments.

There is a pressing need to develop robust evaluation methodologies to measure the impact of Agar art exposure in prospective research endeavors. Therefore, implementation of a pre-/post-activity assessment design could further strengthen the rigor of these investigations, ultimately enhancing understanding of the educational impact of Agar art. Subsequently, future studies will encompass including pre- and post-activity questionnaires involving more students from diverse institutions. This comparative analysis can also consider students' personal backgrounds and social identities to investigate the impact of Agar art integration, as most often, the impact of educational interventions may vary significantly among students with different background characteristics. Regrettably, this aspect remains unaddressed, mainly in studies incorporating Agar art into course curricula, as presented in Table 1. Notably, the design of the assessments should seek to ascertain the extent to which Agar art enhances collaborative work, fosters scientific and communication skills, and deepens students' understanding of laboratory topics. In addition, introducing new bacterial strains that have not yet been used in Agar art competitions can enhance student interest and make the contest more motivating and engaging.

Conclusion.

The Bachelor of Science in Biological Sciences program is taught in English and can be compared in scope and structure to available programs in internationally leading academic institutions. Introduction to Microbiology laboratory course has been running for 10 years, and its learning outcomes match soundly with the B.Sc. in Biological Sciences program outcomes wherein a graduate will be able to apply scientific methods and integrate fundamental theoretical concepts to address real-world problems in biology-related fields, communicate clearly, and analyze data in biological sciences both ethically and critically. In this study, we maintained a research-oriented microbiology syllabus by obtaining all course learning outcomes and smoothly integrating artistic creativity. The latter resulted in a total student participation rate, which augmented their scientific and communication skills.

To the best of our knowledge, this case was the first in the Central Asia region to successfully integrate Agar art into microbiology laboratory training for initial explorations of the impact of such activity on students. This will be further continued by disseminating such a curricular approach with local universities in Kazakhstan to find a correlation with our findings.

Having integrated Agar art into our research-based syllabus, we could maintain CURE, increase the number of high achievers, and support the comprehension of each applied experimental method. Popularization of the course with Agar art incorporation among current and future students in science and non-science majors potentially enhances student engagement with STEM classes and, therefore, their retention in STEM careers. Our long-term goal is to develop a curriculum that other universities can use as a CURE in their microbiology courses.

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