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Board 71: Innovation-Based Learning. Learning by Failure

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IBL: Learning by Failure

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Abstract:

Innovation-based learning (IBL) is a classroom structure that lets undergraduate students choose their own focus in projects while relating it to the core principles of the course. It takes a hands-on approach, allowing students to work on projects that have an impact on the world. Students track their effort and learning via tokens in an online learning management system (LMS). More importantly, it provides them the opportunity to fail, and learn from their failures. A major problem with the traditional class structure of today is that it relies heavily on the pass/fail aspect of the course, putting pressure on undergraduate students.

Most students have not been previously exposed to the material before coming into a class, yet their final grade suffers if they make a mistake on assignments or tests. Whether they learned from their mistake or not is irrelevant because their grades have suffered irreversibly. With IBL's structure, students can make mistakes as they learn while still being able to succeed in the course. Instead of being punished for having a beginner's knowledge of the subject and making naive mistakes, undergraduate students are encouraged to begin from a place of curiosity and devise a ‘moonshot goal’ which will require them to study, form hypotheses, perform calculations, and create prototypes/experiments. Often, the hypotheses are disproven, the analyses reveal impracticality, and the prototypes fail to satisfy requirements. In short, they often fail. Understanding why failure occurred at each stage deepens students’ understanding of the material and strengthens their ability to tackle complex problems in the future. This ability to fail, coupled with IBL’s willingness to let students explore topics in which they are personally invested, grants students a unique agency in their learning.

Under their IBL professor's support, undergraduate students can present their work at conferences when they would otherwise never be afforded the opportunity. IBL students can participate in applied research at a level usually reserved for graduate students. By being afforded the ability to take on large projects with complex problems, undergraduates under the IBL structure develop professional skills and have access to experiences well ahead of those entering the workforce through traditional educational models. This better prepares them for the challenges they'll come across in their careers, strengthening their knowledge after undergraduate programs. This paper will provide a first-person account of one undergraduate team's experience during their first semester in IBL. Students will reflect on their developing self-image as student engineers, not as engineering students. Students will share their initial project aspirations and the failures, pivots, and learning which occurred during the semester. Students' use of tokens to manage planned work and education achievements will be discussed. Students will state their achievements from this course and contrast traditional learning structures, such as high-stakes testing, active learning, and project-based learning, to IBL

Keywords:

Innovation, IBL, LMS, engineering, education, learning

Introduction:

This paper's discussion will follow the Innovation-Based Learning course called Biomedical Engineering Innovation-Based Learning 1, or BME 180. This is the first semester, freshman level course for biomedical engineering students. Innovation-based learning takes a combination of engineering education styles and uses them to fuel learning [1]. The core of the class is centered around fundamental principles. These principles are class topics based on physiology and biomedical engineering concepts. For example, action potentials, cardiac vasculature, and equilibrium potentials are all fundamental principles discussed in the course. In our university's classroom structure, one principle is assigned each week. These principles are to be researched, investigated, and discussed using a very high level of active learning by the students. Thus students are actively involved in the learning process, giving them the ability to master the topic in a way that they can understand and apply it [2]. Students apply this new knowledge by presenting it to their peers. Once the students feel they understand the topic they make evidence of their knowledge in whatever format best suits them, such as a short video of them explaining the topic with graphics or even making a detailed comic from scratch explaining the topic. This proof of understanding is then uploaded to a token in an online proprietary learning management system. As stated by professors who started an IBL program at NDSU, "To evaluate that token, peers provide blind reviews, reviewers evaluate whether the evidence provided matches the level of the token and provide feedback" [3, p. 4]. This encourages collaboration and professionalism in peer reviews. Then the tokens are evaluated by instructors to determine if the student has provided sufficient evidence of their knowledge according to the course's objective scales [4].

