Addressing the Differences between Intention and Retention in Engineering Classrooms: Possible Ways to Design Classes for Students' Knowledge Retention.

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Motivation

An individual's learning method is often subject to personal inquisitiveness, initiative and inspiration from instructors or other mentors together with persistent hard work. Since it is not easy to cater to either inquisitiveness or student initiative in conventional classrooms, the role of the instructor becomes critical in moulding a student's learning method [1]. Meanwhile, instructors face the challenge of juggling many hats at the same time. They are required to deliver content, monitor students' progress and assess periodically. In such busy environments, arguably, many instructors cannot afford spending time on facilitating aspects of inspiration nor can they encourage students into creating connected stories of their knowledge, thoughts and reflections about their learning [2].

If learning is such a personalized process, why do we as instructors attempt to teach all in the same way? This is a question that engineering education as well as educators in many other areas have been facing for many years [3,4]. The general intent of being all inclusive and equal is well served. Nevertheless, learning approaches differ, and challenges persist in engineering classes. However, each student brings his/her own experience to the discussion and builds on his/her own connected stories from the sub-stories/experiences they go through [5,6]. Consequently, the learning process is a negotiation between the intention of the faculty, the students' interest and the learning and knowledge retention processes. The authors would like to argue that actual learning occurs in this stage, the disparity in the intended communication and student's acquisition. This is often considered as a flaw on the student's end in receiving what the instructors conveyed. However, it is a value to their learning and growth. The real learning occurs when students can engage 'who they are' with 'what they learn' [7 - 9].

To assess the student's actual learning, in this work, an assessment of the disparity between intention and retention is performed via review of reflections in an inquiry-based course. The students are initially provided with a traditional lecture and associated lecture notes and are asked to reflect about what they know. Then, the students are asked to explain how they could use the idea to explain something of their interest or apply the knowledge to a specific task. When the students write and attempt to connect their knowledge/learning to their own interests, their stories and experiences had far greater value than the instructor's initial intent. Finally, with the students at the center and possessing an awareness of the differences in an instructor's instruction and student's retention, classes can be designed to make learning an enjoyable experience for both students and instructors.

Introduction

In the present-day classrooms, students have access to multiple sources of information such as web content, videos, instructional utilities and other forms of resources. Consequently, they are constantly forming their views about varied matters. In such environments, the instructor becomes one among many, a single point of contact who has a lot of experience but can only provide compressed information and direction of study within the limited duration of the lecture. Meanwhile, keeping at par with their learning interests and curiosity, most students tend to find different means of learning. Some of them form small study groups, others learn from videos and some others work diligently through the instructors notes etc. However, it is important to note that students are learning from more than one source and therefore there is a need for greater freedom and exploration in classrooms to enable students to connect their views and experiences to their learning. In addition, many students have learned to only focus on what they need to do to pass the assessments to achieve desirable grades. Consequently, one can see that students can take many approaches. In this work we focus on the type of learning process and activities that would facilitate a personal ownership of their learning and gaining knowledge that would hopefully be connected to students' own stories and learning and integrating their knowledge.

Engineering courses are generally content heavy, and students tend to memorize concepts and problems necessary to pass the exams [10,11]. Some students also study based on the instructors grading schemes. While most engineering courses aren't necessarily designed for learning with optimized shortcuts, student's experience a disconnect between what they learn and their "real-life" experiences and tend to use memorization/pattern matching as an easier approach/shortcut towards learning [12,13].

As a first evaluation, it appears that such practices would lead to students who are technically weak and unprepared to meet the demands of engineering environments [14,15]. However, over the years, it has been observed that students who possess necessary soft skills [16,17] related to learning, possess curiosity and are engaged in collaborative learning, can adjust and learn in challenging technical environments despite some deficits in background. In fact, as suggested in [15,18], with the fast-changing pace of technology, it is slowly becoming apparent that classroom education supplemented by other educational resources can't be focused only on technical content. Instead, there is a need to incorporate elements of re-questioning and re-examining knowledge from various perspectives giving equal merit to students' experiences and pre-acquired knowledge/misconceptions. With this background, the main theme of our work in this paper is an assessment of the connection between a student's ability to think and re-examine technical content based on their personal interpretation in contrast to what they are taught with the instructor's directions (the lecture material). In essence, it is expected that the reflective assessment performed shows that students who are capable of incorporating their own views and vision in their everyday learning are far more adaptable and flexible in real-life engineering and problem solving [19].

