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Design Processes for Senior Capstone Collaborations across Biomedical Engineering and Information Computer Science

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Interdisciplinary senior capstone projects allow students to be able to develop real-world product design and development skills as well as practical applications of their knowledge. In order to be able to manage these projects, collaboration and efforts across students and faculty in multiple disciplines require efficient management and alignment of design processes. In this paper, we describe the implementation of an interdisciplinary senior capstone project across the Schools of Information Computer Science and Engineering. The project was hosted by the senior capstone course in the School of Information Computer Science, but mentored and implemented in the Department of Biomedical Engineering. It was found that there were significant differences and alignment between design processes utilized by these two schools. In particular, it was found that the design process associated with biomedical engineering design, namely the BioDesign process, was comparatively slower than the Agile design process utilized in the information computer science capstone course. However, both processes were able to highlight the key components of design and development, such as discovery, planning, and building. Lastly, human centered design was realized as an important strategy to teach students to ensure that diversity, equity, and inclusion are considered throughout their design.

Keywords: information computer science, biomedical engineering, interdisciplinary capstone projects, design processes, virtual reality

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Introduction

In both industry and academia, it has been found that interdisciplinary collaboration is needed to provide equitable and transformative innovations[1]. To be able to train students in critical thinking skills such as problem solving, communication, collaboration, and creativity, higher institutions have implemented interdisciplinary capstone programs, courses, and projects where students of different disciplines collaborate on challenging design problems[2,3,4]. These problems are open-ended in nature, and projects focus on the development and creation of some artifact, such as a prototype[2]. In a senior capstone program, students are oftentimes tasked to design, build, and test a prototype of some form, which can be software, a physical artifact, or simulation.

Interdisciplinary capstone projects have been found to allow undergraduate students to be able to inspire creativity and inspire learning through learning autonomy, active exploration of the problem, and collaboration in teams[2]. They can allow students to learn how to cooperate within and across disciplines[3], work together[3], and trustworthiness[2]. However, prior studies have identified several challenges associated with interdisciplinary project-based learning projects. For instance, students in different disciplines can silo themselves into only disciplinary work via subsystems rather than working together holistically[3]. In addition, open-ended projects often have uneven workloads and the differences in the timing of work across disciplines[2]. For instance, programmers may be required to work on portions of a project after data is collected by an engineering team to implement apps or artificial intelligence algorithms given training data.

To be able to create an interdisciplinary capstone project in which student teams are able to work simultaneously on a project that is multidisciplinary in nature but is still able to work simultaneously, the Schools of Information Computer Science (ICS), Engineering, and Medicine collaborated on a novel research project that included creating virtual reality medical educational spaces. As described below, these schools implemented the novel project through the ICS capstone course, whose students were mentored by undergraduate and graduate students across several disciplines. These disciplines included those from the School of Humanities, Department of

Biomedical Engineering, and School of Medicine. The design processes that were utilized to implement the project relied heavily on biomedical engineering and ICS design methodologies, which had similarities and differences that allowed for collaboration across the schools.

Interdisciplinary Capstone Project

At the University of California, Irvine (UCI), the School of Information Computer Science requires an undergraduate capstone design experience prior to graduation. The capstone program allows students to solve real-world problems in different areas in computer science. To this end, students work in teams to perform a project sponsored by an industry, non-profit, government, or research unit where they design and develop a solution, and present their results or work at the end of the program. The course is offered over the course of two quarters, winter and spring, and class time across both quarters focuses on defining the project requirements, approach and implementation, given the chosen sponsored project. Lectures also include topics such as project management and the practical application of advanced topics on computer science such as artificial intelligence, internet of things, and augmented reality. The winter quarter particularly focuses on design and beginning implementation concepts such as the agile design process, software engineering approaches, and techniques and tools to manage software project development. The spring quarter focuses on implementation and a final interaction of the project by accomplishing all project requirements, testing it in front of real users, adjusting the design given user feedback, and dissemination of their project and findings to a broad audience across academia and industry.

