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An Iterative Design Approach in Biomedical Engineering Student Group Projects

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An Iterative Design Approach in Biomedical Engineering Student Group Projects

Abstract

The engineering design process allows students to establish a step-by-step approach to solving real-world problems. This study explores the practical application of iterative design in a Biomedical Engineering course at The University of Texas at Austin. The innovations we have proposed for the design process involve starting with the analysis of a current technology described in a scientific article and improving the technology through multiple iterations using other supporting scientific articles. Students defined design requirements, generated evolutionary solutions through multiple iterations, and demonstrated the utility of scientific literature by applying knowledge to enhance their designs. This approach facilitated a deeper exploration of biomedical technology, involving critical analysis and improvement of materials, methods, and manufacturing techniques.

Seventeen students participated in the project, divided into six groups, each assigned specific topics related to wearable and implanted technologies. Over 14 weeks, students followed a structured process, making presentations associated with three design iterations, showcasing their progress, and receiving feedback from a teaching team consisting of the professor and a postdoctoral fellow serving as a teaching assistant. The methodology introduced a unique aspect by leveraging scientific articles to suggest improvements in technologies. Students analyzed an average of 41 articles in three iterations, refining their understanding of the technologies. Apart from analyzing the articles used, analyses were conducted on the iterations performed, how learning outcomes were achieved, and a comparison with projects from the previous two cohorts of the course.

The iterative design methodology demonstrated its effectiveness in reinforcing and applying knowledge. Students considered the feedback process crucial, contributing to a better understanding of their solutions and the development of a project with multiple iterations. Comparisons with previous courses highlighted the impact of the methodology on increasing technical perspectives and detailed solutions. The study exemplifies a successful pedagogical practice, emphasizing the importance of starting with known technologies through scientific articles and leveraging iterative processes to enhance learning experiences.

Introduction

In the field of biomedical engineering design, as in other branches of engineering, there is an ongoing discourse about cultivating design skills to train engineers to solve real-world problems [1][2]. These skills can be developed not only through knowledge imparted in academic institutions but also through universal insights obtainable from sources such as scientific papers. Essentially, design thinking advocates for driving innovation to its maximum potential through a process of continuous iteration. This iterative or cyclical approach more precisely encapsulates the cognitive journey undertaken by creative individuals as they strive to shape solutions to intricate design challenges [3].

The development of this design process demands a departure from the notion that idea generation is confined to a single phase. Instead, it requires the transformation and refinement of ideas across multiple stages [4][5]. This approach aims to ensure that the understanding of the problem evolves in tandem with designers' efforts to accumulate and analyze additional information during the phases of idea generation and the subsequent evaluation of potential solutions [6][7]. For a successful design process, effective communication is required among the design team, with user-oriented and technology-focused teams meeting frequently and making decisions collaboratively [8]. Together, the elements described above converge into what is clearly defined as iterative design, which, in the case of this study, was applied in the field of engineering.

The main objective of this study is to demonstrate the practical implementation of the iterative design methodology in the context of a Biomedical Engineering course offered at The University of Texas at Austin. The innovation in this study lies in a methodology that introduces a modification in the problem-solving process, starting with the examination of a non-traditional technology as described in a scientific article. To achieve this, students defined design requirements derived from the article analysis and information search [9]. Subsequently, students generated solution ideas that evolved through multiple iterations, reaching an idea with greater technical detail and possible implementation. Additionally, it provides a comprehensive insight into how this process unfolds among students working collaboratively in groups, navigating through multiple iterations of the design—a dimension seldom explored in conventional design courses, where students typically propose a single solution [10].

This approach facilitated a deeper exploration and practical application of the concepts covered in the course, involving critical analysis and improvement of a biomedical technology in terms of its materials, methods, and manufacturing techniques. This study presents an analysis from the literature and tools used, the proposed learning outcomes in the course, and a comparison with two previous courses. We aim to offer future instructors another application possibility for design projects in their courses, using methodologies such as iterative design, enhancing students' interest in scientific literature and its utility.

Methods

For the development of this study, we propose some research questions related to the use of the proposed methodology: What impact on students can occur when using the iterative design methodology, starting with an existing technology resulting from research in a Biomedical Engineering course? How can the reading of scientific literature be encouraged in Biomedical Engineering students? Can the iterative design methodology be used to deepen the concepts of bioelectronics and biointerfaces in an advanced Biomedical Engineering course? To answer these questions, we proposed the development of a teaching strategy based on the development of a design project.

The development of a design project using the iterative design methodology was proposed in the Bioelectronics and Biointerfaces course offered in the fall of 2023. Seventeen students enrolled in the course, including 12 undergraduates, 1 master's student, and 4 doctoral students in the field of

Biomedical Engineering. The innovation we propose involves leveraging the review of scientific articles to enhance technologies, combined with engineering design processes.

The progress of this study was presented to the Institutional Review Board (IRB) with the study number STUDY00005150 at The University of Texas at Austin. The IRB determined that this protocol meets the criteria for exemption from IRB review under 45 CFR 46.104 (1) for educational settings.

