1 Improving Undergraduate STEM Education

STEM undergraduate education faces several challenges in training students for new and emerging industry-relevant fields. One of the main challenges is that traditional STEM curricula often prioritize technical proficiency over soft skills such as communication, collaboration, and leadership. However, in today's fast-paced and interconnected world, these soft skills are increasingly important for graduates to succeed in their careers [36, 56, 64, 101]. Another challenge is providing practical experiences to students. While theoretical knowledge is important, it is often insufficient for graduates to excel in their roles in the workforce. Employers are looking for graduates who can apply their skills in real-world settings and adapt to new challenges quickly [60]. Lastly, there is a need to bridge the gap between students and industry [37, 51, 77, 95, 96]. STEM undergraduate programs must stay up-to-date with the rapidly evolving demands of the industry and equip their students with the necessary skills to meet those demands.

Living labs (LL) are innovation ecosystems that often operate in a territorial context (e.g., city, university, research lab) that concurrently integrate research processes and hands-on learning [94]. According to the American Association of Community Colleges, LL refers to "hands-on learning opportunities for students that merge academics and cutting-edge campus facilities to provide students with real-world skills" [23]. In another definition, researchers from Portland State University state that LLs are "a given place where problem-based teaching, research, and applied work combine to develop actionable solutions" [78]. Overall, the goal of LLs is twofold [94]: (i) to provide a playground inside a controlled environment to test new concepts, enabling rapid low cost prototyping while simultaneously being a catalyst for innovation in the creation, testing, and demonstration of new technologies, and (ii) to present these concepts with demonstrators through an exhibition space that evolves as new technologies are developed.

Increasing evidence shows that adopting LLs is beneficial in educational environments [97,98]. The Schools as Living Labs project proposes a new framework based on open innovation methods for schools across Europe to make STEM education more relevant, systematic, and inclusive [1]. At Stanford, a project is in course to transform the university into a LL [92]. Its goal is to apply the concept of LL to boost sustainability actions throughout the university. Rutgers University is another higher education institution that is looking to create living laboratories on its campuses [85]. However, there is no current initiative for employing living labs in STEM undergraduate education, especially relevant to the large and important health domain. Health-tech is a high demand area, as demonstrated by the reached record levels of funding (US$29.1 billion in 2021 and the market is expected to continue growing in the next few years) for health-tech organizations in recent years [6, 27, 61, 62].

In this project, our primary goal is **to implement and evaluate living labs as means of enhancing multidisciplinary STEM undergraduate education**. We propose a Living Lab of Intelligent Systems for Health, called iHealth-LL. It will (i) serve as a national model of experiential learning of multidisciplinary STEM undergraduate training in this area while also (ii) address the major shortage of highly qualified professionals who can create and maintain intelligent systems for the health domain. The LL will be implemented in the Department of Computer Science of the College of Engineering with the support of the Department of Neurology of the School of Medicine at Virginia Commonwealth University. The research processes will be implemented by professors from the software engineering laboratories of the Department of Computer Science. The target population will be undergraduate CS students, who will also interact with VCU Health employees and patients. Finally, besides NSF IUSE, iHealth-LL partners with VCU Health, one of the nation's leading academic medical centers [32].

The iHealth-LL will prepare undergraduate students to combine health and software engineering skills while tackling one of the most pressing recurring questions of STEM undergraduate education: How can we enhance multidisciplinary STEM undergraduate education to better prepare the new workforce considering both soft and technical skills? Table 1 illustrates the specific objectives driving the proposed work and expected outcomes.

Table 1: Project Objectives and Expected Outcomes.

Specific Objectives	**Outcomes**
Objective 1: Create a LL of development of intelligent systems for health	Creation of a living lab for research and teaching & Development of training materials
Objective 2: Create a training program on the development of intelligent systems for health	Increased workforce that is able to program cutting-edge health systems
Objective 3: Create an internship program at iHealth-LL in which fellows will work on supervised projects	Increased ability (technical and soft skills) to complete tasks required to develop intelligent health solutions
Objective 4: Create an Annual Workshop on Intelligent Systems for Health	Presentation of projects and talks
Objective 5: Institutionalize the LL through a new undergraduate certificate	Certificate in Engineering of Intelligent Systems for Health (iHealth-Eng) developed and institutionalized
Objective 6: Evaluate iHealth-LL as a new model to support multidisciplinary STEM undergraduate education	Benefits, lessons learned, and limits of the proposed approach

The proposed LL and its program components enable the following research questions: **RQ1** - Does the LL model transfer effectively to undergraduate STEM education? **RQ2** - Does the LL model train students to be better developers of reliable, safe, and maintainable intelligent systems for health? **RQ3** - What are the benefits of experiential learning activities in education of engineering intelligent systems for health? With these questions answered, firstly, we will be able to define how LLs can be implemented to support experiential learning multidisciplinary STEM undergraduate education. Additionally, we will be able to define the bounds of using LLs to support undergraduate education on developing intelligent systems for health, determining the limits of this approach.

2 iHealth-LL - A Living Lab of Intelligent Systems for Health

LLs promise the opportunity for experiential learning and employability skills for students, a rich and real-world learning experience for academics, an improved student experience, and new levels of student satisfaction [85]. Regardless of their scope, size, or definition, all LLs have experiential learning at their heart [68]. In experiential learning, students actively engage in complex tasks that reflect the problems graduates likely encounter in the workplace. To bridge the academic and employment skills and knowledge they are developing through these tasks, students participate in reflective activities that help them articulate the relevance and implications of the experience for lifelong learning. There is a significant and continuous improvement in the perceived educational value of the experiential assignments, suggesting LLs are promising for experiential learning [68]. In this section, we present how we leverage the LL model to develop the iHealth-LL.

