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ARTICLE

Engaging student opinions on vaccine development innovation: Experiences from a "Shark Tank" project

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Abstract

A graduate course on vaccine development challenged students to propose concepts to improve upon current vaccine development paradigms in the context of a "Shark Tank-style" format where students were asked to develop an abbreviated business plan and make a pitch to the "Sharks" (experienced academic and industrial vaccine researchers and developers) where they could request funding, research collaborations or regulatory guidance. Students were graded based on the components of their plan and on their ability to convince the "Sharks" of the feasibility and innovation potential of their project proposals. This approach to teaching vaccine development explored areas where novel approaches would be helpful and assessed current gaps in vaccine innovation. The class also utilized artificial intelligence-based contributions using ChatGPT which has also been summarized. This summary of the collective view of the class provides recommendation for future campaigns to develop new vaccines and therapeutics.

Study Highlights

WHAT IS THE CURRENT KNOWLEDGE ON THE TOPIC?

Most curriculum in vaccine development use a standard didactic approach with content focused on immunology, vaccinology, and the stages of development. There has been little consideration for how artificial intelligence (AI) teaching approaches can be incorporated into teaching practices in general and especially in translational research courses.

WHAT QUESTION DID THIS STUDY ADDRESS?

This study addressed the question of how can curriculum on vaccine development benefit from project-incorporated techniques engaging student interaction with subject matter experts to pursue innovation in vaccine development (e.g., Shark Tank-style project) and successfully utilize AI-based learning techniques to enhance the learning experience in a transparent manner.

WHAT DOES THIS STUDY ADD TO OUR KNOWLEDGE?

This study adds a relevant class experience on vaccine development curriculum to incorporate non-didactic approaches to improve student engagement and

address vaccine innovation sharing experiences from students and subject matter experts participating in a Shark Tank-style class project.

HOW MIGHT THIS CHANGE CLINICAL PHARMACOLOGY OR TRANSLATIONAL SCIENCE?

The disciplines of clinical pharmacology or translational science will benefit from the classroom/educational experience with AI approaches and innovation in vaccine development is hopefully a topic that will grow to include a clinical pharmacology and translational science component as this is much needed.

INTRODUCTION

Around the world, people are living longer because of advances in medical science and public health interventions. Global life expectancy has increased substantially and 25 of the 30 years of increased life expectancy in the US population over the course of the 20th century are attributable to advances in public health.[1] One of the century's greatest and perhaps most impactful medical advances was the development and widespread use of vaccination against multiple infectious diseases.[2] Through vaccination, endemic smallpox has been eradicated worldwide, poliomyelitis has been eliminated in the Western hemisphere, and diseases such as measles, rubella, tetanus, diphtheria, and Hib, once responsible for significant morbidity and mortality in the United States and other parts of the world, have been controlled.[3] Whereas advances in vaccine development have been numerous over time, the pace of innovations in vaccine research and development increased over the past decade and most recently in the wake of the coronavirus disease 2019 (COVID-19) pandemic.[4,5] Still, there are gaps in our knowledge that could improve the efficiency of the development time course as well as increase the probability of technical success over the various stages of vaccine development.

Pre-pandemic studies have estimated that 2%–39% of vaccine candidates introduced into phase I trials progress to regulatory licensure.[6–8] These studies primarily evaluated trials that predate 2009; since then, new techniques, such as next-generation sequencing and atomic-level structural biology approaches, have emerged that may speed the pace of viral vaccine development. More recent evaluations[8] have concluded that the probabilities that development trajectories would advance from phase I to II, phase II to III, and phase III to approval were 38.2%, 38.3%, and 61.1%, respectively. Whereas there are caveats and limitations in these findings (e.g., time invested in preclinical development or manufacturing and distribution, reliance on ClinTrials.gov reporting and weighted influence of influenza and HIV vaccine development), they do suggest a shift in probability of success across the stage of development.