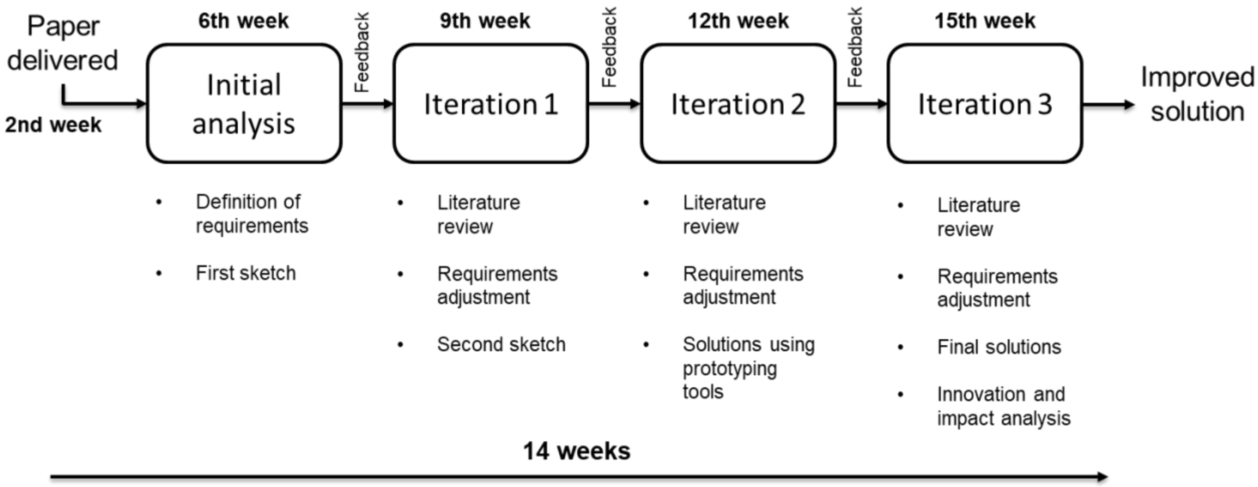

Figure 1. Iterative design process carried out by each group of students.

The students were divided into 6 groups, each associated with 4 topics: Wearable Fabrication, Wearable Materials, Implanted Materials, and Implanted Fabrication. Topics 2 and 3 were taken by two groups. Each group consisted of one graduate student and 2 undergraduate students, except for one group (group 5), which was formed with only two undergraduate students.

In the first week of class, the complete process that each student group had to follow over a period of 14 weeks was explained, as shown in Figure 1. In weeks 6, 9, 12, and 15, students made presentations of their progress to their classmates. Three feedback sessions were conducted during these presentations for each group, highlighting important presentation elements and suggesting improvements for the next presentation. In the final presentation, students also submitted a brief document summarizing the entire process, describing the iterations performed, the anticipated innovation, and the impacts of the final design generated in the last iteration.

Each group was given a paper related to a study associated with the assigned topic in the second week of classes. Over 5 weeks, students read the initial paper, analyzing the technology developed and the disease studied in the research. After this analysis, students identified improvement features, established initial requirements, and created individual solution sketches. All this analysis was presented in the sixth week.

With the initial requirements defined, each group of students initiated the redesign process consisting of 3 iterations. For each iteration, students had to review literature articles to analyze the possibilities for improving each requirement. The knowledge provided in the course and the feedback generated by both the course instructor and a teaching assistant, a postdoctoral fellow with expertise in technological development, were also crucial. During this process, we analyzed the articles read by the students, the evolution of the requirements, the tools used by the students, and the development of the learning outcomes.

The data used for this study included the quantity of papers used in each iteration, the number and type of requirements defined by the working groups, the design tools used, and feedback comments from the project. Additionally, a comparison was made with the cohort of students from the previous two years (2021 and 2022), where the number of papers used, and the characteristics of the project were employed.

Results and Discussion

Papers consulted

One of the most significant innovations proposed in this study is the use of papers to suggest improvements to technologies, utilizing information found in the papers by the students. We counted the references used in each of the presentations, many of which were placed on slides describing the improvement to each of the requirements (Figure 2). In the iterations, 8, 13, and 20 papers were worked on average, respectively. Regarding the number of references used by each of the groups, students were not asked for a specific value in any of the iterations or the final presentation. After each presentation, feedback was provided to each group indicating which concepts and aspects of the design they could delve deeper into. This showed proactive independent work and an interest in drawing from literature to support project development.