Students' peer reviewing in the learning management system (LMS) is a major indicator for student's success. This is largely due to cooperation and collaboration. "Relative to students taught traditionally - i.e., with instructor-centered lectures, individual assignments, and competitive grading - cooperatively taught students tend to exhibit higher academic achievement, greater persistence through graduation, better high-level reasoning and critical thinking skills, deeper understanding of learned material, more on-task and less disruptive behavior in class, lower levels of anxiety and stress, greater intrinsic motivation to learn and achieve, greater ability to view situations from others' perspectives, more positive and supportive relationships with peers, more positive attitudes toward subject areas, and higher self-esteem" [5, p. 3]. Peer review has a significant amount of research and experimentation that supports it in the educational space [6]–[8]. These two concepts combined give students the required knowledge for the course's core principles.

Not only does IBL allow undergraduate students to research these core topics, but it also allows them to relate it to semester-long projects [9]. These projects take the hands-on experience of project-based learning, allowing undergraduate students to work on topics related to the course. Project-based learning [10] is an important model of learning that houses a fundamental building block for IBL. By having students work on projects, they are more actively engaged in the engineering design process. The downfall of project-based learning is the inability to encounter failures without significant repercussions to their grades. Being able to fail on a project and learn from that experience without jeopardizing the students ability to pass the course has been proven to be an effective way to teach engineering concepts [11]. Teaching students the ability to pivot, or to change the direction of their project towards their goal after each failure is critical to teaching good engineering design.

However, in IBL, projects are not just implemented to engage students in activities. This learning model requires that these projects must be innovative. Students are encouraged to find real-world problems that they are passionate about and take them into the classroom. They discuss the problem with other students, professors, and a group of peers who work on the project with them. Once the group settles on a topic to solve, they start working on how to solve it. Through research, experimentation, and design, students can work on a project that has a real-world impact. This impact can come in the form of research papers, patents, business creations, and more. Although this seems like a daunting task for a single semester, the students are expected to make multiple failures along the way. The point of IBL learning is to pivot from those failures and take what you learned from it into the next iteration of your project [12][13]. If students put in a good-faith effort, work on their project consistently throughout the semester, and attempt to make an impact outside of the classroom, they will pass the course easily. This paper will go over a first-person account of a student group in the IBL structure, focusing on the failures, and the pivots from those failures.

Methods:

Participants

Four undergraduate students comprised the project group. Three of these students contributed to the writing of this paper, with direction from professors. They took an IBL structured course in the Fall 2022. This is the same course explored in the discussion. These students were all in the biomedical engineering bachelors' program at the University of North Dakota (UND), which also started in the Fall 2022. Of the group, two were male and two were female. The same student group helped write this paper and share their experiences throughout the semester.

Using MOOCIBL to store progress and provide information

During the semester, the students kept track of their project progress using tokens in an online proprietary learning management system, MOOCIBL. They linked these tokens to presentations, meeting notes, and research concerning the project topic. In addition, MOOCIBL archived these tokens for later reference, and to measure their overall progress through the semester. The team could also share their tokens with peers to share progress and network for ideas and collaborations. This platform is the main way the student group documented their project and efforts.

Discussion:

When the course started, our group formed after a couple weeks. We had till the end of the semester to work on it and were expected to make a couple of presentations throughout the semester. Before we could present though, we needed to have a gap. The gap is the need for that project. With innovation-based learning, defining a solid gap is crucial to the project. What problem needs to be fixed, improved, explored, and innovated. The whole point of innovation-based learning is making innovation in the outside world. Not to do something that has already been done. When deciding on a gap, we were encouraged to think divergently. Moonshot ideas and outlandish proposals were highly suggested. What our group decided as an innovation was to use the body as an energy source for pacemakers. Our group first looked into pacemaker research. Where to put the pacemaker, what has already been done in this field, and how pacemakers themselves work. We also looked at the problems with current pacemakers and looked at what could be improved. The problem with pacemakers we found was the need to replace the pacemaker. We wanted to eliminate the need to replace the pacemaker, or at least lengthen the amount of time that the pacemaker can be used.