The iHealth-LL achieves several original training components, divided into technical and soft skills.

The technical skills comprise program components focused on how to engineer intelligent systems for health:

- Engineering Intelligent Systems for Health: Students will learn software engineering concepts and methodologies focused on requirements, architecture, design, evolution, and quality. In particular, students will be exposed to the latest research in engineering systems for health, including cutting-edge areas like the intersection between health systems and software quality and evolution (e.g., [4, 5, 14, 31, 53, 59, 104, 109]).

- Artificial Intelligence (AI) Applied to Health: Students will learn techniques and methods in AI that can be employed to implement intelligent systems for the health domain (e.g., [67, 71, 72, 88]).

In complement to technical skills, the iHealth-LL also covers the soft skills:

- Industrial Engagement: The distance between academia and industry is a recurring concern for advancing knowledge [37]. We intend to reduce this gap by achieving a close relationship with VCU Health [32]. iHealth-LL will also host invited talks of industry specialists on engineering systems for health.

- Professional Development: For a successful career in computing, students must acquire non-technical skills like communication, collaboration, entrepreneurship, and critical thinking. To this end, the iHealth-LL allows trainees in supervised projects to develop highly sought-after professional skills by performing group tasks that require oral and written communication, discussion of key issues, and creativity for solving real-world problems. Participants will also be part of the organizing committee of the annual Workshop on Intelligent Systems for Health, in which they will present their projects to a large and diverse public.

- Leadership and Mentorship: see Section 2.5.

- Diversity, Equity, and Inclusion (DEI): iHealth-LL assumes DEI as a central part of its goals and provides participants with information and experiences in creating and sustaining an equitable and inclusive environment as the best approach toward leveraging this asset into universal excellence and success. To successfully accomplish this, all the participants will take part in at least one DEI training and activity. An example of an initiative they will take part in is the Mary and Frances Youth Center at VCU, which provides programming and training to enhance the lives of youth in the Richmond metro area [100]. Besides, we will design educational materials that are inclusive to a variety of populations (more details in Section 9.1.1). We will also target recruitment and advertisement of the program to underrepresented populations (see more details in Section 9.1).

Participants in iHealth-LL will be eligible for a new undergraduate certificate in Engineering of Intelligent Systems for Health that we will develop and institutionalize (see Section 2.2).

2.1 Program Elements

We envision an environment composed of development and demonstration areas, as illustrated in Figure 1 (**Objective 1**). The demonstration area comprises the necessary technology to allow the rapid prototyping and demonstration of new solutions for the health domain, such as mixed and virtual reality headsets, wearable sensors, drones, surface displays, collaborative robots, and medical devices. The development area will be composed of 15 workstations and appropriate software licenses, as well as resources to catalyse idea generation and discussion, such as digital discussion boards and flip interactive signage. The iHealth-LL team will combine these technologies to provide the students with a unique environment that stimulates their creativity, critical thinking, and innovation. Lastly, as important as all the technological devices and infrastructure is the access to the valuable source of information through a close partnership with members of VCU Health. Actual challenges faced in the organization as well as controlled access to data necessary to run studies will be timely analyzed respecting all ethical and legal aspects.

Experiential learning is central to our iHealth-LL. In the following, we describe the planned experiential learning activities.

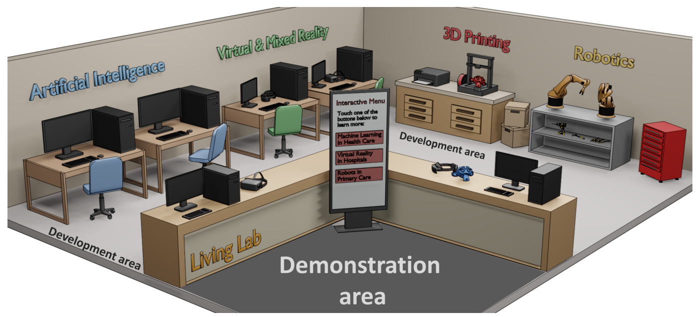

Figure 1: LL sketch.

Course-based activities (Objective 2). We will initially develop students' knowledge and skills through courses. Two completely new courses on *Artificial Intelligence Applied to Health* and *Engineering Intelligent Systems for Health* will be offered as part of the current CS undergraduate program at VCU. The idea is to have highly practical courses, totally integrated with the living lab. The *Artificial Intelligence Applied to Health* course will focus on the following learning objectives based on state-of-the-art literature [17, 42, 55, 73, 86, 103]: (i) understanding the use of machine learning in healthcare; (ii) developing deep learning models for image analysis in health records; (iii) predicting disease and patient outcome using artificial intelligence tools; and (iv) understanding bias and ethics on the use of algorithms in health. The *Engineering Intelligent Systems for Health* course will have the following learning objectives based on state-of-the-art literature [4, 5, 14, 31, 53, 59, 104, 109]: (i) understanding how to elicit and describe requirements for health; (ii) employing best practices of software maintenance and evolution to health software systems; (iii) applying software architecture best practices in health systems; and (iv) proposing quality assurance strategies for health systems. The learning objectives and the course implementation will be discussed between the PIs and the External Advisory Committee, who will provide feedback to adjust the course structure as needed, including relevant content, scope, practical and theoretical assignments, and bibliography. We will ensure the activities' understandability and compatibility with the lab infrastructure by conducting initial pilot studies with the GRAs, PIs, collaborators, and members of our lab. We will run multiple rounds of discussion and refinement for each course until reaching a consensus among the PIs and advisory committee about the suitability of the courses and their assignments. During and after each edition of the course, based on the data collected, the PIs and the external committee will meet to reflect on and adjust the courses as needed.