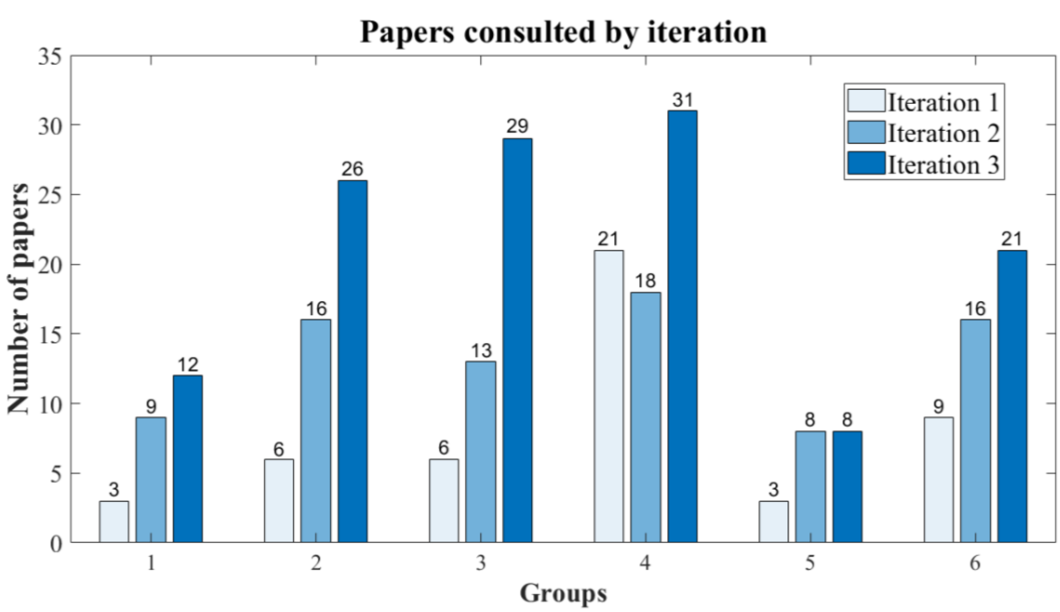

Figure 2. Papers consulted by each group in each iteration. Groups 1. Wearable Fabrication, 2. Wearable Materials, 3. Wearable Materials, 4. Implanted Materials, 5. Implanted Materials, 6. Implanted Fabrication.

In the first iteration, it was observed that most groups sought references to first understand the diseases and some concepts given in the initial paper. The groups, in order, worked on the diseases of Stroke, Chronic Non-Healing Wounds, Parkinson's, Acute Pain and Opioid Addiction, and Paralysis & Amyotrophic Lateral Sclerosis (ALS). For the second iteration, 4 out of the 6 groups conducted searches on more than double the number of papers from the first iteration. This search was highlighted by the specific search for new techniques, materials, and processes to improve the proposed technologies. In the last iteration, the groups further specialized their searches since they had a clearer understanding of how to improve their requirements. We also want to highlight that in the first iteration, two of the groups (3 and 6) conducted additional searches related to patents, and two other groups conducted searches for commercial devices (1 and 2), which also enriched the design process.

This was one of the main achievements of the students, as their commitment to the course and the design project regarding reading papers was evident. The students expanded their specific knowledge on the project's topic, reflected in increasingly technical descriptions in each of the presentations. We have taken the metric of the number of articles as an indicator of students' pursuit of new knowledge. In describing the solutions, students included diagrams, concepts, methods, and results in their presentations, which demonstrates their engagement with the articles.

Defined Requirements

One of the most important findings of this study was the analysis of requirements. Only one group maintained the number of requirements, indicating that iterative design is necessary to develop better solutions to problems. In the first iteration, three groups provided more detailed requirements, either by adding or dividing those initially proposed in the initial analysis. One group made adjustments in the second iteration by adding one more requirement. In the case of group 2, upon reviewing the literature, the students realized that several of the initially proposed requirements were not feasible for the scope of the project, so they reduced them by half (see Figure 3).

Regarding the requirements, we grouped them into 6 main categories:

1. Material: considering the possibility of changing the type of material with which the solution from the paper is proposed.