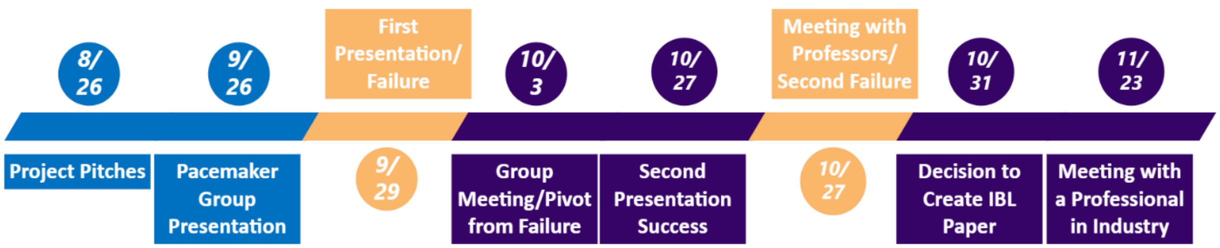

Figure 1: Timeline of failures throughout the IBL project. It details the time between 8/26 to 11/23 during the fall semester of 2022. The red indicators are for failures during the project, and green are the pivots from those failures. Blue describes neutral points of project pitches and group formation.

The first time our group felt like we failed, or fell short of our goals, was in our first presentation to our class. A large part of the IBL project is peer review. Each project group presented their ideas to the class in the form of a presentation and was able to hear feedback from the class and professors. We could take this feedback and use it to refine our project and project goals. Our first presentation was the basics of our gap and why it was an innovation. This is very important for the development of professionalism in a presentation setting. Our failure was not being professional. We didn't take the time to research the very basics of our project and made up answers. For example, a classmate asked how long current pacemakers last. We had no idea and made educated guesses of the lifetime, passing them off as researched answers.

We were so paralyzed by the possibility of losing points by not being experts, like so many class structures before, that we bluffed. We were immediately called out and proven wrong by a professor who had access to google. In a traditional class structure, this probably would have cost us a significant amount of points. However, instead of grading us on our presentation harshly, the professors simply corrected it and talked with the class about professionalism and knowing when to say you don’t know yet. IBL doesn't punish you for failure. That's the point of the IBL class structure. You are supposed to fail, learn from that failure, and learn more about why you failed, how you failed, and how to not fail in the future. “This learning requires students to embrace their failures, something they have been trained to avoid in the past [13, p. 2].” The system was set up to make us learn from our failures and give us a chance to prove we learned it in the next presentation.

However, we had a significant amount of time between presentations. After the first presentation, we had a lot to talk about. We discussed what went well and what we needed to improve for the next time. Our professionalism wasn’t our only failure during this presentation. The comments and suggestions from our peers pointed out many other failures in our group. We narrowed these problems down to a couple of main parts. For a start, we didn’t communicate well enough in our group to give the class a coherent presentation. We were unclear about our goals and needed to refine what we all wanted to pursue. We were pulling our project in a few different directions in terms of outcomes. This was one of the most influential pieces of feedback that helped us later. It allowed us to create a more concrete vision of our group's goal and how to communicate it.

Secondly, to communicate this clarified goal, we needed to clearly state the purpose and scope of our project for the class. The class and the instructors were confused by our project and weren't sure what we were working on. For example, we constantly highlighted that we wanted to work on "in-vivo" power generation, but never explained to the class that it meant "in-the-body" power generation. This may have been a clear subject for us because we researched it, but for the rest of our peers, it caused confusion. We needed to explain the topic in a way that could clearly be understood by everyone. On top of that, we also didn’t make the innovation of the project clear to the students or the professors. We never specified what was already out there and how we planned to improve it. These failings are the main operation of the IBL structure. Being able to fail and learn from those failures without repercussions to your grade is a relief to many students. When asked, one of the students in our student group said,

> *“I felt super nervous right away during the failures, but after talking about it with our group and then discussing it with the professors I felt better about it.”*

As a student, you are meant to take these lessons and learn from them in an environment that doesn’t irreversibly take points away for failure. IBL sets up these failures as good points to refine your path to a completed project. Being able to pivot directly from failure to another path of innovation separates IBL from project-based learning. We took this information as a pivot point to aim our group in a direction of research that would help us reach our goal.