As part of the University of Pennsylvania's Master of Science in Translational Research and Master of Regulatory Affairs programs, the REG 6180 course on Introduction to Vaccine Development lays the foundation for conducting vaccine research (https://www.itmat.upenn.edu/education-and-training/itmat-education-courses.html#spring). It begins with a brief review of the history of vaccine discovery and development and explains the phases of vaccine development in detail. Global Health history and impact of vaccines is described as well as the various stakeholders (e.g., World Health Organization [WHO] and World Bank) involved which distinguish vaccine from drug development. The decision-making process, vaccine development milestones, and compound progression metrics are defined and explained with examples. At the conclusion of this course, students are expected to have a working knowledge of the vaccine development process, and to understand the regulatory basis by which new vaccines are evaluated, ultimately approved, and distributed around the world.

In the context of the course students are asked periodically to assess the tremendous innovation in vaccine development that has recently come to bear during the recent COVID-19 pandemic as well as assess the still prevalent gaps and opportunities to innovate further. Some studies[9] have pointed to the fact that these innovations and recent advances have, in fact, started to improve the appreciation for science and vaccine confidence, although this is a multifactor problem requiring a diverse solution. Others[10] have promoted more modern teaching techniques to challenge students to extrapolate in-class didactic training with projects and assignments that require some independent research on top of the classroom lessons. In that spirit, the REG 6180 class was challenged to identify areas still in need of innovation to facilitate more efficient and/or informative vaccine research and development. The class was given broad latitude in scope and asked to prepare proposals consistent with a "Shark Tank" format requiring them to develop their concept, construct an initial business plan, and pitch both to a panel of "Sharks." As part of their pitch, they could request financial support, guidance with respect to regulatory or

market requirements, or additional assistance in the form of partnering or other mechanisms of collaboration. The panel of "Sharks" were to represent academic, industry, and global health perspectives with the guidance that they grade the students based on plausibility of their proposal and the potential of their project to impact vaccine development in an innovative manner.

This paper summarizes the majority of the project proposals and articulates the places where students felt vaccine innovation could be best addressed. It also highlights the feedback from the "Sharks" based on the student presentations as well as the overall value in the assignment and further necessity of vaccine innovation in general.

METHODS

Problem-based learning and scaffolding

Problem-based learning (PBL) is the primary instructional strategy for this assignment, which is the culminating course project. PBL is "a teaching method in which complex real-world problems are used as the vehicle to promote student learning of concepts and principles as opposed to direct presentation of facts and concepts."[11] The Shark Tank/business plan project is a classic example asking students to choose their own real-world problem to address with an intervention of their own devising. The solution could take any form but required evidence-based backup. The open-ended assignment allowed students to choose issues relevant to their own careers and research interests, leveraging their lived experiences and professional expertise.

The course also provided scaffolding for the final assignment. In two reflection assignments formatted as blog posts, students were asked to write about (1) an idea for a plan, mock-up, or working demo of a tool that could assist in phase II trials, and (2) pandemic readiness, including factors facilitated the global readiness for the COVID-19 pandemic and factors that still need improvement to accelerate pandemic readiness. These reflective assignments asked students to begin thinking about problems and problem-solving, both in the analysis of a problem (pandemic readiness) and in brainstorming ideas to improve public health (phase II trial improvements). These assignments set the stage for the Shark Tank/business plan.

Additional scaffolding was available in one-on-one consultation with the instructor. Students were asked to prepare their project concept a month prior to the due date, and then to communicate the concept to the instructor for feedback on suitability for the assignment and a feasibility check. The week prior to the presentation students were permitted a consultation with the instructor as a check-in on their project progress with any final discussion on topic, ask, or pitch. In this way, the instructor provided additional guidance.

Transparency in Learning and Teaching framework

During the course of the class, the instructor and program staff worked to revise class assignments in alignment with the Transparency in Learning and Teaching (TILT) framework. TILT emphasizes three core elements in assignment design which have been shown to boost students' sense of belonging, academic confidence, and work quality, among other domains.[12] These elements are purpose, task, and criteria.

In the case of the Shark Tank/business plan project, the instructor discussed the purpose and real-world utility of the exercise extensively in class. In the university learning management system, Canvas, the assignment contained written instructions and specific sections of the business plan project and task steps; the instructor also provided examples of the content to be found in the business plan and pitch (see Supplementary Material appendices). The criteria for success included reflection of the instructions in the task assignment and clarification of the weight of the assignment in students' final grades and course performance.