2. Structure: analyzing new ways to generate structures with materials.

3. Fabrication: reviewing methods and processes for better manufacturing of the solution.

4. Measure/improve signal: exploring new ways of measuring and improving signals concerning noise and signal quality.

5. Circuits and Sensors: proposing new circuit schemes and adding sensors for measuring biological variables.

6. Drug delivery: analyzing other ways of delivering drugs more efficiently.

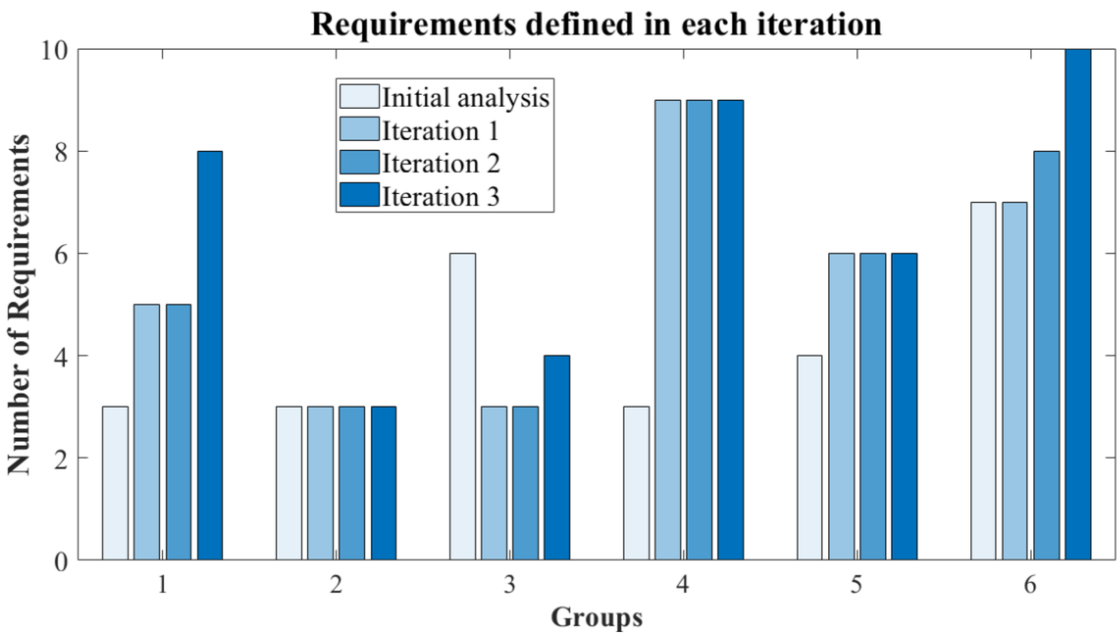

Figure 3. Requirements defined by each group. Groups 1. Wearable Fabrication, 2. Wearable Materials, 3. Wearable Materials, 4. Implanted Materials, 5. Implanted Materials, 6. Implanted Fabrication

In traditional engineering courses, on average, a group of students proposes a single solution based on initial requirements, which are related to desired characteristics in the solution to solve a specific problem. However, iterative processes are lacking, where solutions are evaluated, and improvements are established. By making adjustments to the solutions in each iteration, students were asked to analyze their requirements, exploring how they could improve them using information found in the state of the art. Most groups made adjustments by specifying their requirements further.

For example, this was the change proposed between the initial analysis and the first iteration in one of the requirements of group 3:

Initial requirement: *Sensor Integration: The smart bandage has sensors for skin impedance and temperature, but implementing more sensors such as monitors for pH, oxygen levels, and other biomarkers will further optimize the healing process.*

Requirement first iteration: *Incorporation of pH Sensors and O2 Sensors*.

- *Incorporate pH sensors to ensure that wound pH is between 7.3 - 8.3 and has not become alkaline (which is indicative of a chronic, infected wound)*
- *Incorporate O2 sensors to monitor O2 levels at the wound site (if wound O2 levels fall below 90% saturation, remove bandage to allow for increased O2 flow)*
- *Monitoring wound pH and O2 in addition to wound impedance and temperature will allow for increased validity/reliability in assessing the state of the wound healing process*

The variables to be measured, numerical values, operating ranges, and specificity in the characteristics of the sensors to be used are included.

Tools and design evolution

An important aspect of the iterative design methodology is the evolution of solution prototypes. In the initial analysis, students first created individual sketches, as the diversity of ideas generates multiple potential solutions [11]. They then constructed an initial group solution, incorporating the best elements from each of the individual sketches. Figure 4 shows an individual sketch in the upper right and the group sketch in the lower right, as presented in the initial presentation. For idea generation, some groups utilized ideation tools such as brainstorming and benchmarking-type comparative tables. Throughout iterations 1 to 3, students showcased group solutions. In iteration 1, they continued to present hand sketches, delving deeper into the requirements. In iteration 2, they employed CAD software and platforms like Biorender to enhance the visualization of solutions. Figure 4 illustrates the CAD drawings of the solution in iterations 2 and 3. In iteration 3, the bottom part shows one of the designs created in the Biorender platform.

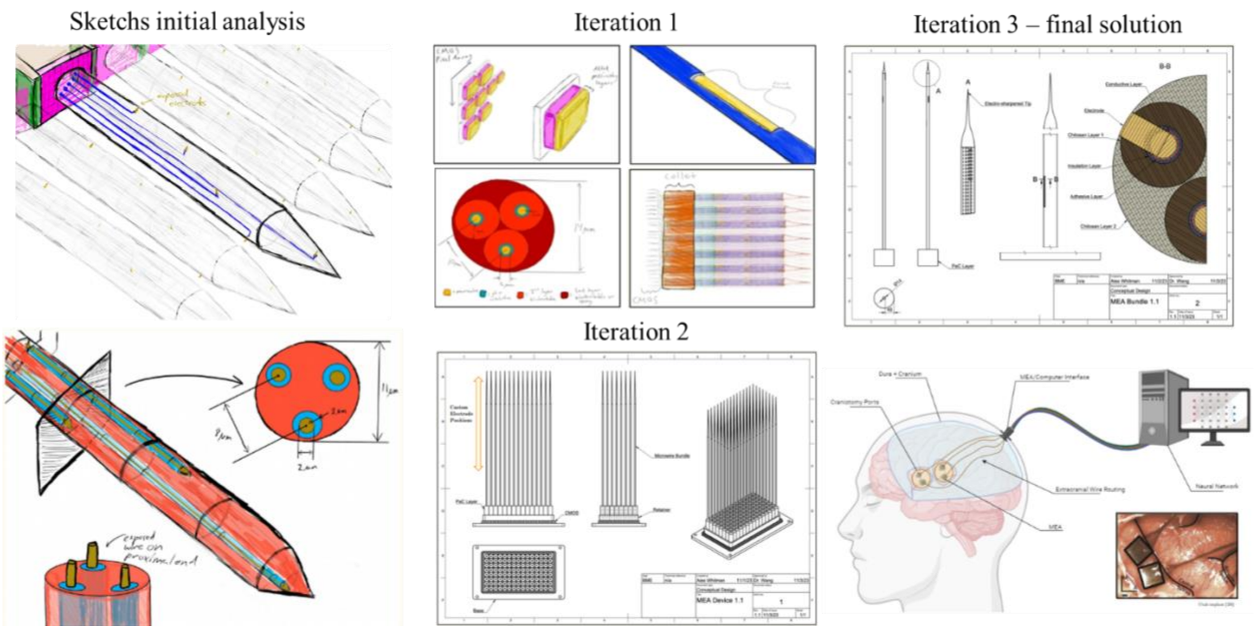

Figure 4. Example of the iterative process with the four phases carried out by each group of students.