After the presentation, when we were forming our ideas of how to properly implement a more efficient way to maintain power within pacemakers, we discovered that we knew little about pacemakers and the overall longevity of the battery. Coming from different educational backgrounds, none of us had experience with heart monitoring devices. With innovation-based learning, we were able to conduct our research into the topic. After a few weeks of research and sharing our findings as a group we were able to narrow our focus on power from a few different ideas to just one: using piezoelectric materials to generate electricity from the applied stress of the heart. We lessened our divergent ways of thinking and began to utilize our convergent ideas to set our main goals.

This is about the time that our group realized that we could use help from our professors. We were fortunate enough to have a professor with experience in the cardiac system who was very invested in our group. Our professor pointed us in the direction of pressure differences, power generation of piezoelectric materials, and what power we needed to supply to a pacemaker. This meeting was a launching pad for our research that led us to a very convergent way of thinking. He gave us things to research, experiment with, and determine if they helped us in our project. We were solving problems with our project, learning more about the body, and learning more about how pacemakers function.

From our peer feedback and instructor feedback, we were able to see the flaws in our project and work on them before our second presentation. Armed with the knowledge we gained in the first presentation; our second presentation went much better. We were able to communicate a much clearer and more refined project to the class. We took a full page of notes from our first presentation on things that went wrong and needed improvement. We communicated our goals and the class was able to clearly see our innovation. Not only that, but we had researched out project a lot more, and didn't pretend we knew all the answers. Because of this, the presentation went off great with constructive conversations and useful critiques strengthening the project. We learned from our mistakes in the first presentation and had quantifiable proof. The list of notes we took from this presentation was only three lines long.

Although this was a great success, there was just one glaring issue that halted us in our tracks. We weren't sure that we were making a good innovation. Our presentation went great, and our idea seemed solid, but we weren't sure that our innovation was useful. Because of this, we met with our instructors. They helped us to realize that we were creating more problems than we solved with our current iteration of the project. In short, we failed again. We had shot for the moon, learned a lot on the way, and failed again with a little over a month left in the semester. In a normal class structure, this failure would have cost us a significant portion of our grades and possibly caused us to fail the course. Fortunately, with an IBL structure, this was exactly what was expected. We were encouraged to continue our advancements and find new avenues of research to consider while keeping hold of our past findings.

This was a complete shock to our project group. We had never experienced a class in which learning was prioritized over standardized testing of our abilities. We were being told that not only had we not failed the course, but now we could continue with what we learned and strive to make innovations. This showed us how IBL actually worked. We had just become the exact picture of what IBL is all about. This is when we also decided to undertake the creation of this paper. From a student's perspective, IBL is the closest thing to the real world that we could ever hope for. The following are two direct quotes from our undergraduate group members,

> *"I learned that engineering is mostly failing. I now know that every failure needs to happen to learn something new. I feel like each time we failed, and we realized why it failed, the next idea we had was better and we didn't make the same mistakes."*

> *"I feel as though, the failures we experienced throughout the project were solely mindful concepts rather than a futile task. After I began viewing the failures as ways to improve, I feel as though I was able to contribute useful ideas with the intent of fulfilling our team goals."*

IBL's willingness to let students fail and pivot from their failures allowed our group to not waste a day before redesigning and diving back into the research. Although we did dedicate a certain amount of time to the creation of this paper, it didn't slow down our progress at all. We continued making great strides in our project.

