

Facilitating Students' Learning and Success in Electromagnetism, Reengineering Mistakes

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Abstract— This work in progress paper presents an approach to introducing the basics of Electromagnetism for 3rd-year students in Electrical Engineering. Electromagnetism is one of the essential subjects by faculty and programs in Electrical Engineering education. It has been the foundational knowledge, historically and practically, of many areas in Electrical Engineering as well as other fields. However, students often view it as a very theoretical, mathematically challenging, and conceptionally difficult subject.

In this work, we present our experience in teaching Electromagnetism using an inquiry approach based on the Deweyan philosophical basis [1]. We also introduce the modified Kolbian cycle to the students to help them examine and reflect on their learning and intellectual journey in the class. The main perspective of the class is based on the premise: If we all learn from mistakes, why do we punish them and not reengineer them as an experiential learning process. This paper describes the foundational assumptions, methods, and tactics associated with this approach. We will examine some of the students' work, reflections, and reviews. The approach focuses on how we encourage and facilitate the students' journeys in getting more comfortable with the material and with their process of learning. It is important for the students to learn from mistakes, and not assume all mistakes processes are failures. We all learn from mistakes and expand our knowledge based on that. This is particularly true when learning Electromagnetism. Finally, we will present examples of the students' reflections, on the challenges, and propose a pathway to apply this method to other classes in different areas.

Keywords — Electromagnetism Education, Reengineering Mistakes, Rethinking learning

I. INTRODUCTION

As educators, our goals are focused on conducting classes to facilitate students' journeys to learn, practice, make mistakes, learn from mistakes, emancipate in connecting knowledge and experiences and try to enrich and expand their knowledge base [1]. We hope that the students become successful members of the profession. Historically, this has been done by conducting lectures, class activities, assignments, quizzes, and tests. We know that students learn by doing, and we know that students learn from mistakes [2][3]. Research shows that students would benefit from group work thus well-established methodologies have been introduced such as team-based learning and problem-based learning [3][4][5]. Consequently, based on our experience

and informed by current research in engineering education, we designed a class that allows students to work together on problems (that are conceptually connected to facilitate their learning and growth) while learning from the process. In this class, each activity is designed to avoid threatening students with the specter of bad grades. We provide ample opportunities for the students to do, make mistakes and learn from their mistakes.

The class environment is designed to first focus on the basics before moving on to more advanced topics. During the journey of the class, the instructors provide the important concepts, ideas, definitions, and examples. The assignments help students to work on their own, be challenged to review, think, and make more effective connections between the material and their understanding. Finally, the tests are to see if students can work on the material and show their deeper understanding of their practice and capabilities. Our experience and evaluations show that this methodology creates a more friendly, collaborative, and constructive environment for the students to learn, try, relearn, and advance their overall competence as well as create meaningful connections between the theoretical and practical aspects of their learning [6][7].

II. THE CHALLENGES OF ELECTROMAGNETIC (EM) CLASSES IN THE 3RD YEAR ELECTRICAL ENGINEERING (EE) PROGRAMS

Most EM classes are conceptual and mathematically heavy. However, the goal is to empower the students to be able to connect the concepts and the methodologies of EM to their overall EE knowledge. These concepts are part of the fundamentals of EE as well as Physics. The challenges of teaching EM to the 3rd-year classes are multifold. Students are coming out of circuits, electronics, and signal classes. In addition, they are out of practice in calculus, in particular, multivariate calculus which is important for EM [8]. This paper introduces a new approach to facilitate the students' learning, belonging, and striving in their journeys, and hopefully retain what they did, and why.

III. CLASS DESIGN AND ACTIVITIES

Our approach to facilitating the students' learning and conducting the class is based on philosophical perspectives that are built on Deweyan Inquiry-based cycles. We also use empathetic design to facilitate the students' learning. Figure 1 summarized how we build in the Inquiry-based concepts [1].