Implementation and reflection

Implementation of the PBL approach required planning and integration with an established didactic course curriculum. Figure 1 provides a simplified schematic of the integration adopted herein.

Following an initial viability consult and second consult/feedback from the instructor on the pitch itself, students gave their pitches at the end of the course. Students were graded based on the components of their plan and on their ability to convince the "Sharks" of the feasibility and innovation potential of their project proposals. Grades for the assignment were based on the average of all three "Sharks" individual grades (based on project feasibility and innovation potential) with final adjustment by the instructor (up to 0.5 points) based on how well they addressed the question and answer (Q&A).

Pitch characteristics:

- During one class period, with six participants.
- Pitching to three "Sharks" with expertise in different disciplines.
- 10 min limit followed by an "ask" to "Sharks" and Q&A.

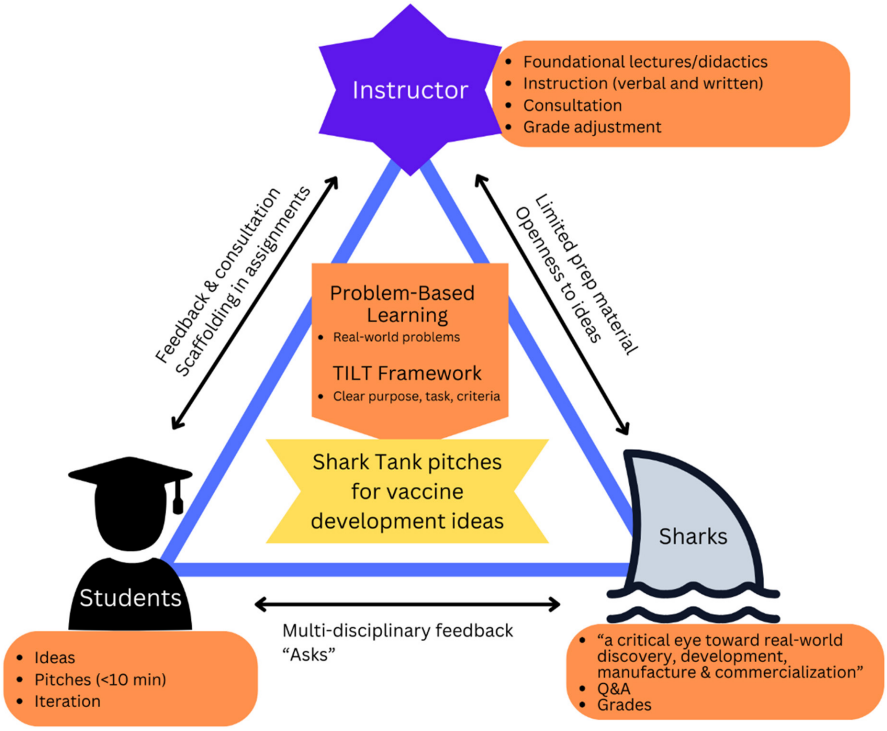

FIGURE 1 Integration of the TILT framework to the Shark Tank Project as part of the vaccine development course curriculum illustrating the problem-based learning approach.

- Should focus on healthcare innovation over incremental technological improvements, but no specific format required.
- Contain substantial research and effort to vet as a viable product.
- Aimed at convincing the experts that the idea was not only "good," but also clinically viable, regulatorily sound, feasible for a marketing plan, and commercially possible.
- Show an understanding of the US Code of Federal Regulations and possibly regulatory pathways, including potential investigational new drug considerations; details on each development phase, trial designs, costs, and expectations on timelines and execution.

The career scientists serving as judges or "Sharks" for the assignment were given guidance about the assignment and a brief pre-read about the projects prior to the actual presentations.

The role of the "Sharks":

- Prepare by reading through the assignment and brief pre-reads about the projects.
- Assume students are presenting a realistic product/project that they might actually be interested in moving through research and development (R&D) and into the clinic.
- Share feedback with a critical eye toward the real-world discovery, development, manufacture, and commercialization of the project proposals.
- Evaluate projects on individual merits, not competitively.

In summary, the "Sharks" played a vital role in the project, second only to the students themselves, who deserve much credit for the quality of thought, the degree of planning and modeling that was performed, and the ability to think through product development from beginning to end in a short time, as a specific result of what they had learned in the class.