The next stride was to reach out to the professionals. We were encouraged by the professors to reach out to someone with knowledge of pacemakers and their installation. This is when we decided to talk to someone that worked in the field we were pursuing, something that we had never been encouraged to do in high-stakes testing or project-based education. Still unfamiliar with the pressures of the thoracic cavity, we contacted Altru in Grand Forks, North Dakota in hopes to speak with a professional who is familiar with the cardiac system and/or pacemakers. A medical doctor in the field of Electrophysiology reached out with his interest in providing the feedback and information that we were seeking. Prior to the meetings, we were uncertain about our narrowed focus, however, the feedback given by the expert provided us with certainty that it would be possible to implement our ideas to further reach our goal of a leadless in vivo powered pacemaker. Although we were given the clarity that we needed from the meetings, we also spoke about some ideas that we had questions about the realistic functionality of. After explaining a few of our ideas we were provided constructive feedback which helped us to rule out some locations of energy harvesting.

With an IBL-focused course, we were empowered to meet with experts and gather the information that we could not possibly obtain in a high-stakes testing course. After this meeting, we got to the point where we needed to make CAD designs and electrical models to test our innovation. Unfortunately, with the semester ending and standardized finals coming up in all our other classes, we ran out of time to continue our innovation. While we do plan to continue this innovation project during the upcoming semesters, we did not make any patents, prototypes, or create a business. Regardless of this incomplete status of our project, we had an impact. We created interest from and formed ties with people in the industry for our project completion, we have compiled papers worth of research into this project, and we submitted this paper talking about the IBL structure to a national conference as undergraduate students. No other teaching structure can compare to the experience the IBL learning structure has given us.

Conclusion:

Innovation-based learning is a learning structure that combines many aspects of other learning methods. This combination led to our student group making leaps we thought were not possible. We have learned more about the engineering process in this one semester than we ever have in traditional high-stakes testing, active learning, and project-based learning courses. We could have never seen this in the beginning though. From our background in traditional classroom structures based on high-stakes testing and individual one-time assignments, there were many times during the project we thought we failed. Our student group kept making failure after failure but always pivoted with the help from professors and peers. Because of this we moved at a very rapid pace toward an innovation each time. We formed hypotheses, made calculations, researched topics we had never seen before, and worked towards our goal. After the semester was done, we created an impact outside of our classroom and submitted an abstract to a national conference as undergraduate students.

With these skills obtained from this learning structure, we feel more confident than ever in our decision to continue with engineering. To be an engineer and participate in a design process, means accepting that at some point you will fail. This is something that none of us in our student group knew before the semester's start. We were so ingrained into getting it right the first time, that failure meant failing the course, ourselves, and those who counted on us. This IBL course has changed the meaning of failure to us. To successfully innovate, you must accept failure. Failure is now a pivot point to launch from. Failure means better designs in the future made with more information gathered from experience. Failure does not mean the same thing to us anymore, and we hope that more students will be exposed to this way of thinking in the future.

References:

[1] R. Striker, M. Pearson, E. Swartz, L. Singelmann, and E. A. Vazquez, "21st Century Syllabus: Aggregating Electronic Resources for Innovation-Based Learning," in *2019 IEEE Learning With MOOCS (LWMOOCS)*, Oct. 2019, pp. 75–78. doi: 10.1109/LWMOOCS47620.2019.8939640.

