Engaging undergraduate students in a biomedical research project: a virtual collaboration across institutes under the pandemic environment

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***Abstract*—In this work-in-progress (innovative practices) paper, we introduced a biomedical engineering research project to students in our primarily undergraduate institute (PUI) where sources and research activities are limited. Here, we present the motivation, background, best practices, initial assessment, and future work. Through virtual collaboration with a research institute, the project helped engage students in research activity, broaden the current scope of our project-based pedagogy, and address the typical challenges in online learning. In this semester-long project, a group of seven students from two schools developed a highly coupled Simulink model that captured the behaviors of the human cardiovascular system. The model aimed to study the aging effect of the aorta on cardiac power and blood pressure. Regarding the project design, we introduced the concept from the software engineering, i.e., "Agile Principle" and "Minimal Viable Product". Students started to develop a working model of one component (i.e., O_2 and CO_2 exchange model in the tissue) from the entire system. Through multiple iterations, the model was debugged, expanded, and polished. We recognized the critical role of communication in the virtual space. Besides routine team meetings on Zoom, we also mentored students with model debugging time through the Slack platform. Students developed their professional skills through weekly learning journals where ideas, reflection, confusion can be shared with faculty. The preliminary assessment indicates positive impacts, such as growth mindset, time management, and more career options.**

Keywords—Project-based Learning, Undergraduate Research, Virtual Space Collaboration

I. Introduction

In 2020, the outbreak of Covid-19 pandemic has significantly impacted many aspects of the society [1], far beyond the healthcare system where frontline professionals are directly combating against this respiratory disease. Heavily relying on social interaction, higher education, inevitably, is also in crisis due to the restriction on campus facility and limitation of in-person learning [2]. A rapid transition to online teaching created great concerns for many universities and colleges. In a recent study, Babatunde et al. [3] summarized major challenges reported by students and faculty: accessible technology (availability, affordability, and digital competency), heavy workload, compatibility of various disciplines (theory vs. hands-on) and even human/pets' instruction at home. As the pandemic showed no sign of improvement in Fall 2020, anxiety and stress started damaging students' mental health conditions [4, 5]. However, on the positive side, faculty and administrators across the nation are highly collaborative and creative to mitigate the challenges. Some faculty introduced engaging activities in breakout rooms and transited from teaching complex abstract concept to more problem solving [6]. Some graduate mentors offered research symposium focusing on technical writing and data analysis that could be done remotely [7]. Others overcame physical isolation by implementing virtual reality (VR) technology [8] in conducting experiments. Interestingly, the VR technology is reported to effectively relieve the "Zoom fatigue", since it can involve with non-verbal body language in teaching practices [9, 10]. Despite trial and error, educators have gained valuable experience and deeper understanding that digital transformation of higher education is no longer optional but essential to every student's success.

Unlike large universities, with less technological resources available and funding, small institutes and programs are more likely to experience severe hardship under such a radical transition. Our program, Iron Range Engineering (IRE), is also unavoidably affected. Located in rural area of Minnesota, IRE is an integrated engineering program supported by Minnesota State University, Mankato. Since IRE has fully adopted Project-based Learning (PBL) for all classes and design projects, the disruption of hands-on activities created major hurdles for students to gain valuable experience in industry.

Although no perfect solution exists, we stay positive and recognize it as an opportunity for growth. Some essential features of online education, such as accessibility, lower cost, and flexibility [11], could virtually benefit students in rural areas. Additionally, the pandemic has extended the possibility for virtual collaboration across various campuses, allowing small programs to receive support from resourceful institutes. For these reasons, we design a virtual collaborative space by introducing multiple computation-based research projects, in which students applied MATLAB and Simulink to model the behavior of human cardiovascular system. Comparing to physical experiments, research depending on modeling, simulation and computation may have less disruptions. In this paper, we will discuss the structure of one research project inspired by the "Agile" method, our motivation, some best practices of virtual collaboration as well as preliminary assessment. We believe the innovative practices may be helpful for other similar engineering programs to design their own project, especially in a virtual space.

