Applications of Reflective Thinking Exercises in both Technological Literacy and Standard Engineering Courses

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Abstract

After seven years of working on creating, implementing, advancing, and expanding technological literacy classes at our institutions, and studying and working with programs at other institutions, we have found many interesting issues, challenges, and questions facing our efforts. This paper is an attempt to review the goals, objectives, achievements and possibilities for future developments. However, most importantly this paper focuses on the relationship between classes in technological literacy and engineering. In particular this paper focuses on students’ reflective practices utilized in the classes. Is it possible to learn from the developments and implementations of one to improve the other? Should there be a connection between these two sets of classes? On the surface there seems to be very little in common except basic concepts. However, upon further reflection one can find identifiers, trends and experiences from one that can help develop the other. The main objective of this paper is to explore the relationship and introduce findings and possibilities.

Introduction and motivation

The growth in technological literacy efforts that were connected with two major publications Technically Speaking and Tech Tally have brought about many interesting programs and developments in the area of technological literacy. Different schools have since developed programs, minors, and classes whose major goals are educating a non-engineering workforce and non-engineering students so they might have a deeper and functional understanding of technology and engineering, and develop life-long competencies in understanding the basics of technology. The premise has been to develop a national level awareness and education for technological literacy. Currently the effort is synergistically advancing technological literacy as well as helping STEM and STEM education activities.

Many of the instructors who are designing and teaching technological literacy classes are also active faculty in engineering/technological departments. Consequently, they are teaching engineering and other technological competency as well as technological literacy classes. The natural question is how would such experiences reflect on the faculty’s approaches to teaching? The authors are also faculty in engineering who have been trying to advance institutional level programs for technological literacy, and who have strong connections to the national effort.

This paper reviews some of these experiences and reflects on how teaching technological literacy classes and the developments of technological literacy programs have and should reflect on our
approaches to teaching engineering (and naturally vice versa.) In addition, the paper discusses how some of the engineering education approaches have been used in technological literacy classes. Finally, discussions on how these two approaches can interact and how our findings in technological literacy can help overall approaches are provided. Some of the questions, challenges, and possible approaches to enrich both efforts are presented and discussed.

As many engineering programs are looking into the new curricular development, we hope some of these findings would shed light on ways that we can improve our engineering education efforts as well. Perhaps this effort could help engineering educators to slowly transform our approaches to make a more synergetic effort in training an engineering, technologist, and technologically aware workforce to face challenges of the future\textsuperscript{3-5}. Toward this goal, Blake has examined the similarities between ABET accreditation criteria for engineering programs and the standards for technological literacy of non-engineers\textsuperscript{6}.

**A conceptual approach to technological literacy and competency**

For the purpose of the technological literacy classes at our institutions, and in accordance to the research and developments at the national level we decided to follow the definitions and descriptions that is defined in Technically Speaking\textsuperscript{1}. One of the early activities in our technological literacy classes is to read the first few chapters, discuss the ideas, and reflect on the issues. Students in non-engineering programs find the definitions, discussion, and approach of the book very refreshing and use it through their classes and work in the undergraduate program. We see those references in their senior design and senior thesis developments in our non-engineer programs. We have found that the freshman-engineering students also find these chapters of interest, and their learning shows in their reflective activities in their third and fourth year portfolio or similar classes.

Another important item that is emphasized in our technological literacy classes is providing a conceptual approach to understand engineering, engineering problem solving, and engineering design. Besides teaching the basics of engineering we engage the classes in what is the goal of engineers, what is the role of an engineer, and what are the perspectives and problem solving approaches that engineering utilizes. We adopt some of the leading work by the ASEE technological literacy group and follow the national developments in this area\textsuperscript{7-23}.

Best practices have shown that the practical approach in teaching technological concepts to all patrons (engineering and non-engineering) is via a systems level approach\textsuperscript{4-6}. This should start with an overall functional systems level breakdown of the concepts all the way to the appropriate details that are suitable for the level of students and their interest.

The conceptual perspective that the functional and practical systems level approaches bring about can be one of the most practical and integrating approaches for learning complex systems. This is proven by years of work in learning methodologies as well as efforts and
developments in Bloom’s Taxonomy. Based on this premise the authors have adopted the same approach in all of the undergraduate classes offered to engineering and non-engineering students.