The chosen interdisciplinary project proposed in the 2023 offering of the course focused on virtual reality for medical clinical immersion. Sponsored by a research laboratory in the Department of Biomedical Engineering, and in collaboration with the School of Medicine, this project focused on developing a virtual reality platform for students to be able to immerse themselves in clinical environments[5,6]. To this end, several medical procedures were filmed in 360° and first person view for medical and biomedical engineering students to be able to perform clinical immersion. This process is imperative for biomedical engineering students to be able to innovate and design medical devices utilized in these spaces, and for medical students to be able to understand the environments they will be working in. An example video describing the environment being developed can be found here: https://youtu.be/hlCnx9urynE.

To improve the implementation of the virtual reality clinical immersion environment among courses and to allow students to be able collaborate within these environments, ICS capstone students were tasked with the design and implementation of multiplayer functionality, chat, and whiteboard features (Figure 1). The ICS student senior design team received technical and overall guidance from biomedical engineering students, a graduate student in the school of humanities, and mentored by a biomedical engineering professor. To this end, the students utilized Unreal Engine 5 software (Epic Games Inc., Cary, NC, USA) to develop characters and customization options for students to be able to enter the virtual reality environments and stream videos simultaneously over a secured Amazon Web Services (AWS) server (Amazon, Seattle, WA, USA). They also implemented features such as text and voice chat as well as whiteboards so that students could identify unmet needs within the environment through collaboration with each other while watching the virtual videos. The initial development of the multiplayer functionality was developed during the winter quarter, while other features such as customization options, whiteboard, and chat features were developed during the spring quarter of the course.

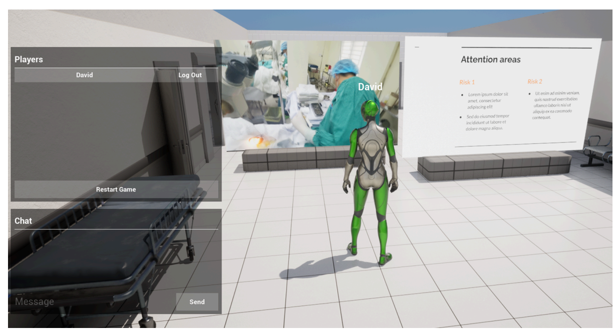

Figure 1: Screenshots of the multiplayer functionality and whiteboard and chat features within the virtual reality clinical environment.

Design Processes Utilized

Capstone design courses rely heavily on structured design processes that are commonly used in industry within the specific discipline. In the field of biomedical engineering, this is typically the BioDesign process[7]. In the ICS and computer engineering disciplines, this is typically the agile design process. Both processes are iterative and require students to ideate, plan, build, and test a solution to an open-ended problem. There are, however, several differences across these processes, such as how a new iteration is initiated and when testing and deployment of the solution is performed.

BioDesign Process

The BioDesign process[7] was originally implemented by the Stanford Byers Center for Biodesign and has since been adopted by several institutions' biomedical engineering curricula. The BioDesign process focuses on the "three I's" for innovating medical technologies: identification, invention, and implementation (Figure 2). During the identification stage, students perform needs finding and needs screening where they identify unmet needs within a medical environment and screen all identified needs to determine which one to select given existing solutions, stakeholder and market analyses, and the disease state. In the invention process, students develop needs and design specifications and perform ideation and concept selection. They screen concepts and solutions based on intellectual property, regulatory affairs, reimbursement strategies, business model strategies. These first two processes are iteratively repeated until a viable solution is developed. Once the final solution is developed, the solution is then implemented through intellectual property development via patent filing, FDA approval, and business development via marketing, sales and distribution, and development of a competitive advantage in the clinical marketplace. Through this holistic process of innovation and design, students have been able to design and create medical devices that are implemented within the clinic with an entrepreneurial mindset, and the Department of Biomedical Engineering at UCI has experienced great success with students being able to utilize this process to create startup companies[8].

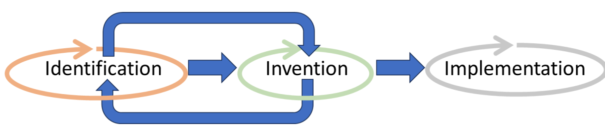

Figure 2: The BioDesign process[7] that was utilized to develop the virtual reality clinical immersion platform.