For each of the presentations, students were asked to enhance their designs by describing the articles used to support the proposed improvement. This allowed students to review in more detail the characteristics of materials, manufacturing methods, possibilities for signal improvement, among other aspects. The use of digital tools was crucial for visualizing the prototypes and, above all, for observing the evolution of students' ideas.

Learning outcomes

The course of Bioelectronics and Biointerfaces, in which the iterative design methodology of this study was applied, introduces different modalities for recording and stimulating biological systems, including electrical, optical, mechanical, chemical, ultrasound, magnetic, and genetic approaches. The focus of the course is on the concepts and strategies in materials development, electronics fabrication, and genetic innovations that interface with biological systems.

Two of the five learning outcomes proposed in the course are related to the design project, aiming for the development of learning environments to produce solutions in clinical contexts, which are crucial elements in engineering fields such as biomedical engineering [12]. The learning outcomes are:

1. Students will develop a group engineering design project, including the application of concepts both learned with the course and outside the course.
2. Students will use engineering design methodologies and iterative design process in the development of a project to improve a reported technology in the field of bioelectronics.

We will analyze each of the learning outcomes, relying on the process carried out by each group, the final document presented, and a survey sent to the students at the end of the design process. Each student answered 7 questions grouped into the following categories: the Iterative Design Methodology used (student's definition of the design process, contribution of the methodology to the project, and differences with other classes taken), Relationship with the course content (usefulness and topics utilized, and contribution of the project development to the understanding of the themes), and Comments on the Iterative Design Project (useful aspects of the iterative design process and improvements in the application of this methodology).

Concerning the first learning outcome, all six groups developed a design project, demonstrating improvements to the technology proposed in the paper with clear applications to the mentioned diseases. Regarding the application of knowledge, in the second part of the survey, 14 students indicated that the course concepts were applied in the project, and 3 mentioned partial application. The three students were from a group related to material fabrication, stating that the course did not delve deeply into this topic. It is clarified that, being an introductory course to bioelectronics, manufacturing processes were not extensively covered. A relevant comment from a student was, *"As we learned more about different bioelectronic/biointerface principles, they became part of our design. My group also utilized most of the neurotechnology topics discussed to produce our final design. An interesting relationship emerged between the two, with the course teaching us the content and the research for the iterative design process reinforcing and applying the knowledge."*

Concepts learned outside the course were associated with searches conducted in papers, which were related to understanding diseases, properties of new materials, manufacturing methods, bioinstrumentation, sensors, drug delivery, among others. All these concepts supported not only a better understanding of requirements but also the development of more detailed solutions regarding technical descriptions.

Being a specialized course, most undergraduate students took it in their career final year. For graduate students, most took it as it was related to their current research topics. When comparing the methodology of this course with others taken, most students compared it with Senior Design or Capstone design courses. Some of the most relevant comments were:

"The iterative design process used in this course compared to the ones used in other courses is that the iterative design process used in this course was much more structured, streamlined, and easier to follow; it also had a much greater emphasis on the 'deployment' phase of the engineering process."

"This is very different compared to other team projects where we often focus very heavily on research in the beginning without much design, and we only design at the very end. In these versions, it is difficult to incorporate feedback because there is only one version created."

Most students found significant differences from previous design courses, such as starting with an already created technology, the feedback generated between presentations, the iterations, and the use of literature to support their improvement ideas. Almost all students indicated having taken design courses where only a single design was achieved by the end of the course, with feedback from the end-user. Starting with a proposed technology was mentioned as a challenge by the students, as they not only had to understand the technology but also analyze possible improvements. They highlighted the use of papers to clarify concepts and as a source of inspiration to generate more ideas with real elements that could be implemented in their technology improvement ideas described in the article.

For the second learning outcome, we began by asking students for their concept of the iterative design methodology after completing the course project. Some definitions were:

“Iterative design methodology is a process for creating a design or solution where several iterations take place before reaching the final solution. Each iteration is improved upon based on feedback from the previous iteration.”

“Iterative design is characterized by a process in which the design is refined and improved through a series of multiple iterations. Each iteration, the design is improved incrementally based on feedback and testing from previous iterations.”

“More specifically, the iterative design methodology begins with an initial planning step, wherein the engineering requirements for a new device are developed and enumerated.”

“Essentially, each subsequent stage of the iteration process only occurs after the current stage has been made successful. This leads to much more efficient development of technologies and ensures the final device will satisfy the necessary engineering requirements.”

In these definitions, not only the appearance of the word "iterations" (in plural) is highlighted, but also concepts like feedback, requirement, and improvement. This is important because students recognized through the practice in the course project the importance and necessity of developing iterative processes that lead to better solutions.