Seminars (Objective 2). We will host invited talks by industry specialists on engineering of intelligent systems for health. These talks will spark discussion on the state of the art with industry experts and help connect students to the industry. We will run at least two seminars per semester.

LL Internships (Objective 3). Students going through this experiential learning experience will work on supervised projects, what we call an internship in the lab. The experience will be similar to a capstone project, in which the students will develop a small project proposed by a client and supervised by the lab instructor. The clients of these projects will be faculty members or graduate students from VCU Health. In the LL, the students will have all the necessary infrastructure to develop and demonstrate intelligent health software solutions. Through close interaction with mentors and clients, participants will develop soft skills.

The students will work on group projects. Each group will be composed of 4 CS undergraduate students + 1 graduate student from the School of Medicine. The graduate health student will act as the customer and will be responsible for defining the requirements of the project to be developed. Projects are required to benefit from the interplay between the use of cutting-edge devices, artificial intelligence techniques, and a problem from the health domain (see Section 2.2 Sample Projects).

Annual Workshop on Intelligent Systems for Health (Objective 4). Students will be stimulated to exercise their leadership and professional development skills through a workshop. Students will be mentored by the co-PIs, who will be the general organizers of the workshop. The workshop will allow students to present their projects in the demonstration area of the LL, helping to increase awareness of the field. Professors and leaders from other universities will be invited to participate, and we will hold a special session dedicated to presenting the program to them.

iHealth-Eng Certificate (Objective 5). iHealth-LL participants will be eligible for a new undergraduate certificate in Engineering of Intelligent Systems for Health (iHealth-Eng) that we will develop and institutionalize. The certificate will be issued once the participant has completed all iHealth-LL activities, including taking the Artificial Intelligence Applied to Health, Engineering Intelligent Systems for Health, iHealth Supervised Project I, and iHealth Supervised Project II courses. The last two courses institutionalize participation in the mentored project in the iHealth-LL internship. Students not interested in the certificate can still take Artificial Intelligence Applied to Health and Engineering Intelligent Systems for Health as electives. We will also work to create adequate prerequisites and corequisites for the courses.

2.2 Sample Projects

(i) Machine Learning for diagnosis and treatment of ADHD in VR. Research in the area focus on the development of diagnostic tools for Attention-Deficit/Hyperactivity Disorder (ADHD) in children based on ML and VR [39]. Researchers developed an ADHD-VR diagnostic tool [106] based on the DSM-5 ADHD diagnostic criteria to build a ML application that can produce an intelligent model to receive complex and multifaceted clinical data. Deep learning models proved to diagnose more easily and accurately [107] by combining quantitative and qualitative data to reduce bias and collect essential information. However, these works focus on the diagnostic phase, not on treatment and intervention in VR environments, and especially not for among adults. The focus of the project would be to develop machine learning models to classify, in real time, the users' activity in the VR environment, providing immediate intervention to help the user to refocus on their task. Figure 2 presents an initial version of such system in our lab. The classification of real-time data is a well-known research area known as data streams. Dr. Cano has extensive experience in designing ML algorithms for real-time data classification [3, 11, 12].

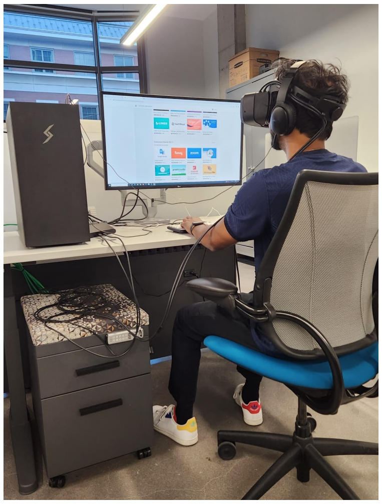

Figure 2: ADHD Project.

(ii) Stroke rehabilitation system based on brain computer interface and mixed reality. Stroke is the second-leading cause of death and disability combined in the world [63]. The primary method to

induce motor recovery in stroke patients involves active motor training via physical and occupational therapies [43]. However, these treatments are some times unsatisfactory due to time and cost involved. Rehabilitation based on brain-computer interface and mixed reality can improve the efficacy of therapy as it will involve the active participation of patients' brains during rehabilitation sessions [105]. The development of such system would have the potential to enhance future stroke treatment both in clinics and at home. Drs. Falcao and Bettermann have extensive experience in stroke treatment and rehabilitation. In fact, Falcao is currently the Interim Director of the VCU Health Stroke Center and Bettermann is the Division Chair for Vascular and Critical Care Neurology.

By getting involved in the development of projects like these, besides contributing with students soft and technical skills improvement, projects can have a chance of being prototyped and evaluated in actual scenarios at VCU Health. Impactful projects would even result in patents and products.

2.3 Building Community via a Cohort Model for Participants

The iHealth-LL will provide undergraduate students with extensive opportunities as described in Section 2.1, from simple contact with cutting-edge devices to the possibility of developing projects in partnership with faculty members and VCU Health students. We envision the participation of 60 CS undergraduate students (30 in years 2 and 3 of the project).