[2] L. Singelmann, E. A. Vazquez, E. M. Swartz, M. Pearson, and R. Striker, "Student-developed Learning Objectives: A Form of Assessment to Enable Professional Growth," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Feb. 13, 2023. [Online]. Available: https://peer.asee.org/student-developed-learning-objectives-a-form-of-assessment-to-enable-professional-growth

[3] E. A. Vazquez *et al.*, "The MOOCIBL Platform: A Custom-made Software Solution to Track the Innovation Process with Blockchain Learning Tokens," presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Feb. 13, 2023. [Online]. Available: https://peer.asee.org/the-moocibl-platform-a-custom-made-software-solution-to-track-the-innovation-process-with-blockchain-learning-tokens

[4] E. M. Swartz, R. Striker, L. Singelmann, E. A. Vazquez, M. Pearson, and S. S. Ng, "Innovating Assessment: Using Innovative Impact as a Metric to Evaluate Student Outcomes in an Innovation-Based Learning Course," presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Feb. 13, 2023. [Online]. Available: https://peer.asee.org/innovating-assessment-using-innovative-impact-as-a-metric-to-evaluate-student-outcomes-in-an-innovation-based-learning-course

[5] R. Felder and R. Brent, "Cooperative Learning in Technical Courses: Procedures, Pitfalls, and Payoffs.," Oct. 1994. Accessed: Feb. 13, 2023. [Online]. Available: https://www.semanticscholar.org/paper/Cooperative-Learning-in-Technical-Courses%3A-and-Felder-Brent/f788f2139e2d85838f5ec0dddff65ddb43b00bb1

[6] T. Larkin, "Peer Review From A Student Perspective," presented at the 2009 Annual Conference & Exposition, Jun. 2009, p. 14.950.1-14.950.13. Accessed: Feb. 13, 2023. [Online]. Available: https://peer.asee.org/peer-review-from-a-student-perspective

[7] A. Russell, P. Carlson, W. Waggenspack, W. Hull, W. Monroe, and C. Wilmot, "Engineering Education: Oral And Visual Communication Using Enhanced Calibrated Peer Review," presented at the 2009 Annual Conference & Exposition, Jun. 2009, p. 14.553.1-

14.553.7. Accessed: Feb. 13, 2023. [Online]. Available: https://peer.asee.org/engineering-education-oral-and-visual-communication-using-enhanced-calibrated-peer-review

[8] S. Hamilton, "Learning Through Peer Review Of Work," presented at the 2005 Annual Conference, Jun. 2005, p. 10.882.1-10.882.13. Accessed: Feb. 13, 2023. [Online]. Available: https://peer.asee.org/learning-through-peer-review-of-work

[9] M. Pearson, R. Striker, E. M. Swartz, E. A. Vazquez, L. Singelmann, and S. S. Ng, "Innovation-based Learning: A New Way to Educate Innovation," presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Feb. 13, 2023. [Online]. Available: https://peer.asee.org/innovation-based-learning-a-new-way-to-educate-innovation

[10] J. S. Krajcik and P. C. Blumenfeld, "Project-Based Learning," in *The Cambridge Handbook of the Learning Sciences*, R. K. Sawyer, Ed. Cambridge: Cambridge University Press, 2005, pp. 317–334. doi: 10.1017/CBO9780511816833.020.

[11] S. J. Phillips, K. Giesinger, R. Al-Hammoud, S. Walbridge, and C. Carroll, "Enhancing Student Learning by Providing a Failure Risk-free Environment and Experiential Learning Opportunities," presented at the 2018 ASEE Annual Conference & Exposition, Jun. 2018. Accessed: Feb. 13, 2023. [Online]. Available: https://peer.asee.org/enhancing-student-learning-by-providing-a-failure-risk-free-environment-and-experiential-learning-opportunities

[12] A. Jackson, A. Godwin, S. Bartholomew, and N. Mentzer, "Learning from failure: A systematized review," *Int J Technol Des Educ*, vol. 32, no. 3, pp. 1853–1873, Jul. 2022, doi: 10.1007/s10798-021-09661-x.

[13] R. Sleezer, J. J. Swanson, and R. A. Bates, "Using Failure to Teach Design," presented at the 2016 ASEE Annual Conference & Exposition, Jun. 2016. Accessed: Feb. 13, 2023. [Online]. Available: https://peer.asee.org/using-failure-to-teach-design