RESULTS

Each student walked the "Sharks" through their hypothesis and proposed solution via slide deck, with an explanation of their product. The presentation often included epidemiology assessments, biological mechanism of action explanations, relevant product production/manufacture components, and basic approaches to clinical testing and subsequent commercialization. In general, each student explained the current bottleneck or problem in vaccine development and the hypothesis of the solution they proposed. Their collective clinical development plans varied in complexity and depth. The "Sharks" provided examples or steps that could be added to improve upon the likelihood of success.

Additionally, the "Sharks" were occasionally required to explain the regulatory reality of what the student would face when presenting their clinical plans to, for example, the US Food and Drug Administration (FDA). It was not expected that the students fully understood the regulatory implications of their development plans, although in most cases the course itself had prepared each student well, and

whereas regulatory feedback was often required, it was not extensive.

It was clear that each student had thought thoroughly through each step of the development process for their project, and, in general, the "Sharks" were impressed with the presentations and outcomes, offering critiques based on decades of experience, rather than on flaws in the presentations themselves. Students were engaged and seemed to absorb the feedback appropriately, and an appropriate next step would be, if the student was serious about their project, to return to the "Sharks" with an update, having addressed these questions.

This problem-based learning experience emphasized innovation, critique, and real-world application; students gained skills that could be applied in product development for products meeting medical and public health needs. These skills will serve them well as professionals in various contexts, from research to regulatory to commercialization, as they advance in their careers.

"Shark Tank" pitches – student narratives

Narratives for five of the six student projects listed in Table 1 and presented at the "Shark Tank" class event are provided below. In each case, the student describes the background, innovation concept, and opportunity and the "ask" to the "Sharks."

Project 1: LymeDetect, a point of care Lyme disease diagnostic to assist in phase II trials of Lyme disease vaccines

Lyme disease is caused by infection with the spirochete Borrelia burgdorferi, which is often transmitted to humans through the bite of a deer tick that is carrying the bacteria.[13] The Centers for Disease Control and Prevention estimates that about 500,000 people may be infected with Lyme disease in the United States every year,[14] and the US Environmental Protection Agency notes that the occurrence of Lyme disease has almost doubled since 1991, with the greatest increase in cases occurring in the northeastern states.[15] Furthermore, the occurrence of Lyme disease is projected to keep increasing as warmer temperatures associated with climate change increase the land regions that are habitable for ticks.[15] There is no current vaccine for Lyme disease, but clinical trials for vaccine candidates are underway.[16] However, because the symptoms of Lyme disease are highly variable, a major challenge in designing clinical trials for Lyme disease vaccines is defining an end point. Current clinical trials define end points as positive laboratory tests confirming infection with Lyme disease. These factors – unpredictable symptoms and the requirement of laboratory confirmation – make it difficult to identify infected individuals. As a result, clinical trials for Lyme disease vaccines take a long time.

A point of care (POC) diagnostic to facilitate at-home Lyme disease diagnosis would help to shorten the duration of phase II clinical trials. The proposed company, LymeDetect, would sell a novel at-home urine test for Lyme disease. Working much the same way as inexpensive at-home urine pregnancy tests, this test would identify the presence of Borrelia burgdorferi antigens in the urine. Non-infected individuals could be enrolled in the trial and instructed to go about their daily lives as usual. They would be asked to do the at-home test monthly or at the onset of symptoms. This would provide much better resolution of Lyme disease among study participants, allowing phase II trials of Lyme disease vaccines to end earlier, require fewer participants to attain sufficient power, and advance sooner and more confidently to corresponding phase III trials.

At first, LymeDetect's tests would be marketed to the sponsors of clinical trials (e.g., pharmaceutical companies who have developed candidate Lyme disease vaccines and are funding clinical trials). If, in several years, successful Lyme disease vaccines have reached the market and there is reduced demand for these diagnostic devices in clinical trial participants, the technology could be marketed to the general public and sold over the counter in grocery stores and pharmacies. With the projected increasing prevalence of Lyme disease,[15] a rapid, at-home diagnostic would be of market value for the foreseeable future. Considering the significant current demand – and the expanding market – for this device, we value the proposed company at $5 million US dollars. Because this technology still needs to be developed and validated, we are requesting $1 million US dollars in seed funding to help grow the company. This would be in exchange for 20% equity in the company.