The PIs will recruit undergraduate students to participate in the program, focusing on attracting a diverse set of students. For example, the PIs will implement mechanisms to ensure a minimum of 50% participation of women and other minorities. **We aim to increase diversity in computer science and maximize our impact on students' educational trajectories**. To recruit students, each fall, PIs Spinola and Falcao will give talks at their departments. Because of their extensive experience in delivering academic and industrial talks, they are able to inspire students to become excited about the iHealth-LL activities, emphasizing the importance of intelligent solutions for health for society. Additionally, we will send emails to student lists and promote our program via social media.

To select students, we will not, like many traditional academic sites, always choose the best students according to only academic metrics such as standardized test scores, which have been shown to favor advantaged students [75]. We intend to identify and recruit students who do have talent but, due to previous lack of opportunity, family circumstances, and systemic bias, are currently struggling to attend graduate school. To identify under-invited students we will use questions on our application questionnaire that correspond to risk factors, such as parental educational levels, information about how they are financing their degree (e.g., through a work-study program), and low standardized test scores. From this group, we will then use performance-based metrics, such as college GPA and performance within their major through the lens of the students' life circumstances to select talented students that would benefit from our program.

Co-PIs have a long history of recruiting women and students from underrepresented communities to their labs; the demographic of their labs has been majority (50-100% in any given semester) women, black, and students of Latino or Hispanic descent. This positions the proponents in an advantageous position to attract underrepresented student populations as part of this project.

2.3.1 Supportive Community

We will strive to build an inclusive community and provide adequate support for individual necessities. We strongly believe that the social ties and the social capital that students build during their participation in the program are critical for their success not only in college but also in their professional lives. Besides promoting group activities, we will create communication channels (e.g., Slack or Discord) so students can keep connected and help each other. In terms of more objective measurements, we will design and administer surveys. The surveys will be adapted from the User Engagement Scale (UES) [70] and sense of belong instruments [41, 87]. Sense of belonging has a strong association with the intention of people to stay in a college [93].

2.4 Integration into CS Curricula

We outline a typical plan of study (Table 2) for a student in the iHealth-LL program pursuing a CS bachelor degree in the iHealth-LL emphasis area, our primary target population. During one academic year (Fall, Spring, and Summer), participants will fulfill required training elements—especially coursework and the team-based research project(s)—and to establish a strong sense of community and collaboration. While students will participate in new activities that form the basis of the iHealth-LL program, they will also follow a standard time-line established for the general CS undergraduate student population at VCU.

Table 2: Example timeline of a typical CS undergraduate student's trajectory through the iHealth program. a. Indicates if an activity is a required component of the iHealth-Eng certificate.

	Year 1			Year 2			Year 3			Year 4			iHealth-Eng
Activity or iHealth Program element	**FA**	**SP**	**SU**	**FA**	**SP**	**SU**	**FA**	**SP**	**SU**	**FA**	**SP**	**SU**	**Certificate[a]**
CS undergraduate coursework													Yes
iHealth coursework													Yes
iHealth internship													Yes
iHealth seminars													Yes
iHealth annual workshop													Yes
iHealth DEI													Optional

2.5 Mentoring Plan

The professional development of the students planned for this proposal will be supported in different ways and by different mentoring. The ultimate goal of these activities is to ensure that the students will acquire the technical, scientific, and professional skills necessary to complete the IUSE program and develop their careers. Before diving into details, we recognize that no "one size fits all" approach to mentoring will work for all students. It is important to consider the individual differences, needs, backgrounds, and circumstances that change the way that mentoring may happen. The PIs of this proposal adopt a live mentoring process, in which the mentors and mentees will learn how to create a healthy relationship, which will tailor the activities. At a higher-level, the expected mentoring activities for the undergraduate students for this proposal are planned as follows.

Orientation. We believe that the mentor-mentee relationship must be close. From the beginning, we will make clear that the PIs follow an "open door" approach, in which the students are welcome to stop by at their offices when necessary. That said, we will have frequent meetings (once per week) in the first month of joining. The topics will include the expectations, defining the timeline, follow-up on topics of study, research methods, interaction with the lab members, processes, and ethics in research. After that, we will keep monthly meetings and the "open door" approach.

Developing presentation and communication skills. The students will give presentations in the PIs research group meetings and in Annual Workshop on Intelligent Systems for Health. The PIs, graduate students, and other faculty will provide feedback that will help the student improve the effectiveness of their presentations.

Constant feedback. Feedback is key for guiding undergraduate students. We provide individual feedback to our undergraduate students, assessing their progress and offering guidance in topics that they need improvement. Feedback meetings may happen at any time—and can be requested by the student—however, we formally have individual feedback sessions every semester.

Ethics. Given that we deal with human subjects—specifically students—we take ethics and responsible behavior in research very seriously. The PIs will follow up on every study to guarantee that they are ethically designed and conducted.

Career counseling. From the beginning, career will be a central conversation topic between PIs and students. We will help the students to set their career goals in a variety of areas, and help them building different areas, including publishing papers, networking with peers, or giving effective research and/or classroom presentations.

Helping in building a strong publication record. The PIs will advise students in planning publications in workshops and conferences, according to their progress in the program. This will help them develop their skills and make them known among peers. Through writing papers with the PIs, the student is expected to improve their critical thinking, writing, and scientific skills.

The effectiveness of this mentoring plan will be evaluated by monitoring the progress of the student toward the goals defined in the iHealth-LL, as well as gathering feedback from the students themselves. Adjustments to individual parts of this plan will be made as needed.