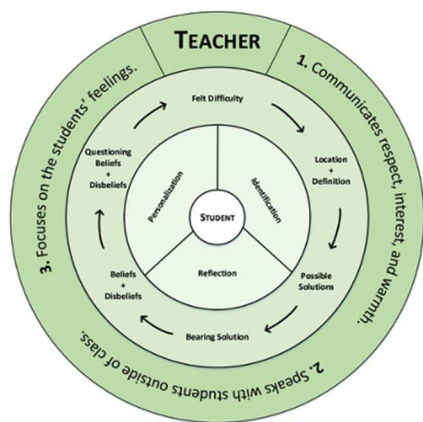


Figure 1. Inquiry-based cycle: Students' perspectives, understanding their challenges, and educators' roles [1]

In addition, we consider the students' work to reflect their understanding, learning, and thinking process as they learn the subject and practice. Therefore, every student's work is considered a valuable reflective activity that contains a roadmap to the students' processing, problem-solving, and communication [9][10].

In tune with our intention to encourage the students to be brave with sharing their ideas, we supplemented the regular in-class activities with games. These games are carefully designed to preserve the connection of the material while maintaining their effectiveness in the students' learning and growth. The conventional class culture is to avoid making mistakes and students are punished by lowering their grades. The games enable the students to avoid this mental conditioning and reflect openly to show what they think without worrying about repercussions. In our approach, the students are encouraged not to be afraid of making mistakes, and when mistakes do happen, it is a good opportunity to review, learn, and improve their work. We monitor the students' learning, growth, and struggles by carefully analyzing their games. The information is used to prepare for the next games that builds upon and caters to the students' most recent development.

Each term, the students work on 50 to 70 games. Additional assignments are also provided to help students explore and work on more in-depth problems. There are also four or five hour-long non-cumulative exams (based on each major topic in EM) during the term plus a cumulative final. The goal is to have students review, practice, and examine their knowledge and strive in integrating their learning. The games are worth 40% of the final grade while the assignments and tests are worth another 25% each. Finally, we also request for a class portfolio, worth 10%, which consists of the students' collections of work and reflections on their journey and learning experience. The portfolio should be arranged to have a meaningful context to review their experience and foundational knowledge. The portfolio shows each student's unique, concise, and continuous learning journey as they build their foundations in EM and expand from it.

We also explain and review the Deweyan Cycles on inquiry and modified Kolbian Cycles of learning at the beginning of the semester. Students will provide frequent reflections on their

learning, challenges, and their overall experience and journeys. Some of the reflections before and after the tests are based on the ideas of a modified Kolbian cycle [7][9][10].

Each class session, we start with a brief introduction about what we have been doing and are doing in the session. We also provide different conceptual examples for the students to review. This includes reviewing the solutions and discussions of previous games. Then we introduce the class activity (game of the day), and teams of students start working on it. We highly encourage the student to work in teams inside and outside of the classrooms but each team member should submit their personal work instead of a copy of the collective's work. We want to study everyone's personal discussions, ideations, and perspectives in order to provide individual and group guidance. While the students work on the problem, the instruction team will be moving around, joining in the team activities, and discussing with the teams. The goal is to facilitate their discussions and ensure the teams are working effectively and constructively on the problems. During this period, if we observe an important concept or methodology that needs clarification, we will bring the class together for a short presentation and explanation. It is important to catch this misguided thinking before it becomes a permanent misunderstanding which is harder to catch or amend later.

The games need to be designed carefully in a progressive manner to maintain the connection of the material as well as be effective in the students' learning and growth. The environment of the class is to encourage students not to be afraid of mistakes, and to do their best, think, work together, and provide their answers. The culture of the class is the belief that we would like to avoid making mistakes but we can also learn from mistakes. Making mistakes should not be the be-all and end-all of their EM class.

IV. THE THREE STAGES OF THE STUDENTS' JOURNEYS

The class can be described by three stages of the members' learning. As they go through each stage, the students become more familiar with our approach and modus operandi. They become more comfortable with our style, and they come to understand and appreciate the opportunities presented for making mistakes. The students' in-class behavior and learning attitude changes drastically as they go through the process.