Agile Design Process

Agile development was first introduced to the general public with the publication of the Agile Manifesto, and experienced a fast dissemination and rise to prominence since[9,10]. Agile has become a process-framework or "umbrella" term for many popular process models, such as SCRUM, XP, Lean, Kanban, and so on. Thus, Agile rests upon 4 core values (from the Manifesto), then 12 core principles, then a specific method such as SCRUM, is used to manifest or implement Agile in an actual project environment. Some Agile principles that became useful and influential include: Welcome Changing Requirements (anticipation of change); Deliver Working Software Frequently; People Work Together Daily; and Self-Organizing Teams. Then, SCRUM adds on the useful notions of SCRUM Master/Product Owner and the Daily Stand-ups and SCRUM retrospectives.

Discussion

Given the Agile/SCRUM design process taught in the capstone course, students were able to use this process to improve the virtual reality clinical immersion platform such that student and instructor collaboration could take place. Through collaboration with the instructor and biomedical engineering undergraduate students, the "customers" of the platform, the capstone students were able to develop multiplayer functionality using customizable avatars, chat features, and a collaborative whiteboard feature. They iteratively built these features with weekly student and instructor feedback and testing, ultimately leading to a working prototype. Further, they were able to provide complete documentation for future developers of the platform through descriptive videos published on YouTube (Google LLC., San Bruno, CA), shared code with text documentation published on GitHub (Microsoft Corp., San Francisco, CA), and full text documentation via Google Drive (Google LLC., Mountain View, CA). The resulting prototype and documentation demonstrated that ICS students were able to work on a medical and biomedical engineering education application through collaborative mentorship with biomedical engineering and information and computer science faculty. The top principles and best practices of Agile/SCRUM that contributed clearly and visibly to the team's success include: (1) self-organizing teams; (2) Deliver valuable software frequently; (3) Continuous Integration/Continuous Delivery (CI/CD), using GitHub and related tools; (4) two-week sprints, and delivering written sprint-reports to the instructors; (5) the roles of SCRUM Master and Product Owner; (6) product backlogs, sprint backlogs, and retrospectives.

Although the students were able to successfully develop a prototype with complete documentation, the faculty observed some significant differences among their structured design processes. For example, the Biodesign process heavily relies on unmet needs screening and evaluation in the initial design phase of a project, as human factors and the ability to demonstrate validation of meeting user needs in regulatory affairs for FDA approval is paramount in healthcare innovation. However, this process is not as applicable in typical software development applications, since designs do not need to be "frozen" for FDA approval processes to ensure safety and efficacy. Instead, frequently changed requirements are employed through small releases of the software in the agile design process[10]. In the context of the medical education application developed by the students, this led to issues associated with appropriately identifying user needs and screening these needs, as well as understanding the current pedagogical literature and frameworks that are utilized in unmet needs finding. Without a clear understanding of how students learn, and how medical professionals learn healthcare procedures and techniques, the capstone students were not able to understand the underlying learning strategies their collaborative software features are trying to promote. Instead, rapid feedback through individuals led to a prototype that is functional, but missing human-centered design principles associated with promoting learning outcomes. For example, the students did not realize that the small sample size of biomedical engineering students they received feedback from did not require design features associated for those who may require Americans with Disabilities Act (ADA) compliant text, or did not consider diverse character customization features for those who "look different" than the features provided. This led to instructor and mentorship recommendations and changed design requirements of the character customization and whiteboard features, which the capstone students did not fully understand their importance.

Given the success and struggles associated with the collaborative pilot project between ICS and biomedical engineering faculty, the instructors and mentors have several recommendations for future adoption of interdisciplinary projects across these disciplines. First, instructors should be aware of the course timing constraints of capstone design courses, as medical and biomedical engineering applications are typically much more lengthy in timing given the need to meet regulatory requirements unlike in computer science applications. Instructors should also attempt to align the different design processes across mentors and faculty, as different disciplines rely on different design process frameworks. This can be done through the education of the design processes that are taught in the course prior to mentorship with the students. This education of mentors is paramount in successful project completion and to provide students with appropriate planning and coordination across the course and project itself.

Conclusion

This paper highlights these differences and alignment of the processes utilized, and recommendations for other institutions interested in collaborating across these schools are provided. In particular, it is important for instructors and mentors to learn about the differences and similarities of the design processes that are utilized across disciplines. Through an understanding of how different discipline-based design processes can be aligned, we can better educate students on how to use the knowledge gained in their disciplines to develop interdisciplinary applications and products.

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