Project 2: Stem cell memory (TSCM) via electroporation of transduced T-cells to facilitate cancer vaccine trials

Electrus Biotherapeutics Inc. is a preclinical stage cell and gene therapy company developing a paradigm-shifting oncology platform for long-lasting persistent CAR T cells. The platform is targeted toward solid tumor, with an opportunity for tunable phenotypes, multiple payloads, and applications beyond oncology. Electrus offers persistent CART cells resistant to exhaustion primed for tumor killing. It utilizes the power of electroporation to induce the overexpression of carefully characterized and optimized transcription factors, which are expressed for a limited

TABLE 1 Shark tank projects on vaccine innovation proposed in the REG 6180 class.

Project	Phase of development targeted	Innovation potential	Request to "Sharks"
LymeDetect – a point of care Lyme disease diagnostic to assist in phase II trials of lyme disease vaccines	Phase II	An inexpensive, painless, POC diagnostic for Lyme disease has significant market potential, for both the current Lyme disease vaccine clinical trial landscape and the general public	$1 million in seed funding to help grow the company in exchange for 20% equity in the company
Stem cell memory (TSCM) via electroporation of transduced T-cells to facilitate cancer vaccine trials	Preclinical and phase I	More informative and effective early-stage vaccine development	Request for access to academic manufacturing facility
PanReady – a comprehensive pandemic readiness app	Phases I to IV targeted with improved clinical trials participant engagement	The app provides personalized pandemic preparedness information and recommendations to users, promotes trials and research programs, and organizes trials or appointments users attend. Upon consent, user's specific biogeographic data can be shared to appointed research teams for better trial efficacy studies.	Funding for initial app development and marketing; connection to data analysis team and reliable data source; connection to legal consultation for user data management
Multiplexing E-Nose for optimizing patient selection for clinical trials	Phase II (POC studies)	Utilizing biomarker(s) from specific cancer or infectious diseases, inexpensive, rapid, portable and non-invasive E-Nose screening could effectively stratify patients into subpopulations. POC studies can focus on the specific patient subgroup or the highly susceptible group in clinical phase II trial, which adaptive designs may be applied.	Investment on E-Nose business, including R&D, manufacturing and patent. Collaboration for E-Nose in clinical studies.
Manufacturing innovations for next generation non-egg-based influenza vaccines	All phases involved with the manufacture of clinical supplies (phase I–IV4)		
Machine learning-based model to accelerate vaccine development process	All phases in scope	The product will provide researchers in vaccine development a new way to accelerate vaccine research and development process. It will reduce the cost of vaccines.	Funding for model building and product development

Abbreviations: POC, point of care; R&D, research and development.

time, resulting in reduced immunogenicity and adverse events. It is more cost-effective than traditional methods utilizing lentiviral transduction, resulting in improved tolerance allowing for repeat dosing, more cargo types and capacity, and decreased development costs and manufacturing time.

The platform utilizes engineered mRNA for the purposes of overexpressing our lineage defining transcription factors which we have demonstrated to confer a central memory or naïve cell phenotype, with demonstrated enhanced persistence and resistance to exhaustion in preclinical animal models. In pioneering the development of TF-mRNA, Electrus offers a disruptive approach to immunotherapy, giving our patients hope in the fight against cancer.

Project 3: Multiplexing E-Nose for optimizing patient selection for clinical trials