However, students who are successful in the approaches proposed by instructor, aren't deemed unsuccessful. They also show success once they overcome the focus on only the rigor and find their own definitions (personalization) in their work.

Course Design

In this paper we have performed a qualitative assessment of reflections from a course for non-electrical engineers. The course included conceptual and practical issues of electromagnetism without the rigor of calculus. This course is inspired by methodology that was developed for Technological and Engineering literacy courses. We do have few students who take it from college of design to satisfy their technology requirements and other colleges, but the numbers are not high. Most of the students are from different engineering programs. They take this class for technical requirements of their program. The class is most popular for students in Computer Engineering. It is designed for students who are interested in electromagnetism (EM) but are not necessarily inspired by calculus-based version. While the students see and discuss the relevant mathematical tools and concepts, they are not required to show the mastery on that, unless they decide to have their final project in area that require calculus depth. The course is focused on concepts, applications, the progression of the development of the ideas, experiments, and practical aspects of the field including observations, experimental and historical developments of EM.

A brief summary of the course contents may be observed in Table 1.

Table 1: Brief summary of course content for electromagnetism for non-electrical engineers

Weeks	**Course Content**
1-3	Basic definitions and background of electromagnetism
3-8	Electric and Magnetic Fields, Wave propagation, Radiation effects
8-12	Transmission Lines, Bounce Diagrams
12-15	Quantum theory, theory of relativity

The course starts from the basics of EM, connecting to what they have had in prior physics courses. Broadly, The topics that are covered include Lorentz force, the basic circuit theories and elements, Maxwell's equations in the integral and differential forms (visualization and developing practical understanding). This is followed by extensive discussions on transmission line and EM waves. Next, the course focuses on the development of modern physics in early 20th century and moves to development of quantum mechanics, relativity, and quantum computing. Finally, at the end of the course we address some of the newly developed ideas such as string theory.

The approach of the course is to start from early ideas of electricity and magnetism. The course moves through the historical development from Faraday to Maxwell, and the late 19th and early 20th centuries. We look at the development of the ideas that starts with Maxwell's formulation and EM and then became a part of the development of modern physics, quantum, and other areas. The course focuses on the connected story of cognitive and theoretical development from Faraday, Maxwell, and Einstein and others who were important icons in the development of the current physics and engineering. This includes the development and applications of special/general relativity, quantum mechanics, quantum computing, and some of the new ideas such as string theory. The last part is not done in mathematical form but in conceptual approach to provide the students a background of the development and forward projections of the work of Maxwell and Einstein.

The students engaged in reflective activities in every class each week besides assignments and a final project. For the final project students need to find an area that they are interested and is connected to applications of EM and do an in-depth study, research, and work on their interest. The goal of the final project is to facilitate students' learning more in depth about something that they care about. The projects are mostly in-depth study of some interesting subject to the students. Projects are both research, theoretical, as well as experimental. Some of the more popular projects have been "Magnetohydrodynamic design of small car, boat, or fluid pumps". "Magnetic levitation system that would sustain a permanent magnet design". There are many theoretical projects on foundation of quantum mechanics and applications in different fields. Some are based on antenna design for high speed planes and shuttles. Interestingly, there are few projects on challenges of creating and protecting against Electromagnetic Bombs. In particular, how can sensitive equipment be protected against huge EM discharges. In addition, few students are interested in health aspects of electromagnetism, looking at the danger as well as medical treatments based on EM. Other projects such as Tesla coils, musical Tesla coils, and Theremin development are also there but not as popular for this course.

Research Process

Through a study on the reflective writing, it is observed that the students are genuinely interested in learning about electromagnetism and seek to achieve in-depth understanding and connecting their learning to their everyday studies. These observations led us to further evaluate their reflections via a phenomenographic assessment technique [20]. Two reflective activities were selected for assessment. In the first activity, the students were first instructed about a specific topic and then asked to reflect about their understanding. This was followed by another reflective activity where they applied their learning and personal perspectives in proposing solutions to a given problem. The purpose of selecting these activities was multifold. Firstly, we ensured that the students were at the same basic level of understanding through the first reflection. Next, we wanted to understand the views and ideas the student had formed on the specific topic either from prior experiences or through the course.