3 Project Management and Timeline

In the following, we describe the administrative structure of iHealth-LL and key partnerships. PI Spinola will serve as the LL Director (LL-D), supported by the LL Coordinators (LL-C) Damevski and Cano (CS in alternate years), and Falcao and Bettermann (Health in alternate years). An External Evaluator (LL-EE) will be in charge of, independently, evaluating the LL activities. Lastly, the iHealth-LL also counts with a LL External Advisory Committee (LL-EAC), which will provide independent and unbiased input about the LL activities. See Table 3 for the administrative structure and role of each stakeholder group.

The PIs will work collaboratively on planning and executing the proposal. PI Spinola will be responsible for the recruitment and managing the lab. PIs Spinola and Damevski will be responsible for designing the Engineering Intelligent Systems for Health course and PI Cano will design the Artificial Intelligence Applied to Health course. All the PIs will be responsible for overseeing the Diversity and Inclusion aspects of the courses.

Communication is key to project coordination. The LL-D and LL-C will meet weekly. LL-D and LL-Cs will meet each semester with LL-EAC. The LL-D and LL-C will meet with iHealth-LL students each semester to elicit feedback about the pros and cons of the LL and identify potential areas for improvement or enhancement. A kick-off meeting will occur in year 1: LL-D, LL-Cs, LL-EAC, and LL-EE will attend the meeting and develop specific plans for initializing the LL.

The LL-EACs (see letters of support) bring relevant experience to the project: Dr. Barbara Boyan (expert in Biomedical engineering and medical product development and commercialization; Executive Director of VCU's Institute for Engineering and Medicine), Dr. Clemente Izurieta (expert in Cybersecurity and Software Quality; Professor of Computer Science at Montana State University), and Dr. Franklin Bost (expert in Biomedical engineering and medical product development and commercialization, StatFive Consulting LLC).

Table 3: Summary of plans for organizing and managing the iHealth-LL.

Stakeholder	**Primary responsibilities**
LL Director (LL-D)	Oversee initialization, maintenance, and revisions of the LL; communicate regularly with LL-C, LL-EAC, LL-EE, and NSF; oversee production and delivery of reporting to NSF; assume an active role in the development of the iHealth-Eng certificate and the workshops; implement a comprehensive evaluation plan.
LL Coordinators (LL-C)	Day-to-day operations; coordinate LL and iHealth-Eng certificate; meet with the LL-D to ensure experiential learning elements are in place and properly functioning; serve as a liaison between participating departments and students; coordinate regular meetings; coordinate student recruitment activities; assist with reports for sponsor (NSF); arrange workshop and seminars; assist with placing students in mentored projects; meet regularly with stakeholders; propose and implement potential refinements to the LL based on student, faculty, and evaluator feedback.
External Evaluator (LL-EE)	Attend the kick-off meeting and annual retreats; implement a comprehensive evaluation plan; review reports from LL-D; provide guidance and input to LL-D and LL-C that will be used to make formative improvements to the LL and to ensure its long-term sustainability.
External Advisory Committee (LL-EAC)	Attend the kick-off meeting and annual retreats; review reports from LL-D and LL-C; provide guidance that will be used to make formative improvements to the LL and to ensure its long-term sustainability.

Project timeline. The iHealth-LL will run as follows: (i) the first year of the project will be dedicated to elaborating the new courses and preparing the iHealth-LL infrastructure. (ii) Year 2 will run as the pilot year and year 3 as the final evaluation of the program as a whole. Co-PIs will recruit two cohorts of undergraduate STEM students who will participate in 9-month (Spring, Summer, and Fall) internships: 30 students in the second and 30 in the third year of the project. In Spring, fellows will be enrolled in the Artificial Intelligence Applied to Health and Engineering Intelligent Systems for Health courses. The intention is for them to have all theory necessary to perform their activities at the LL. The supervised projects in the iHealth-LL internship will comprise three stages: (i-Spring) definition of groups, projects, requirements, and design, at the same time they learn the concepts and practice the activities from the courses, (ii-Summer) refinement and prototyping of the project, and (iii-Fall) development of the final health system and its deployment at the LL demonstration space. The Summer will also be dedicated to developing fellows' DEI activities. Finally, during the Fall of each cohort, we will organize the Annual Workshop on Intelligent Systems for Health.

4 Sustainability and Scalability

The **sustainability** of iHealth-LL is based on four factors: **(i) Effort invested in course-based activities**, the iHealth-LL will be integrated into the CS undergraduate course. Only two completely new courses will be created. **(ii) LL infrastructure cost**: The devices that will compose the infrastructure of the LL are reliable, allowing us to expect to use them for a long time ahead. **(iii) Target population interest:** There is a significant shortage of highly qualified professionals who can create and maintain intelligent systems for health. We anticipate being able to recruit participants for a long time in such a growing and promising area. **(iv) Support from the CS Department:** While experiential learning activities of the project are important, overall support for PIs activities is a key driver of sustainability. To ensure it, VCU has committed to support the creation of the two new courses and the new Undergraduate Certificate in Engineering of Intelligent Systems for Health (see letter of support from the CS Department Chair Dr. Preetam Gosh).