II. BACKGROUND

A. Our current PBL model

Founded in 2008, IRE offers Bachelor of Science in Engineering degrees for students who mostly transfer from local community colleges. The program enrolls around 50 students and was ABET accredited in 2012 and received multiple awards since then. The PBL model requires students to take a 3-credit design class every semester in the upper division, meaning they are spending about 20 hours on design projects each week. (Detailed information of the program can be found in [12].)

Typically, at the beginning of a semester, projects from local mining companies (served as industry clients) are assigned to a group of 3-4 students. Starting from scoping, students will draft a team contract, develop CAD drawings or fabricate a physical model, perform calculations and test the model as validation, have multiple client meetings to receive feedback and finally deliver the work to the client. Students acquire knowledge of design principles from weekly design classes and immediately apply them into their daily work. Meanwhile, students can gain industry experience through project management, oral presentations, and on-site visits. Each student team is guided and critiqued by a facilitator who could be a faculty member or an experienced engineer. Moreover, the structure of student project is under dynamic changes to constantly push students outside their comfort zones. For instance, we recently introduced "Agile Principles" from software engineering [13], which demand iterative design work continuously taking in feedback. After 4 weeks into the project, students are required to present the preliminary design known as the "Minimal Viable Product" (MVP) [14] that meets client's basic requirements but suffers many loopholes. Receiving feedback and critiques, students are working on improving the product in the next two iterations.

Under this PBL framework, building research element in a design project could be also beneficial. First, first it will broaden the scope of projects beyond mining and heavy machinery design which covers 90% on our current project menu. Students will gain exposure to essential parts of modern technologies (e.g. simulation and computation). Potentially, it will create new career paths outside the rural community. Second, the benefits to engage undergraduate students even as early as their time during community colleges [15] into research projects cannot be overstated. Research Experience for Undergraduates (REU) Program, for example, supports thousands of students in STEM research across more than 600 sites. Assessment on REU participants [16, 17] indicated that undergraduate researchers generally could improve their academic performance, enhance technical communication skills and develop their pathway to graduate studies. To prepare the students for the future global workforce equipped with knowledge of Industry 4.0, we create this computational research project in collaboration with a research institute that grants access to essential resources such as coursework and personnel.

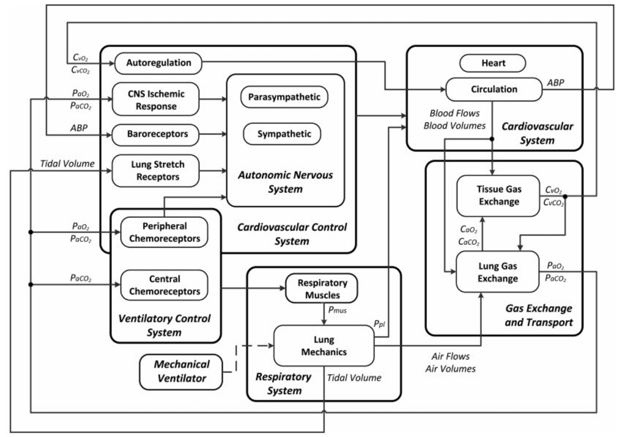

Fig. 1: Overview of the cardiovascular system diagram. [18] (Students are working on the subsystem of "Gas Exchange and Transport")

B. Modeling a human cardiovascular system: a brief technical overview

The motivation to pursue research in cardiovascular system stems from the recent development in computational studies on arterial stiffness, a well-known factor associated with heart failure and responsible for about 25% mortality in America [19]. With a stiffer arterial wall, the afterload of left ventricles increases, and coronary perfusion alters [20]. Studies also found that stiffening promotes excessive pulsatile energy into the cerebral microcirculation, leading to organ damage in kidney and brain. Arterial stiffening becomes severe with aging, especially for people older than 50 years old or with medical history of hypertension [21] or obesity [22].