The initial state of the journey is when the students are first introduced to our process. They are learning new material while getting comfortable with the process. The second stage is from a practical standpoint. The students are trying different games and homework while examining their learning via discussions, collaborations, and reflections on their mistakes and processes. Finally, the last stage is when the students finalize and collect their process and knowledge. They examine their understanding and misunderstanding to have a more cohesive, and clearer collection of their concepts and learnings.

A. First stage: Formulation

In this stage, the students are familiarizing themselves with the culture of the class. During the first few weeks of class, the participants are getting used to the process and the platform of experiential learning offered. During this time, they are mostly worried about grades, and this can be observed because their

attention is often dictated by their scores. Most of them are not focusing on deeper learning. This is reflected in their submitted work, where there is more focus on “formulation based” and finding equations to use and finish the games. They are afraid of making mistakes. They try to hide their doubts. Their questions and verbalization are undeveloped and center around the ‘correct’ equations. After the first month of the class, participants start to understand the process better. The instruction team reminds and reviews the process of learning and the construction of their knowledge base. They are encouraged not to worry about mistakes, but to learn from them. By the end of this stage, they are more willing to think and write based on their knowledge and accept mistakes as a valuable part of learning (low stakes activities help). They understand that they do not have ample time to copy examples from external resources during the games.

B. Second stage: Maturation

The second stage is when the students start to be in the practical stage. In this state, they start dealing with mistakes differently. They start to think, learn, and progress more systematically when doing the games. They define and commit to their own work and do not let the scores to hold them back. There is a clear improvement in their work and reflections. In this state, they grow faster, do more teamwork, and focus on learning. They question what they are doing, learn from solutions provided by the instruction team, and make progress through discussions. They gain the confidence to share their thoughts and ideas. They started a bit confused and become more comfortable with their work, details, and they learn more systematically from their mistakes, and of their teammates.

C. Third stage: Emancipation

Finally, by the last stage of the class, the participants start delivering the types of solutions and discussions that indicate their understanding of the aims of the class from theoretical, conceptual, as well as pedagogical perspectives. Our observations in the last few years, including both pre-COVID and post-COVID periods, indicate that the students understand the value of this process, can reflect on it, and act accordingly. It should be noted that there are always a few who may not be comfortable with the process. Based upon their reflections, however, they understand what the instruction team is looking for, and try to present their work accordingly. At this stage, we see the students’ efforts which indicate a deeper understanding and better connection (emancipatory stage of learning) of their knowledge and understanding. Final stage students and their teams are more comfortable with their knowledge and capabilities. They have better questions; they challenge the solutions provided by the instruction team in more constructive and well-thought-out ways. The instruction team can clearly see that many of the students and their teams actively try to unify their knowledge.

V. WHAT WE EXPECT FROM STUDENTS

The class will have brief discussions, reading, and thinking assignments. However, the most important part is the multiple games per week. Each game is built upon previous topics, slowly ramping in knowledge and difficulties. In addition, each game has a low impact on the students’ grades thus creating a

low-stakes, less stressful situation for the students to truly attempt the games. In order to maintain the high effectiveness of our approach, we encourage students to remember three key points:

1. Discipline and commitment: Students should keep up with the games since it is happening every day. They know that missing multiple games can cause a disconnect from previous topics and would demand harder work to catch up. Most 3rd-year students are also taking other higher-level classes which demands significant time commitment and further complicates any attempt to catch up.
2. The games are designed to be completed in a pre-allocated time slot hence students do not have time to do an extensive search, use online resources, or watch tutorial videos to find solutions. Instead, we encourage them to talk to their team, make their assumptions clear, and be experiential in their learning, discussion, and understanding of connections and main concepts.
3. The students know that they can reach out to the instruction team at any point when they need new perspectives or have questions. At the beginning of the class, there are a good number of questions. Within the first 2 to 3 weeks, the student teams work more cohesively and face the challenges as a functioning unit.

VI. STUDENTS’ REFLECTION ON THE CLASS AND THEIR EXPERIENCES

The outcome of this class has been very positive for the majority of students. More than 75% of the students are very successful in their work. Students’ reflections and feedback about the class are generally positive.