Concerning **scalability**, one of the missions of the iHealth-LL is to spread the word on the importance of the area and facilitate its implementation by other institutions. In the annual Workshop on Intelligent Systems for Health organized in the context of the project, professors and leaders from other universities will be invited to participate. We will hold a special session dedicated to presenting the LL. Additionally, all instructional materials will be open and publicly available on the website of the project, so other institutions will benefit from them in their undergraduate programs. Lastly, we envision our proposed iHealth-Eng certificate as another, more direct and formal way to foster participation from students (and their faculty advisors) across STEM units. The iHealth-Eng certificate will formally persist beyond the NSF IUSE funding period.

5 Performance Assessment / Project Evaluation (Objective 6)

Our project will employ a comprehensive utilization-focused [74] evaluation plan that includes ongoing assessment of processes and outcomes. The plan adheres to the Guiding Principles for Evaluators [66] and The Program Evaluation Standards [108], which call for the conduct of program evaluations with honesty, integrity, and objectivity. The evaluation will be managed by Drs. Spinola, Damevski, and Cano, who have extensive experience in research involving software engineering practices [26, 34, 35, 38, 40, 45, 58, 79, 80, 82, 83, 89, 102]. This will be complemented by the External Evaluator, Dr. Seaman. The evaluation will provide ongoing feedback to project stakeholders to make data-informed decisions toward program improvement and to highlight program accomplishments and challenges. Table 4 presents some evaluation questions and data sources.

Evaluation of the program will focus on the use of findings by program decision-makers (LL-D, LL-C, and LL-EAC). The evaluators will provide the leadership team with regular feedback from the evaluation for ongoing program assessment, as-needed data analyses, and formal annual reports at the end of each fiscal year. Reports will include evidence-based recommendations for program improvement in the form of clear action items that the program leadership can directly apply. The reports will be provided to program leadership in advance of the annual retreat so that the evaluators can discuss recommendations with the leadership team and develop clear next steps and time frames to implement needed changes.

A final summative report will examine whether or not the program succeeded in meeting its goals. The leadership and evaluation team will ensure that the results will be widely disseminated within the higher education and evaluation community through publications and presentations at conferences and workshops.

6 Why VCU?

VCU is exceptionally well-positioned to lead an experiential learning initiative focused on academic, practical, and professional skills in the development, deployment, and servicing of intelligent systems

Table 4: Guiding formative (F) and summative (S) evaluation questions for each stakeholder group (SG), with types of data sources to answer these questions, and timing.

SG	Evaluation questions	Data sources (timing)
Undergrad students	• To what extent are target students involved in the program, including underrepresented populations? (F) • Is the program providing students with the necessary tools and support to achieve their goals? (F) • To what extent do/did students: (F,S) – attain competency in developing intelligent systems for health? – develop the ability to translate and communicate complex ideas and research results? – develop the ability to collaborate in teams and across areas? – become prepared for successful careers within or outside of academia? – disseminate scholarly products related to their work in the project?	• Analysis of program records (monthly) • Student performance in assignments and exams (monthly) • Student surveys (within 1 week of entering and completing the program, as needed during program participation–i.e., after participation in various program elements) • Student interviews (annual) • Leadership team interviews (biannual)
Proj. faculty	• Are project faculty provided the necessary information to meet project expectations? (F) • How has participating in the project affected faculty teaching? (S) • How has participating in the project affected faculty research and spurred collaboration? (S)	• Faculty survey (annual) • Faculty focus group (biannual) • Analysis of program records (monthly) • Student interviews (annual)
Department	• To what extent are targeted departments involved in the project? (F) • What is the added value of the project on departments with project students? (F,S)	• Analysis of program records (monthly) • Leadership team interviews/discussions (annual)
Leadership team	• Is the iHealth-LL program being implemented as designed? (F) • In what ways can iHealth-LL improve its operations? (F) • What lessons were learned during the program? (S) • Did iHealth-LL achieve its intended goals? (S) • Is iHealth-LL structure translatable to other areas? (S) • In what ways has the leadership team disseminated curricular materials for adoption by other institutions, and how have they been used? (S)	• Analysis of program records (monthly) • Leadership team interviews/ discussions (annual)

for health. We will leverage the existing infrastructure of the Computer Science Undergraduare program. Moreover, the iHealth-LL will grow and add innovations to the program by adding a new emphasis area: Intelligent Health Systems, while making training elements accessible to the other emphases, and more broadly to other STEM-related undegraduate programs on campus. Both the iHealth-LL program and its associated (new) iHealth-Eng certificate will create significant added value to multiple existing undergraduate degree programs at VCU, including Biomedical Enginnering, Epidemiology, Health Related Sciences, Neuroscience, and Information Systems. These degree programs span several departments within the College of Engineering, College of Health Professions, School of Medicine and School of Business.

The iHealth-LL will partner with **VCU Health**, one of the nation's leading academic medical centers [32]. This partnership is central to our experiential learning experience because it provides actual scenarios to be supported by intelligent solutions and the chance of deploying them benefiting the society.

The collective experiences of our team will contribute to an effective and innovative LL. Spinola has prior experience on the conception and implementation of LLs. Spinola and Damevski are software engineering researchers with significant practical experience. Cano is an experienced artificial intelligence researcher. All of them have extensive experience in computer science education, which will be decisive to support the evaluation and improvement of the iHealth-LL. On the health domain side, Falcao and Bettermann from VCU Health will provide scenarios motivated by real-world health software needs. Those scenarios will be used as input to define the use cases that will be solved by the students in the iHealth-LL internships.

The iHealth-LL will be a unique opportunity for fostering interdisciplinary synergies emerging from ongoing research activities between the involved Departments in the areas of artificial intelligence, software engineering and health. The diversity of students and faculty at VCU involved in the project and our collective expertise and collaborative experiences create a unique and compelling strength of our proposed iHealth-LL program.