The computational approach to study cardiovascular system dates back in 1950s, when Grodins et al. [23] formulated equations for steady state operations of two ventricles and heart-lung preparation. With the rapid growth of computational power, cardiovascular model also becomes more capable of predicting physiological dynamics. In the past decade, several works focused on developing control models for a better coupling between the cardiovascular and respiratory systems, making it possible to monitor key physiological parameters (e.g., heart rate and blood pressure) based on the human metabolism. Albanese et al. [18], notably, integrated the five major systems (i.e. Cardiovascular, Respiratory, Autonomic Nerve, Cardiovascular Control, Gas Exchange and Transport) into one comprehensive model that is able to study the cardiopulmonary interactions (Fig.1). In their follow-up validations [24], the dynamic model took in hundreds of parameters and was tested under hypercapnic and hypoxic conditions. The output response of the model (e.g., hear rate arterial pressure, and cardiac output) demonstrated consistent results in comparison to clinical data available in literature.

Despite its great importance, arterial stiffness, has not been well studied in the modeling context. Building mostly on the mathematical work of Albanese et al. [18], the current project constructs a Simulink model to evaluate the effect of arterial stiffness on blood pressure. It is suitable for a multi-semester undergraduate research project considering the level of difficulty as well as significance.

TABLE I TASKS DISTRIBUTION OVERVIEW FOR FALL 2020 AND SPRING 2021

Time	Tasks
Aug-Oct 2020	Team IRE: MVPs development of "Gas Exchange & Transport" model. Team NDSU: three other models in Fig.1
Nov-Dec 2020	Both: Model integration and testing
Jan-Mar 2021	Team IRE: Team transitioning Both: Model validation with experiments.
Current	Both: Parametric studies on arterial stiffness; Report and dissemination.

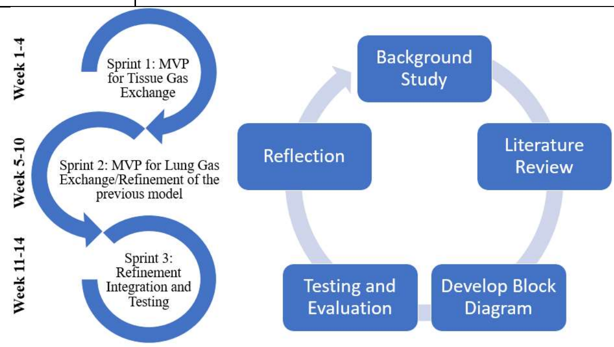

Fig. 2: Project structure (Fall 2020) integrated with Agile Method

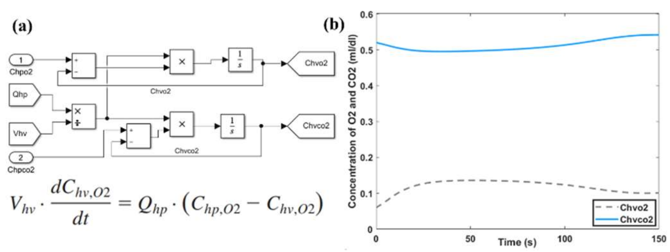

Fig. 3: (a) Simulink block diagram that describes the O_2 and CO_2 exchange in Coronary Peripheral Vessels (part of the tissue gas exchange). [18] (b) A testing plot of O_2 and CO_2 showing the correlation of gas exchange. The system stabilizes itself around 150s.