What stood out the most for the students was the feedback process, which is crucial for improving students' performance [13]. Through the Canvas platform of The University of Texas at Austin, students submitted documentation, and feedback was provided after each of the presentations. The feedback included two elements: positive aspects in the design and process, and recommendations for improvement. Improvement recommendations focused on questions to the student group regarding the relevance of using a material, structure, manufacturing method, among others, possible new paths to explore, and a more detailed description of how a requirement could be expressed in the design.

The first feedback given to the students was of great importance, as some expressed. The work team, when dealing with a developed technology, first needed to understand the theoretical, experimental, and application aspects of a disease described in the paper. In this initial feedback, suggestions were made focused on the clarity of the initial requirements and how they could improve them through feasible solutions. For iterations 2 and 3, students were asked to show in their presentations the feedback and how they had addressed it in the improvements to their designs. All groups showed that the feedback allowed them to delve deeper into their solution ideas, besides feeling challenged to review what knowledge allowed them to reinforce the improvements they had in mind. Some comments were:

"I enjoyed that the presentation was broken down into three separate iterations, and that we were given feedback for each iteration. I think that originally, I felt overwhelmed by the new information and was not sure where to start/where to innovate, but the feedback from the first iteration presentation was helpful as to what areas we were lacking in, and thus which areas to focus more on."

"I think that the iteration was incredibly helpful, as the first solution and first iteration that we came up with was not exactly what was required of the project, and having the chance to iterate on the design after receiving feedback allowed us to pivot and have success."

"I found the detailed feedback and suggestions given by the teaching team for each iteration of our device to be tremendously useful, as it provided valuable guidance to the team in regard to what specifically the team should focus its efforts on and what the team was doing correctly throughout the entire iterative design process".

All groups succeeded in developing a project that enhances a technology in the field of bioelectronics. Below is a brief description of each group's results and highlights of the iterative design process:

Group 1. Graphene Tattoo Forehead EEG for Personalized Treatment of Depression: The students proposed the use of a new material for diagnosis through electroencephalography (EEG). The group's PhD student encouraged his peers to conduct tests with real prototypes using graphene and gold films. This led to issues in signal capture and the appearance of noise in the signals. In the end, they proposed a system with technically detailed and justified requirements in the literature.

Group 2. Porous Conductive Biogel for Functional Electrical Stimulation and EEG Recording During Stroke Recovery: This was the only group that maintained the number of requirements, albeit with a more detailed description iteration by iteration. The final design includes a step-by-step description of the biogel manufacturing process, aiming for electrode manufacturing reduction and greater skin adherence.

Group 3. Closed-Loop Smart Bandage for Accelerated Wound Management and Healing: This group was one of the most outstanding with a comprehensive design approach. The group redesigned the entire technology, considering 4 elements in the design: sensor layout, electroactive drug release, closed-loop feedback, and system design. The final design proposed developing the entire matrix on organic semiconductors, in addition to showing in detail the manufacturing process of the entire technology.

Group 4. Bioactive Coating for Graphene Fiber Electrodes to Treat Parkinson's via Deep Brain Stimulation (DBS): This group initially proposed 3 requirements, but after reading the papers and receiving feedback, they divided all requirements, resulting in 9 requirements in the end. In the final design, they developed an electrode using new materials and coatings. They provided a detailed description of the manufacturing process of this technology and its use for the analyzed disease.

Group 5. Bioresorbable Peripheral Nerve Stimulator with Closed-Loop Control: This group was the only one composed of two undergraduate students. Although the search for scientific literature was not extensive, which was reflected in a solution with less detail than the other groups, the group had the technical challenge from the beginning not only to propose a design for the electrodes but also for the electronic system. The final design included the electrode design and a proposal with a block diagram of the electronic system components.

Group 6. Microwire Fabrication and Implementation: This group stood out in the development of a mechanical design related to the implementation of a microwire array for measuring brain activity. Their design process is based on the evolution of their initial sketches, showing detailed CAD designs in the end, including not only the microwire matrix but also connectors and a detailed description of the materials and how they would be in the solution.

Comparison with Previous Courses

This is the third cohort of this course at The University of Texas at Austin, which is offered once a year in the fall. In 2021, a project was proposed to be presented in the last third of the course. Twenty-three students were grouped into 5 groups with topics similar to those described in this study. Each group was assigned a paper with a technology. Each group made a presentation and a written document describing the disease, proposing 3 objectives in the development of the technology, observing improvement strategies. The requirements raised by the students are shown in the development of closed-loop systems, systems with wireless connection, the use of electric and focused ultrasound stimulation, and methods of drug delivery.

In 2022, a group of 27 students took the course, divided into 6 groups with similar topics to this study. Like the previous year, students prepared a course project in the last third of the course, where each group was given a paper. In addition to the previous year, students were asked to describe existing solutions to the problem and propose solution ideas with some sketches. They also highlighted limitations in the design as an element at the end of their presentation and written document.

We will compare three elements: papers consulted and used in the solution, requirements raised, and final solution. Regarding the papers consulted, the average of the papers used for the final presentations was found for each of the years. For 2021 and 2022, there was only one presentation, and for 2023, it was the last iteration. All referenced papers in the documents (presentation and written document) were counted, and then references used solely to support the description of the proposed solutions were counted. The results are shown in figure 5.