Our evaluations for this study which are the two reflective activities are both based on forces on a current carrying wire (Lorentz force). The students first hear the instructor's discussions on Lorentz force, some applications, and then attempt to evaluate the Lorentz force needed to move an object with a fixed mass and under specific conditions. They then discuss the practicality of the solution they obtain. In the following reflective activity, they are asked to apply their understanding of the Lorentz force equation to describe the propulsion of a boat via magnetohydrodynamics. In each reflective activity, the students work in teams and can collaboratively obtain solutions. The reflection questions are:

Question 1 (Rail Car) *(Analyzed for 29 students)**:** Let us think of a simple design. If you have a 1kg car (in a rail gun experiment) and would like to cause an acceleration of 0.01 m/s^2. Knowing that you can create a B field of 0.0001 T, how much current would you need? Examine your answer and discuss what you think? Is it realistic, what would you change to make it more realistic? You may also include sketches to help readers understand your views.*

Question 2 (MHD Boat) *(Analyzed for 26 students)**:** This is a conceptual design problem. Our goal is to design a practical boat that operates on the magnetohydrodynamic (MHD) principle. Let us assume that the boat is in a reasonably electrically conductive water (like sea water). Please draw, write and use equations to describe the system and how it works. Let us also remember the basics I =A.J and force may be described as* $\mathbf{F} = i\,\mathbf{dl} \times \mathbf{B}$ *(All vectors are bold face)*

Assessment method

From the two reflection questions presented above, it must be noted that in the first reflective activity, the students try to apply the basic physics concepts to a problem and evaluate the feasibility. Meanwhile in the second activity, the students incorporate the basic concepts to design and propose solutions. The contrast in the intentional question from the first activity and the open-ended nature of the second question are necessary to understand the boundaries of students' interest, learning and creativity of thoughts. Therefore, these questions were selected for our assessment.

In our phenomenographic assessment process, the instructor/facilitator defines a certain set of themes and then performs an assessment based on identifying keywords or actions related to this theme. Once the assessment is performed, the facilitator can update the themes based on observations and perform further assessments. The update in assessment protocol and content presentation is often important since the student's views change as they learn more about a topic and with an intention of assessing growth and emancipation, the rubric needs adaptations [21]. In

Table 2, we see a comparison of the instructor's intention in posing the above-mentioned questions and the student's interpretation on receiving these questions in their reflective in-class activity.

Question	Instructor Intention	Student Interpretation
1(Rail Car)	Can the students set up the problem and identify the drawbacks of the assumptions?	Set up the problem and find a solution that can work
2 (MHD Boat)	Can the students imagine and apply their learning to solve a practical problem? What kind of assumptions do they need to realize their solution?	Imagine possibilities. Create an interpretation of their own to connect their learning.

Table 2: Instructor's intention vs student's interpretation for the two questions used in this study

Findings

The course facilitator observed the reflections and defined four themes which were present in the reflections. The themes classified the student's reflections as equation-based, realistic/practical, imaginative and used images and figures in their work. Some examples of the reflections for questions 1(Rail Car) and 2 (MHD Boat) can be seen in Fig.1 and 2 respectively.