7 Dissemination Plan

Publication. The co-PIs will submit contributions to a number of annual conferences, such as the ACM Symposium on Computer Science Education (SIGCSE) and the Software Engineering Education and Training track of the International Conference on Software Engineering (ICSE-SEET), which are premier conferences on computer science/software engineering education. We also plan to publish in computer science education journals, such as IEEE Transactions on Education (TE) and ACM Transactions on Computing Education (TOCE). We will describe the experience and the evaluation results in these publications.

Workshop. We will conduct annual community workshops on intelligent systems for health each year. During the annual workshop we will disseminate the project results and recruit interested participants for the next cohort. The workshops will be open and widely advertised.

Sharing iHealth-LL at the Academia. Dissemination will be incorporated into the ongoing activities of our learning community. Faculty co-PIs will share project updates and results through departmental communication systems and structures (committees, leadership teams). Additionally, professors and leaders from other universities will be invited to participate in the annual workshop. We will hold a special session during the workshop dedicated to presenting the project. Lastly, information about the project, course materials, publications, and presentations will be included on a project website developed and maintained at VCU.

8 Intellectual Merits

Recognizing the growing importance of soft skills like communication, leadership and collaboration in computer science education, the proposed research creates living labs to train undergraduate students in the growing interdisciplinary area of intelligent systems for health. Living labs combine experiential learning and innovation and focus in-depth on a specific application area. The contribution is significant because it improves students' skills and prepares them for a career area where there is a dire shortage of professionals and a very large national need.

Furthermore, the use of LL to enhance multidisciplinary STEM undergraduate education is novel. The demonstration of LL in computer science education in the context of intelligent health systems will provide an example that others can follow to adopt LL for other domain areas. This project will create new knowledge about LL's efficacy and impact.

9 Broader Impacts

The overall broader impact of this project is improving multidisciplinary STEM undergraduate education in the area of engineering intelligent systems for the health domain. Besides, among the expected outcomes of LLs for universities and their students, we have: facilitating experiential learning and making curricula relevant, improving college completion, fostering internal partnerships within universities, enhancing student learning through impactful courses, instilling students with skills that have real-world impact, and launching a new, innovative model for high education [85]. In the following, we further detail some of the expected outcomes:

(1) **Development of technically strong STEM workforce in an important field.** The combination of the iHealth-LL course-based and experiential learning activities at the LL will equip students with both cutting-edge hard skills in computer science and 21st Century soft skills [30, 65], e.g., teamwork, communication, critical thinking, problem-solving, that will prepare students for a diversity of careers, within and outside of academia [29, 57]. Any undergraduate student in the CS program will be invited to follow the course-based activities and attend the annual workshops. Thus, more students are expected to benefit from individual iHealth-LL elements, such as the new courses on Artificial Intelligence Applied to Health and Engineering Intelligent Systems for Health. It is conceivable that many (e.g., 100 students in any given year) of the CS undergraduate student population will benefit from our iHealth-LL. We expect the number of students benefiting will be sustained and likely grow after the NSF IUSE funding period ends, partly in response to the growing CS department.

(2) **Increased partnerships and collaborations.** The iHealth-LL will be a unique opportunity of integrating different players around the development of the workforce in a high-demand area.

(3) **Enhanced infrastructure for research and education.** Through the execution of the iHealth-LL, we will invest in infrastructure to create the LL. co-PIs will incorporate them into their current teaching and research activities.

(4) **Contribute to the development and adoption of experiential learning practices, and advance research on effective models for undergraduate education.** We will openly disseminate our results and materials via our website and scientific publications. We will also promote open discussions with the education community to transfer knowledge and receive feedback.

(5) **Benefits to society.** By enabling a larger and more diverse pool of talent to solve important problems in engineering and computing.

9.1 Building an Inclusive and Diverse STEM Workforce

VCU is a Minority Serving Institution [99] and has a diverse student population and a strong history of graduating members of underrepresented communities. We recognize that structural inequalities permeate our society, and the sciences are not immune to racism. We are committed to broadening participation in the sciences and being part of the solution to these systemic problems. Our primary goal in this context is to **increase research experiences on engineering systems for health for undergraduate students from underrepresented groups**. By targeting them, we expect to have two impacts. First, for individual students this experience could change the trajectory of their professional life. Second, for broader society, elevating underrepresented students improves the diversity of the computer science field, where diversity is sorely lacking.

We will consider strategies at the institutional, management, fellow, and project levels to successfully achieve this goal. At the **fellows level**, one of the components of the iHealth-LL program is DEI. All fellows will participate in at least one DEI training and one DEI activity (see Section 2.1). These actions will not only be part of the proposed project but, at the **institutional level**, they also will be integrated into daily initiatives from VCU for a more diverse, inclusive, and equal society. VCU values and places priority on policies that enhance diversity, as stated in its institutional mission "Deeply ingrained core values of diversity, inclusion, and equity that provide a safe, trusting and supportive environment to explore, create, learn and serve."

At the **management level**, co-PIs are committed to engaging in training and awareness activities that address racism, diversity, equity, and inclusion in the sciences. co-PIs Spinola and Falcao are Latinos and Cano is a Hispanic researcher. Also, co-PIs will ensure a minimum of 50% participation of women and other historically underrepresented groups in STEM careers.