The papers not used in the designs were related to the state of the art to describe the disease, current treatments, and reinforce the understanding of the technology described in the article. The papers used in the designs were employed to describe the requirements and how the technology could be improved. These papers were crucial for the students to clearly establish the properties of materials, manufacturing procedures, possibilities for the development of closed-loop control systems, among others. In general, the average total number of papers used was similar over the three years, with the highest in 2022, as one of the groups consulted 40 papers. Regarding the percentage of papers used in the designs out of the total, 59% in 2021, 49% in 2022, and 81% in 2023 were used in the designs. This is a significant indicator, showing the utility of the iterative design methodology, as students supported their ideas more from a technical perspective.

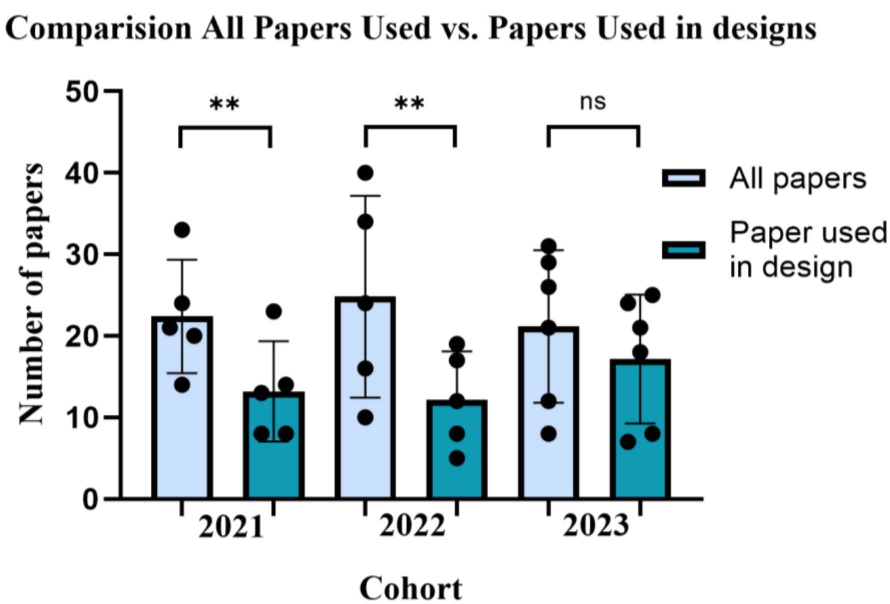

Figure 5. Comparison by year of total papers used in presentations and papers used in designs.

In Figure 5, an analysis is conducted across years. If we compare the means (2021 - 17.8, 2022 - 18.5, and 2023 - 19.1) of the total articles with the articles used in the designs and models, they are similar. However, it was found that in the years 2021 and 2022, there is a significant difference between the total articles used and those used in the designs proposed by the students. For the year 2023, no significant difference was found, indicating that most articles were used in the designs generated by the student groups. This is also evidenced in the difference in mean between the total number of articles consulted and the articles used in the designs: 2023 - 4, 2022 - 13, and 2021 - 9 articles. This means that the use of the iterative design methodology employed in 2023 allows students to make greater technical use of the state of the art, compared to previous years where only a single iteration was conducted.

On the other hand, the average of the requirements that each group proposed was one requirement for each of the objectives for the projects developed in 2021 and 2022. We consider that there may be a bias in addressing the problem by requesting a specific number of objectives, as students assumed one design requirement for each objective. In the case of 2023, as indicated in a previous section, the requirements were adjusted in their number and specificity. To generate this dynamic, iterations were important, and the formulation of requirements, not objectives, at the beginning of the project. This led students to think more about the characteristics of the technologies proposed in the papers, as observed in the quantity of requirements proposed and described in the final designs.

The final solutions in the three analyzed cohorts demonstrate the application of concepts from the bioelectronics and biointerfaces course. Regarding the descriptions of the final solutions in the 2021 group, students focused more on describing the objectives of the technology with some initial sketches of improvement ideas. Many of the ideas presented were good but with gaps in how to implement them in a final design. In the 2022 group, there was an improvement in expressing ideas through sketches in several groups and in requesting the description of innovation and limitations of their proposed solution. This allowed for more detailed designs and additional analysis of the characteristics of the technologies and the obstacles in their implementation in the final solution. In the 2023 group, as mentioned earlier, multiple solution ideas were generated in an evolutionary and iterative process that allowed for a more detailed description of the solutions, meaning that the application of iterative design methodology resulted in positive learning attitudes, leading to a significant increase in knowledge [14]. Although we understand that, not having the same stages, the results may not be comparable, we have conducted an analysis of the possible improvements in working on a project in multiple redesign stages, compared to the development of design projects in a single stage.

Successes and Future Improvements

We want to highlight aspects that students mentioned in their comments as improvements to the methodology and teaching strategy employed in the course. Below, we present some of their comments:

"To improve the project next time, it could be helpful to provide more specific and technical feedback."

"I also think it could be interesting to pair different groups of students together to get feedback on each iteration from other students to expand the amount of collaboration and get a mixture of more diverse ideas. I think that would expand the interaction of students in the class and could produce some interesting results."