Zika and dengue fever are mosquito-borne diseases, and there is no approved vaccine at present. By statistics, ~390 million people were affected by dengue fever,[17]

and dengue fever causes an estimated 40,000 deaths per year.[18] Further, there have been studies demonstrating ~20% of the population are mosquito prone, due to more CO^2 exhaled and more short chain fatty acids in their sweat and exhaled breaths.[19,20] Based on this observation, an E-Nose can be developed to identify this high-risk population by detecting the targeted biomarker amount and/or differences (see Figure 1). Vaccination should focus on what population is more vulnerable globally, especially when the vaccine supply is limited. In addition, Zika and dengue viruses are carried by *Aedes aegypti* and *Aedes albopictus*, which mostly distribute in the tropical regions[21] overlaid, which are mostly in with the low- and middle-income countries (LMICs). In order to consider economic restriction and easy use (i.e., layman design and low maintenance) in LMICs, a portable device can could meet the needs. An automation feature might be a plus to consider in this portable E-Nose. The E-Nose measurement requires no invasive sampling, so E-Nose is a class 2 medical device. To receive regulatory approval, a submission of 510(k) pathway to the FDA Center for Devices and Radiological Healthy should be considered. In addition, emergency use authorization can be considered for the medical devices to address the diagnostic and therapeutic needs of Zika and dengue fever. From prescreening by E-Nose, the volunteers can be stratified into high-risk group and low-risk group, based off of the verified biomarkers. For the POC studies at clinical phase II trials, the high-risk group should be registered, and, in this sense, an adaptive clinical design should be used. The primary advantage for this enriched clinical trial is time- and money-saving during subject recruitment, which expedites the clinical trial process for vaccine development. Further, it could also facilitate the study of mechanism of action for a vaccine. Importantly, based on the validated biomarkers, E-Nose can also be developed for a prescreening tool for clinical development of diagnosis and treatment for pulmonary diseases and cancer (see Figure 2).[22,23]

Project 4: Machine learning-based model to accelerate vaccine development process

Machine learning has been applied to various sorts of industries and this project sought to discuss its application in the vaccine development industry at this time. To gain a comprehensive understanding of the industry, a business plan of an artificial intelligence (AI)-based vaccine development company was developed. First, an extensive analysis of the business landscape was conducted. By using AI tools to assist researchers to make decisions during their process of vaccine development, the company could achieve its ultimate goal to accelerate the vaccine development process.

Regarding our products and services, the proposed company will offer the Smart-Vax Nextgen AI Based Analysis Platform along with AI and data analysis services tailored to diverse requirements. The research concentrated on six key areas: molecules preselection and prediction, mRNA sequence design aid, electronic health record data mining, improved monitoring minority group, event assessment, and phase milestones prediction. Second, a market analysis for the company was performed. Whereas large biopharma companies typically possess internal AI teams for developing their own models, small biopharma companies and academic laboratories often lack this capability. Target customers would be those who do not have their own AI models. Although competition exists in the market, it is assessed as not overly intense, offering exciting prospects for our company.

Next, a marketing plan centered around offering our product as a software-as-a-service to reduce study costs for customers was devised. The product will be categorized into three tiers: basic, pro, and premium plans. The basic plan targets individual users, whereas the pro and premium plans

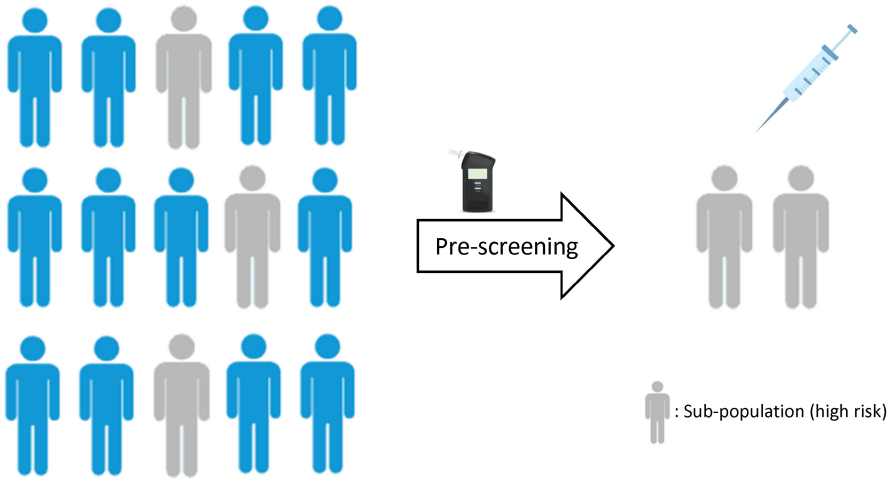

FIGURE 2 Conceptual approach for using E-Nose as a prescreening diagnostic to support vaccine trials targeted at Zika and dengue viruses carried by *Aedes aegypti* and *Aedes albopictus*.

cater to teams. A management and operating plan for the company was also developed. The estimated progress for the company in the next 2 years will be challenging but exciting. The product will be launched in 1 year and our goal is to gain 1000 subscribers in the first year. The major concern for the company is data privacy because the analytical process will be conducted with cloud computing and the vaccine data means a lot to potential customers. Therefore, the company is committed to prioritizing data privacy and ensuring the utmost security for potential clients.