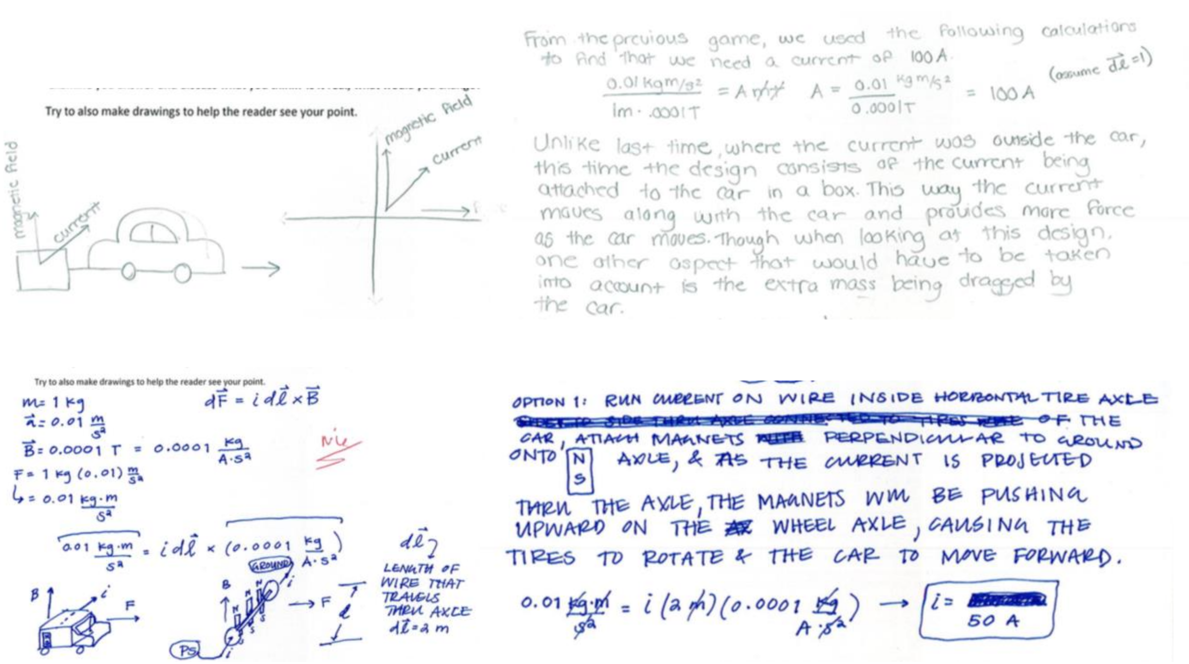

Fig.1: Examples of in-class reflections for question 1 (Rail Car)

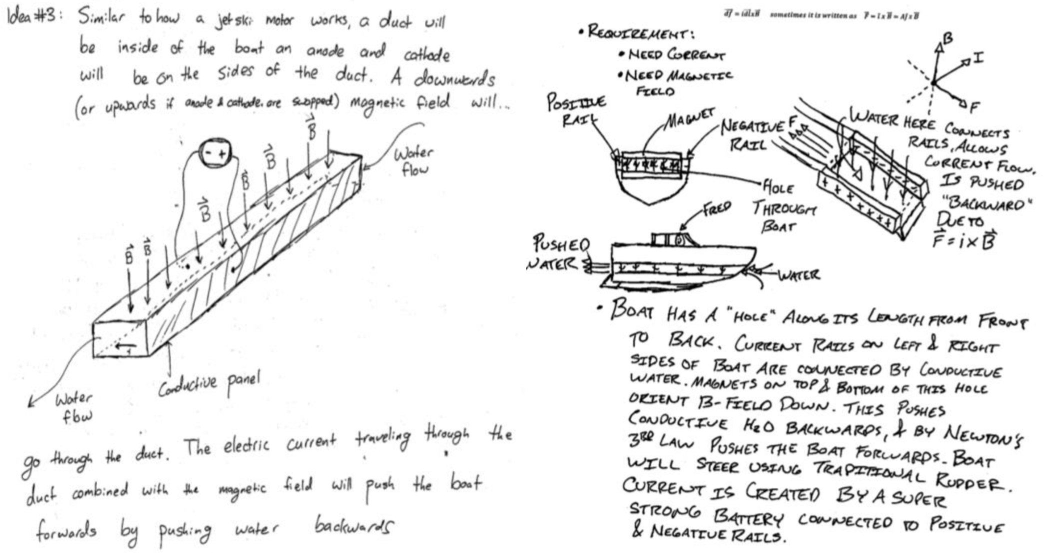

Fig.2: Examples of in-class reflections for question 2 (MHD Boat)

From the reflections it was observed that in the initial question, the students were more directed towards responding to the question. They used the equation provided and even though they were imaginative and descriptive not all the students presented realistic solutions. Meanwhile, once the students were provided a much wider exploration space as in the second question, it is apparent that the students were more expressive, explored possibilities and were less dependent on simply relying on equations. A summary of these findings is observed in Fig. 3.