III. STUDENT RESEARCH PROJECT DESIGN

A. Student Team Formation

The North Dakota State University (NSDU) has provided us crucial resources, including mentorship from two graduate students, online engagement technologies and its recently developed Innovation-Based Learning (IBL) pedagogy approach [25]. In Spring 2020, one IRE student and the two graduate students from NDSU took one of the biomedical engineering classes online and formed a team to work on the course project, simulating blood circulation of a heart model ("cardiovascular system" in Fig. 1). Later, we connected the students with a potential client, Dr. Larry Mulligan. He was a senior consultant working for a pharmaceutical company in New Jersey and was interested expand the model to study arterial stiffness impact on blood pressure. The two teams were officially established when four more A program students joined the research in Fall 2020. Team IRE included all five IRE students who participated this research project to fulfill their 3-credit design course requirement. We did not have an official selection process and allowed interested students to join the team. The two graduate students were in Team NSDU, targeting on more advanced design tasks and trouble shooting. They also served as mentors and the research would partly be included in their master's theses. The entire project was founded on the bottom-up approach, allowing students to work on individual component first followed by integration. The distribution of work is listed in the Table I. Before the project started, Team IRE received Simulink and MATLAB trainings for a week.

B. Agile Method: Project Design and Experience

The first task for the team was to establish a detailed working plan that included three iterations (i.e., sprints) with the Agile Method. Different from the traditional "linear" step-by-step design procedure, Agile Method is an iterative design approach that focuses on "Deliver quickly; Change quickly; Change often" [26]. More specifically, the organization of Agile Alliance listed 12 principles behind the "Agile Manifesto" [27]. To name a few: (a) Welcome changing requirements, even late in development; (b) Agile processes promote sustainable development; (c) Build projects around motivated individuals; (d) The team reflects on how to become more effective, then tunes and adjusts its behavior accordingly. These principles have been widely adapted in software engineering, which demands fast-paced continuous improvement and customer-centered services. Several software engineering programs [28-30] have integrated Agile Method and MVP in their capstone design curricula, improving students' motivation, resilience, and management skills.

Although Agile is originally a software engineering concept, its principles of iterative and customer-centered design may fit well in other engineering design works. The team designed the 3-Sprint model (Fig. 2) inspired by the Agile Method. Each sprint had a focus but also consists of similar basic components such as literature study, development of block diagram, model testing and evaluation, and reflection. They adopted Gantt Chart to track everyone's working progress. However, they soon encountered a challenge to specify the deliverable, also known as the MVP. Even though the students learned about concept of MVP in the design class, it could be rather intimidating for the students to think about an MVP for a highly complex system depicted in Fig.1. Under the business development context, an MVP is a product with some functions that meet basic customer requirements. More importantly, it usually serves as a starting point to learn and gather customers' feedback. Under our context, we asked students two questions: (a) What are most important features you would like your MVP to capture? (b)What would you learn from the MVP?

We encouraged the team to talk to their client, Dr. Mulligan, and to converge the problem by looking at some key physiological parameters from the literature. The ill-conditioned open-ended questions sparked good discussions among the students. Here, they began to adapt to the Agile Principle of "change quickly and often" when integrating information from various sources. Eventually, they defined their MVP as a model that "correctly represented the gas exchange (concentration of O_2 and CO_2) phenomena in the tissues based on a pre-defined purely artificial input (e.g., sinusoidal or step function inputs)". Fig.3(a) depicts one of the twelve equations in [18]. To validate their model, they input a step function. In Fig. 3(b), the plot shows the inverse relation between O_2 and CO_2 and the stabilization of the system after 150s under normal conditions.

At the end of Sprint 1, besides regular team presentations, students reflected on their learning and client's feedback. Some constructive critics made them aware that polishing would be necessary for the next sprint. In Sprint 2, students developed a similar model for the lung gas exchange. After one full iteration, they were confident in translation of differential equations into block diagram. When connecting two models together, they did some independent studies on the solver configuration to facilitate smooth computing. For example, the delay blocks (1/z) were added on in the previous model to minimize the effect of algebraic loops.

In parallel to Team IRE, Team NSDU developed three remaining sub-systems. In the final sprint, both teams revisited their models, set up parameters, connected inputs and outputs and finally integrated five subsystems together. For validation, Dr. Mulligan provided experimental data (e.g., hear rate) as input. The model was able to evaluate the blood pressure but had a few errors that prevented it from making meaningful predictions on arterial stiffness impact. As a result, the project is currently under the second phase of development.