"This project allowed me to grow as a student and a professional, and the only thing I would change is I would have liked to be taught some more methods for ideation."
"I feel that it would be tremendously valuable for students if some lectures could be set aside for meeting with the teaching team and other project groups to exchange ideas throughout the iterative design process."

"Oftentimes, I feel the groups were unaware of the time limit that should be observed when presenting each iteration of their project."

Next, we suggest some practices that we believe can be useful for those who wish to apply these methodologies, considering the feedback provided by the students and aspects observed by the teaching team.

Logistical Aspects: The presentation of well-defined schedules with document submission dates and presentation dates was one of the most consistently positive comments from students. Also, delivering days before the presentation allowed many of them not to leave everything until the last moment and better prepare for the presentation. One aspect to improve is the presentation times, which in our case were from 12 to 15 minutes, which they considered short. Strategies should be reviewed to make students more effective in time management.

Use of Tools: The quality of designs improved when modeling tools were introduced. If students have knowledge of CAD software, this could lead to more detailed solutions. If not possible, modeling tools available online can be used. Our experience with the biorender software was good. In its free version, students were able to showcase their designs and manufacturing processes.

Discussion times: It is suggested to reserve some sessions for discussions among the groups on aspects related to the project. This time could also allow the teaching team to delve deeper into the students' difficulties. Strategies could also be sought to facilitate interactions and feedback among the groups in the development of their projects.

Ideation: One of the most important aspects in the project development was the formulation of requirements and how to express them in the designs. It is suggested to conduct a workshop that provides students with various ideation tools, besides the classic brainstorming. Tools such as morphological chart, SCAMPER, TRIZ, among others, can be useful.

Feedback: It is important to provide feedback as soon as possible; for the course under study, this period was 1 week. As an improvement point, students mentioned the possibility of creating discussion spaces with their classmates, which could enrich the design process further. It is also important to further inquire with each of the groups about the theoretical and technical aspects where they encounter more difficulties, to provide better feedback.

Exemplification: At the beginning of the course, the postdoctoral fellow associated with this study provided an example demonstrating the iterative design methodology in the case of designing two biomedical technologies. This point was crucial because it shows students how the process can be carried out. Examples of this type could be sought for a better understanding of the project and its scope by students.

Project Format: In comparing three cohorts from the previous section, we present two formats. In the years 2021 and 2022, a project presentation format was utilized in the last third of the course where only one iteration was conducted, meaning only one design was shown. In the year 2023, however, the format used spanned the entire course with multiple iterations and designs. For the implementation of the iterative design methodology, we recommend adopting the teaching strategy throughout the entire course. This allows students more time not only for literature reading but also for analyzing and proposing improvements in a more measured manner. We believe it is necessary to give students the time to undergo a process that enables them to better understand the concepts and their application. Additionally, we found it useful to have a maximum of 3 or 4 moments for presenting the process results to avoid overwhelming students with submissions, thereby providing them with more time to contemplate improvements to their designs.

Conclusions

The results presented in this study, although not intended for generalization, aim to exemplify a pedagogical practice in the classroom. We acknowledge that a single course represents a limited sample, and that further application to a larger number of courses would be necessary to thoroughly evaluate the results. However, we want to emphasize that the iterative design methodology, starting with a real and known technology through an article, has a more significant impact on students. We discovered an alternative approach to sparking interest and emphasizing the importance of analyzing articles, using a guiding thread such as a design project.

We identify that the role of feedback is crucial in these types of learning processes. This action guides students towards technically feasible solutions, adding value to the pursuit of understanding concepts and methods proposed in the course. It was notable to witness final presentations characterized by technical language and content firmly rooted in the state of the art.

We observed that students consulted various papers, using the pretext of seeking materials or methods to improve their designs. This demonstrates the usefulness of employing teaching strategies such as design projects as a means for information analysis and the reinforcement of technical concepts. However, we believe that support from a teaching team, such as a teaching assistant (TA), is necessary for success in these types of projects, who can closely analyze the information provided by students in deliverables such as presentations or course documents.

We also demonstrated that the use of iterative design methodology resulted in a greater number of articles being used to support the designs proposed by each group of students. We found that with the methodology used in 2023, 81% of the consulted papers were used in the designs. Comparing this value with the years 2021 (59%) and 2022 (48%), where this methodology was not used as only a single iteration was performed, a significant increase is observed. The articles used in the designs were validated regarding their contribution in the slides of each iteration's presentations and the final document that showed all the iterations. Descriptions related to requirements, material properties, manufacturing methods, use of instrumentation (sensors, electronic circuits for signal filtering and amplification), and drug delivery were reviewed.

The teaching strategy of this study can also be seen as an iterative process, as demonstrated in the comparison between three cohorts of students who took the course. The utility of conducting a design project throughout the semester with feedback in presentations was evident in the last cohort. Improvements were made by proposing a project to be developed throughout the course, outlining requirements, and conducting multiple design iterations that included literature supporting design improvements. All the above resulted in the use of a greater number of papers in the design, clearer requirements, better designs, and an ability for technical description on the part of the students. Students saw the utility of the methodology as they witnessed progress in their projects during the semester, especially in the final submission, where comparing their initial and final designs revealed the transformation of the solution, as well as a deeper application of some key concepts from the class.

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