Finally, at the **project level**, iHealth-LL will increase public awareness of diversity initiatives by disseminating their results to the community through articles, posters, and presentations at the Annual Workshop on Intelligent Systems for Health. The development and distribution of media that portray persons from underrepresented communities in the iHealth-LL will be a means to communicate the opportunities available in the field.

9.1.1 Mitigating bias against minorities in the educational material

We aim to build inclusive educational content. There is a vast literature on how to identify inclusiveness issues (e.g., [9]). Educational content can be non-inclusive if it supports only one style of problem-solving—and the literature has shown that problem-solving styles cluster by gender and cultural aspects [52]. It is known that computer science students exhibit individual differences in how they problem-solve. This has been observed and written about by Brooks [7] and Boehm [7] in their respective seminal contributions. Our goal is to create materials and an environment that supports and welcomes different problems solving styles.

Research spanning approximately ten years shows that people differ in (at least) five problem-solving style "facets" that can directly impact the ways they use software: (1) *Motivations*: People have varying motivations to use technology, ranging from those who use it for what it helps them accomplish to those who use it according to their interest and enjoyment of technology itself [8, 10, 33, 46, 50, 54, 90] (2) *Information processing styles*: Problem-solving with software often requires information gathering, and while some people prefer to gather information comprehensively before proceeding, others use selective styles, following the first promising information, then backtracking if needed [2, 22, 24, 25, 81]. (3) *Computer self-efficacy*: The perceived computer self-efficacy (confidence) may vary according to individual differences, and this can affect an individual's behavior with technology [8, 10, 15, 33, 44, 47, 69, 76, 91]. (4) *Risk aversion*: Some people are more risk-averse than others [28], which can impact decisions about how they use an artifact. (5) *Styles of Learning Technology*: Some people prefer learning in process-oriented ways while others prefer learning by playfully experimenting ("tinkering") [8, 13, 16, 46, 84].

The facets mentioned are the core of GenderMag [9], a technique to evaluate artifacts from a cognitive-inclusiveness perspective. We will employ the method to identify and de-bias the educational content we produce. For example, we will study how to present (help) clues and define learning steps to support the *process-oriented learning style.* We will explore different levels of explanation to support those individuals with low *self-efficacy* and provide *motivation* for finishing the tasks. The educational content will support individuals with a *comprehensive information processing* style by providing relevant information about the example upfront; individuals who prefer to *learn by process* through storylines and clues that guide the students; and so on.

We will continuously evaluate our approach in two ways. First, we will administer pre- and post-self-efficacy surveys and assess the students to understand how they feel about their learning experience. We will also adapt the GenderMag method to identify if (and where) our educational content embeds biases related to cognitive styles and culture and then redesign the educational content to fix those "bugs." The GenderMag evaluations will produce a "cognitive-bias bug report," along with the facets tied to the lack of inclusivity. This report will inform redesigns for each facet identified. After producing a less-biased version, we will proceed with the evaluations, in which we will also observe whether the redesign succeeded in creating more inclusive material. By paying close attention to the design process and ensuring that the educational content is inclusive, we aim to enable all social identities to derive similar values/benefits from the program.

10 Results from Prior NSF Support

NSF IIS-2024561 Amendment 2, $765,593.00, PI: Spínola, (2020-2023), Title: *Collaborative Research: NRI: FND: End-User Robot Programming.* This project aims to: (1) Create a robot programming approach that enables novices to complete realistic programming tasks, (2) create a tutorial-based system that allows novices to be trained on site, (3) create a parallel programming solution that enables the programming of two or more robots by novices, and (4) create a multithreaded programming solution that facilitates higher utilization of single robots.

Dr. Damevski has recently concluded one NSF project and has two ongoing NSF projects in software engineering and security. *NSF Award #1812968. SHF: Small: Collaborative Research: Automatically Enhancing Quality of Social Communication Channels to Support Software Developers and Improve Tool Reliability.* PI: Kostadin Damevski. $250,000. 10/1/2018 - 9/30/2022. *Intellectual Merit:* This project addresses the need for automation in curating for increased quality of the information shared in developer communication [18, 20, 21, 48]. *Broader Impacts:* One large-scale dataset of Slack Q&A conversations has been published as part of the project [19]. This project has provided research training and mentoring for two Ph.D. and one M.S. student at VCU.

Dr. Cano has not had previous NSF funding. His research is funded by the State Council of Higher Education for Virginia, the VCU Accelerate Fund, two industry-sponsored projects, and an Amazon AWS Machine Learning Award. Dr. Cano is among the top 2% best-cited researchers in Artificial Intelligence according to Stanford's study [49].

Dr. Falcao D.O. has not had previous NSF funding. Falcao is board certified in both Neurology and Stroke by the American Board of Psychiatry and Neurology. He serves the VCU Health Systems in several leadership roles, including as the Director of Quality Improvement and Safety for the Neurosciences and as the interim Director of the VCU comprehensive stroke center.

Dr. Bettermann has recently conducted a pilot clinical trial (National Center for Advancing Translational Sciences/NIH UL1TR002014, $70,000) to study pioglitazone treatment in acute diabetic stroke (2019-2021). This project has provided research training and mentoring for a post-doctoral Ph.D. and one undergraduate neuroanatomy student. In addition, Dr. Bettermann has studied new biomarkers of cerebral small vessel disease ($300,000, Clayco Foundation) focusing on retinal imaging and circulating biomarker in peripheral blood (2018-2021). Dr. Bettermann is Professor of Neurology and the Division Chair of Stroke and Neurological Critical Care at VCU, School of Medicine. She has not had previous NSF funding.