In a word, with the help of computing models, the efficiency of the vaccine development industry will be greatly improved and it may take less time and cost to develop a vaccine product. Admittedly, there will be a lot of challenges for the company because of the evolution of AI models. However, it is believed that there will be a lot of opportunities for the company and the vaccine industry will benefit from the product.

Project 5: PanReady – a comprehensive pandemic readiness app

This goal of the project is to create a comprehensive application focused on pandemic preparedness. The idea originated from first-hand experience during the recent pandemic. As a researcher who worked on the development of a COVID-19 vaccine candidate, I was frequently asked questions regarding pandemics. Those questions came from people with very different backgrounds and covered a wide range of topics including vaccine safety, disease severity, etc. This prompted the idea to build a platform providing pandemic-related information in a trustworthy, data-driven, and easily understandable manner. The idea evolved further throughout the REG 6180 course this semester. It became clear that such a platform could contribute significantly to vaccine development across all stages by encouraging the participation of clinical trial participants and facilitating data collection.

On one hand, this application aims to communicate reliable information pertaining to pandemics to the public. The information it communicates can be categorized into three sectors: real-time pandemic updates, Personal Protective Equipment (PPE) usage and disease responses, and personalized health monitoring. First, the app offers real-time updates about both impending and active pandemics in specified regions. This could include, for instance, alerts about potential new diseases based on reported cases, and updates about disease variants during an ongoing pandemic. Second, the app serves as a helpful tool for users seeking medical resources, offering details about symptoms, self-care suggestions, appropriate PPE usage, as well as the nearest testing sites and open hospitals. Additionally, built-in features allow users to schedule and attend doctor's appointments via the app. Finally, with user consent, the app utilizes their biogeographic data to provide personalized health alerts, such as estimating susceptibility to specific diseases, and providing information on the vaccine and drug choice based on age or pre-existing health conditions.

On the other hand, this application could function as a platform to recruit, engage, and manage trial participants, and as a data source for research for clinical trial teams. Upon user consent, the app tracks the user's medical history and biogeographic data and shares them with chosen clinical trial teams per trial. The amassed data can then be used to assess the effects of clinical products on varied populations. It could also assist clinical trial teams in monitoring potential side effects among participants and responding swiftly to any adverse events. Furthermore, the app can serve to attract and interact with trial participants, potentially enabling the recruitment of a more diverse participant population in a shorter timeframe, thereby accelerating the clinical trial process.

To realize these objectives, the project will require resources from the "Sharks" to secure funding for the app's development and marketing. Given the app's focus on data analysis and visualization, connections to dependable data sources and data teams are also essential. Last, due to the contentious nature of data privacy, the provision of legal services for protecting user data is also a necessity.

ChatGPT usage and class engagement

From early 2023, ChatGPT has gained significant attention as a large language model capable of collecting and processing text data. At different points in the course, students decided to test ChatGPT's ability to recommend policies for pandemic preparation with approval from the instructor and the knowledge and interaction of the entire class. Two questions to ChatGPT (model 3.5)[24] were proposed:

1. What factors facilitated the global readiness to the COVID-19 pandemic?
2. What factors still need to improve to accelerate readiness for some new future pandemic threat?

The entire ChatGPT thread is contained in the Appendix S1 but has been summarized herein. Regarding the first question, ChatGPT provided eight perspectives: prior epidemic knowledge, advanced technology, global cooperation, public attention, established healthcare facilities, solid manufacturing foundation, investment in biotechnology, and remote work practices.