C. *Communication and Virtual Collaboration*

The team communications occurred multiple times during a week. These meetings were self-organized by the student teams who planned agendas ahead. On Wednesdays, we met with the students to offer some hints and to help debug the model. The client will join the Wednesday's meeting biweekly and provided experimental data that helped the model validation. On Thursdays, both teams had some peer learning time, in which one student often led the discussion about a technical topic. The graduate students played a key role by introducing important concepts such as solver setting, data interpretation, sampling time etc. A follow-up live demo usually helped students quickly convert concept into practices. Moreover, we added on a few tools to facilitate communication under the pandemic.

a. *Slack*: The slack platform had multiple channels, so that students could post their discoveries and questions in the community. It facilitated efficient off-line communication. We committed quick responses to student's questions.
b. *Trello*: The team suggested this platform for project management. The work could be distributed to everyone with a clear deadline.
c. *Google Drive*: It was mostly for sharing documents and models. It is important to document changes for multiple iterations. Some changes might turn out to be incorrect later. Students also posted their meeting agenda, minutes and recording here.
d. *Flipgrid*: Presentation videos were made and shared to gather more feedback. They also had a chance to watch some of the presentations from the graduate students, which served as excellent peer learning experience.
e. *ZOOM*: Besides routine meetings, we also created community building activities, such as icebreaker questions, Scavenger Hunts, interactive games on *Jackbox*. These activities generated sense of community and relaxed the high stress when staying at home during the pandemic.
f. *Reflection Journals*: Students wrote a reflection journal each week, in which they reflected on their mindset and professionalism. They could also report issues directly to us.

TABLE II EXAMPLE QUOTES OF STUDENT'S REFLECTION JOURNALS

Week 2	"When I looked at the research papers for our design project, I was overwhelmed by the vast amount of information contained in the papers."
Week 4	"I think our biggest challenge is going to be identifying all the errors in the model. I anticipate it is going to be quite tedious."
Week 9	"My project has been going well. The troubleshooting of the model is taking a while, but this part of the project is the hardest."
Week 13	"I feel like more engaged in the project in the last few weeks than previously, and it feels good to contribute in a substantial way."

Regardless of what techniques implemented here, it is also crucial to recognize that the student's success relies on our time commitment, support, and genuine care in their wellbeing.

IV. REFLECTION AND CONCLUSION

Looking back, we reflect on our process with some preliminary assessment, including analysis of reflection journals and interviews from Team IRE in Fall 2020. First, a quick scan of the quotes from reflection journals (Table II) reveals a process of "confused/overwhelmed, acceptance, catching up and well performed". Under the fast-paced Agile environment, as faculty, we need to have patience and posit ourselves as learners. It is OK to say, "I do not know." For instance, besides guidance in technical literature study, Growth-Mindset [31] was a focus of the instruction and "Fail fast and learn quicker" was our encouragement at the early stage. After a few trials and errors, the team digested the level of difficulty and set their expectation appropriately. Towards the end of the project, the team evaluated the takeaways in an objective manner.

Second, the peer learning time is more effective than reading literature only individually. A typical undergraduate research project usually begins with lengthy literature study, which could help build theoretical foundation and yet could diminish their interest if unguided. Working with graduate students with live demos mitigated their fear and promoted understanding of concept by visualization and practices. This echoes with several literature reports [32, 33].

Finally, the project broadens student's view in engineering and has already made positive impact in their career options. In our follow-up interviews, one student revealed that he had secured a job offer from a medical device company. Another said he would consider careers in the computation industry.

V. FUTURE WORK

After receiving the positive feedback from the students, we have extended the research project for future students in areas such as machine learning, medical device design and metabolism. Formative assessment will be done to evaluate their computational thinking before and after the research experience. It would be interesting to compare the UR experience in our rural areas with the national surveys. In addition, we will add more mental health related discussions in the reflection journals to mitigate high stress and anxiety. Interviewing the students is also on our agenda to document their best practices in research and to promote the peer learning experience.

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