However, the COVID pandemic has affected this class considerably. We noticed students, at times, would not be as persistent and struggled with consistency in attendance and submitted work. Students spent more time in the first two stages of the learning which unfortunately shortens the third stage. In most cases, students have expressed that they are busy in other classes, and they think they can always catch up with this class. Despite that, our students still go on and do well in upper-level classes and they enjoy upper-level EM-related classes with more practical and open-minded perspectives.

Our students would tackle upper-level classes with a different approach, and know-how to learn better, learn differently, and, most importantly, how to connect different methods more constructively. Each term, students will communicate with our team about how they enjoyed the process, and how they are following the type of learning that the class established. This also shows in the students’ final in-class reflection and their portfolios.

Included are some of the students’ reflections on their journeys and engagement in the class. Generally, students are kind. They agree with our perspectives and encourage us to continue by providing feedback to better improve our approach to be more inclusive:

- *This class was very different. In the beginning, it was very confusing. I had a few difficult classes, and they all had many labs, assignments, tests, and long lectures and notes. This class was not like any other. It reminded me of the freshman engineering class I took with the same instructor. However, this one was more difficult. The games... were there every day, at times we did two. There were assignments, but the focus of the assignments was not long deviations, pages of formulation like in my other classes. The assignments built on the material we covered and work on in class. They would just help us to connect and get deeper in our knowledge. What helped me in the class was the team we built, the collaboration, the ever-presence of the games, and the instructor going around and talking to us about the game... In the beginning, the whole thing was annoying, but then we got used to it. The class became fun, challenging in a good way. Now that I am done (the final left), what is strange is that I remember almost all that we did in the class. That is strange, this is not the area that I want to specialize in... but I remember it well, and not in a bad way, it is in a connection to the team, and all the games we did...*
- *I took this class as a mechanical engineer since I have friends who suggested I should do this class, it is fun. Was it fun? Yes. Was it easy? NO! It was not easy, was difficult, at times confusing, and very different from any other class that I have ever had. I doubted myself during the first weeks of the class, and kept asking "should I be here?" My team helped me to stick with it. We worked together in the class on the games, and on homework out of the class. The instructor and the TA were helpful, and encouraging, but would not give us the answers. They would ask questions to lead us to better thinking. It was not what I was looking for, but with their comments, and with our team working together, we did it all. It helped that the class never had high % tests, games, or assignments. They were there, building on each other, and gradually we did it all. Because of the games, I was never worried about the tests, I was confident that I know them and could do them. They made me think, I could eventually do them. Each test would help me push myself a bit further, so I would even learn during the tests. I have decided to think about going to graduate school and work on a connection between Electromagnetism and Mechanical Engineering*
- *I hated Electromagnetism! I am a circuit and electronics student. This class is required otherwise I would never take it. I did not like this material in Physics. I did well in all parts of Physics II. This part was terrible and confusing. In this class, the first few weeks I dragged myself to the class, because I did not want to miss any point or any games. I also thought "Game" is a trick to give us everyday quizzes. Long story short...I was lucky to find a good team. I was suggested to change my team after 2 weeks by the instructor, and I did. The new team and I really clicked. From that point on, I began to change. We face*

challenges together, we made mistakes (this is a hard material). We figured it out, we laughed and cried together working on homework and preparing for the tests. By the midterm. I could do it all, was not afraid of missing things, and losing points. I wanted to understand it. Now that is the last week... I am not afraid of the final, I do not hate the material... I believe I can do it. I probably do not need this for the rest of my career, but if I must...I am sure I would be OK.

VII. CONCLUSION

In this work in progress, we are presenting a new approach for teaching Electromagnetism to 3rd-year students in Electrical Engineering. The process, ideas, and approach are presented and discussed. We identify the challenges and the success of the process. Students' expectations, faculty expectations, and the stages as well as the progress of the students and the class are discussed. Some of the students' reflections are also presented. We are in the process of qualitative and quantitative analysis of the class data.

VIII. ACKNOWLEDGEMENTS

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