At an initial glance, ChatGPT's answers seemed valid but superficial. For example, it highlighted previous coronavirus and flu pandemics as evidence that prior pandemic knowledge better prepared us for COVID-19. It states, "The world had faced multiple epidemics in the past, such as SARS, MERS, and H1N1, which provided valuable lessons in public health measures, surveillance, and coordination." This answer was very much expected, as it is universally true. To get deeper to this point, ChatGPT was pressed to elaborate further. It responded with additional details and evidence. On the follow-up response, it mentioned the timeframes and durations of the three pandemics. It further highlighted how past pandemics fostered healthcare infrastructure and global collaborations. Surprisingly, it was capable of mentioning organizations like the World Health Organization (WHO) and International Health Regulations as evidence to support its ideas.

To assess the breadth of its responses, other answers were scrutinized. Although most were quite standard, such as improvements in research and development and investment in biotech, three responses stood out: improved manufacturing capacity, improved public awareness, and public attention to COVID-19. Again, to my surprise, ChatGPT acknowledges the efforts in improving manufacturing capacities which is critical at the early stage of the COVID-19 pandemic.[25] At the early phase of outbreak, the world faced a ventilator shortage. It was through more efficient resource allocation and management,[25] as well as global collaboration[26] that get this problem resolved.

For the second question, ChatGPT provided 10 key points to consider: building global disease surveillance systems, improving global collaboration in health care, building healthcare infrastructure, boosting the healthcare workforce, equitable resource distribution, effective communication to the public, integrating the "one health approach," building epidemic models and disease progression simulations, and investing in pandemic preparation efforts. Its response follows a similar pattern as the previous question. Among these responses, the "one health approach" caught our attention. We ask ChatGPT for further elaboration. It turns out, the goal of the "one health approach" is to identify and address the root causes of emerging infectious diseases by stopping zoonotic transmission of pathogens. This is a solid point given that viruses like coronavirus is more deadly when transmitted from its animal host to human beings and the severe acute respiratory syndrome-coronavirus 2 (SARS-CoV-2) pathogen is thought to be originally transmitted to humans in a seafood market.[27] Not only did ChatGPT recognize the importance of this concept, it also recommended practices to prevent zoonotic transmission, such as building surveillance systems and vaccinating animals.

CONCLUSIONS

In reviewing vaccine innovations – past and future, Geberding et al.[9] highlighted major milestones since 1970 and illustrated some of the broad population health benefits afforded from vaccine innovation throughout history. In addition, the authors exposed some of the related health benefits garnered as a result of vaccine innovation, specifically vaccine confidence. The appearance of condensed progress in response to the recent pandemic may be natural but also may mask innovative concepts which took a great deal of time and effort to mature. One of the benefits to teaching the next generation of scientists who would help develop vaccines in the future is to challenge them to think outside the box and, while learning from the past, embrace new technologies and advances in the immune system, vaccinology, and disease progression. The "Shark Tank" project presented herein was a vehicle for class engagement but also a tool for challenging students to embrace their potential role as future vaccine innovators.

Although somewhat controversial with respect to its potential for plagiarism, ChatGPT has generated much debate with some institutions banning its use in the classroom. Our experience with the AI platform was more positive. ChatGPT offered a fresh perspective for vaccine policy research and in the initial research and information gathering stages. It considered issues comprehensively and highlighted points often overlooked. Whereas it may not replace human policymakers, especially in the later stages of development and commercialization that involve intricate details, it can be a valuable addition for vaccine R&D. As an instructor, it was refreshing to observe that students did not accept the output as gospel and engaged in some form of verification of the responses via their own searching and discussion. It prompted excellent discussion on topics of prioritization and impact potential.

Clinical and translational sciences have evolved overtime to embrace new technologies and the necessity for innovation is ever present. Likewise, the necessity of multidisciplinary engagement is a key element for the future and teaching in this discipline can be enhanced by projects that promote such discussion and collaboration. Optimism for the next generation of drug and vaccine developers should be high when we can promote critical thinking in general.

AUTHOR CONTRIBUTIONS

All authors wrote the manuscript. J.S.B. and N.K. designed the research. M.I., Y.-M.K., A.E.M., R.J., and Y.W. performed the research. J.S.B. and J.M.S. analyzed the data.

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CONFLICT OF INTEREST STATEMENT

The authors declared no competing interests for this work.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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