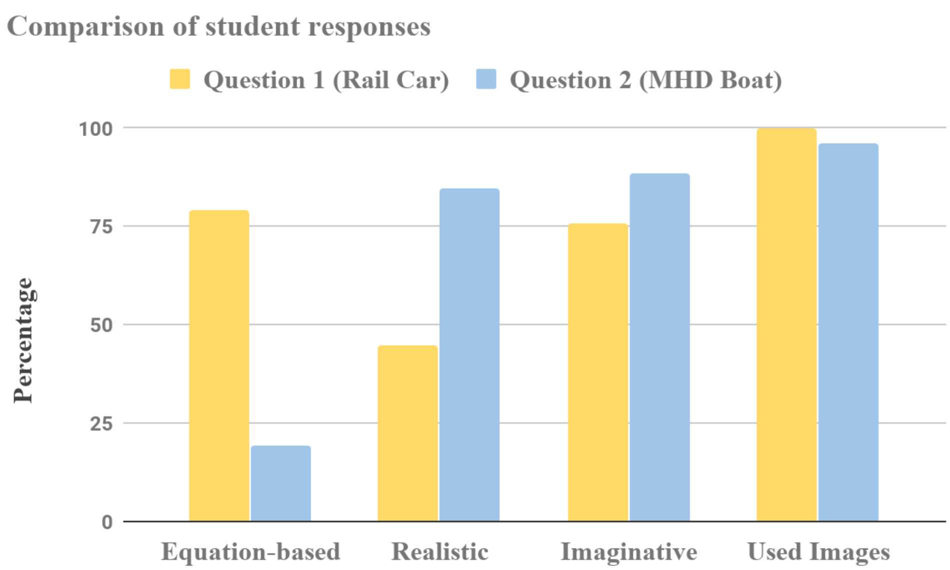

Fig.3: Comparison of student responses for questions 1 (Rail Car) and 2 (MHD Boat) based on the themes described by the facilitator

It must be noted that while students were encouraged to use equations and figures, they were also asked to discuss if their solutions were practical or realistic. By discussing if their solutions are practical, the students can gain personal insights on how to approach practical/realistic situations. Lastly, since the solution space wasn't confined to what the students could use to achieve the end-result, many students proposed ideas using magnets or mechanical assemblies etc. which closely reflected their process of thought and imagination.

Impact on students

The impact of the course on the students is apparent through the development of their reflections over the semester. The students become more engaged, more descriptive in their reflections and start looking into building connections and trying different ideas. Many of the students though initially skeptical are surprised that they like the reflection process and are genuinely curious to learn more. They seek to gain ownership of their work, stay back after class and discuss about their projects with one another. In fact, many of them begin by not knowing what to expect in the class and after learning all semester they encourage their peers to also be a part of the class.

In their final reflections, overwhelming majority of the students do state that they remember most of what we did, and they engaged in the class, because of the way of activities that the class required. Some of the students, from other engineering fields, show their surprise on how much of the material they remember and can talk and discuss with their peers. Finally, the final project (an open-ended selection from the student based on a topic that the students are inspired to learn more about) and the process of the students' involvement with the material, research, and writing the final paper, do reflect students' depth of engagements. Their perspectives on learning, engaging with the material is clear in the final paper report. Their progress and engagement are also monitored in their reflections while working on their project and are conducting their learning and research.

Finally, the number of students in the class keeps increasing, mostly due to the recommendation of the students' who took the class. This is evident from some of the early reflection activities that the students need to talk about why they are taking the class and what they expect to learn from the class. Many students are taking the class since their friends recommended, and they have interest to know more about Electromagnetism, knowing it is one of the most difficult areas of physics and engineering. Some students also indicate that while Electromagnetism was not one of the areas they enjoyed in physics, they always wanted to know more about it.

Conclusions

The results show that there is a greater interest in learning the development and implications of Electromagnetism once the students are personally able to connect to what they learn. Students begin to show interest and remember the applications, ideas, some of the essential theoretical implications, and major experiments that formed the knowledge of Electromagnetism and later quantum mechanics and other related areas of modern physics. One of our main findings is that true learning only begins when students are challenged by the type of framework presented by the faculty. Consequently, the faculty needs to engage in a thematic shift in approaching activities for students, creating a slight learning discomfort and encouraging students to ask better questions and more in-depth answers. The real learning, as seen in this work is when students have slightly more freedom in expressing their views and sharing their curiosities. If they had only responded to the instructor's questions without trying to engage and wonder about the questions, they wouldn't enjoy the learning process, nor would they include their "self" in the learning process. This is a stage of emancipation according to Heabermass and Grundy [22] where the students make connections and understand the bigger picture of the whole knowledge base. Our work shows that when there is a mismatch between the instructor's intent and the student's ideas, the students who are encouraged and active start re-verbalizing and reframing their process do create new directions of learning.

Future Directions

There are few possible directions that we hope to pursue in future studies.

1. Obtaining views from students who have graduated or previously been a part of the course for feedback on future improvements.
2. Focused study group tracks or projects for students who seek more mathematical insights in electromagnetism. Some students do register for the calculus-based electromagnetism course after this course and they could give inputs on their learning, reflections after taking both courses etc.
3. We are working on different approaches to offer more calculus options (Assignments and Projects) to a select group in the non-calculus based as their project and selected assignments to see how they would retain the knowledge. In few cases in the last few years, those who did the calculus challenge in their projects and extracurricular activities did well and claimed more in-depth learning. Since they did it because they liked it, they generally did better in the process and found more meaning and belonging to the material.

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