Setting up the idea: Story of three classes

For the purpose of this study we have compared and contrasted the developments and findings of three classes. Two of the classes are offered to technical people (mostly engineering students.) The third class (which is a sequence of two classes) is a technological literacy class that is offered to non-engineering students. Reflection exercises were used in each class.

The first engineering class (EE1) is an introduction to electrical engineering and problem solving, and is offered to freshmen engineering students, some directly from high school and some transfer students from both US and international colleges. They have a background in algebra, trigonometry, and many of them are in the first calculus classes. This class covers some of the most important skills for engineers via a practical journey in some of the main points of engineering and in particular electrical engineering.

The second class (combination of ENG 1 and ENG2) is offered to non-engineering students. Most of the students are primarily from the College of Design. The Department of Industrial Design has included this sequence in their curriculum to cover technical literacy requirements, and are considered two parts of the same class from the Industrial Design curriculum. The first is called “From Thoughts to Things” and the second “How Things Work”. The first term begins with how engineering works, the engineering process, and the critical points of engineering technology, design, and methodology. The second class works on practical issues of engineering and engineering basics of how things work. These classes cover aspects of engineering and engineering design, practical issues of electrical (electromagnetism is also included), mechanical, civil and other engineering discipline as well as providing better understanding of technology.

These students of technological literacy classes (ENG 1 and ENG2) do not enjoy algebra, trigonometry, or any mathematical manipulation - they reported as much in their reflections during the first week of class. They explain that they enjoy non-engineering approaches (or more clearly, dislike engineering problem solving and approaches) and that is why they decided to go to design college. Over 90% of the students in our technological literacy class are from the Industrial Design program. It is interesting to note that about ¼ of the students in industrial design started in engineering programs but did not enjoy the math and physics aspect of the classes. They have a clear interest in design. However, their experience with the required math and basic science courses prompted them to leave the engineering program within one or two terms.

For the purpose of some important discussions we will also focus on a third class. This class (EE3) is an introduction to electromagnetism for non-electrical engineers. The students of this class are mostly engineering students in their third and fourth years of different engineering fields, all but electrical engineering. We also have students from different science/technology backgrounds such as meteorology, agronomy, bio-systems, industrial technology, and bioscience; these non-engineering students comprise less than 8% of the class. This third class
(EE3) is considered in this study because the practical and pragmatic basis of electromagnetism is covered from engineering perspective. Students are exposed to Maxwell’s equations; the main concepts of physics and electromagnetism are covered and used to explain practical essence of applications of electromagnetism in engineering, in designing products, and everyday life applications. Students in this class do see integrals and differential forms of equations, wave equations, and other mathematical constructs but they do not need to use calculus. This is basically algebra and conceptual based class. It is heavy in concepts, physical understanding and applications, not so heavy in calculus. This will allow the class discussions and development to be focused on application and practical aspects of electromagnetism at all levels. The class covers broad topics starting from classical electromagnetism to the modern physics, special theory of relativity, and quantum mechanics. The concepts of quantum computing, and quantum communications are discussed at the end.

Due to the success of our ENG1 and ENG2 sequence, in the last few years we are seeing a couple students from that sequence taking EE3. They struggle with the mathematics but seem to enjoy the application part and find their way through the difficulties of the engineering approach.

**Some key observations: Benefits of Reflective Thinking Exercises**

One of the most difficult tasks in the technological literacy classes (ENG 1 and ENG2) was to assess the skills the students developed. This includes some back-of-the-envelope calculations, and understanding of some key concepts and connections of concepts. For example, related calculations of circuits, ohms law, resistors in parallel and series, power, as well as understanding the basics of Faraday’s law and how it applies to transformers, motors, and how we can use eddy currents to detect flaws.

Our careful study and examinations showed the students were capable of memorizing and mimicking related solutions, and at times a group could expand and show meaningful connections between the concepts. However, the memory was very short lived. Soon they would not remember them and could not use them in later parts of the class. This is unfortunate because our goal was for the technological literacy students to develop a longer memory of the important conceptual and useful skills that the class offered.

In order to help these students, we decided to include systematic in-class individual as well as group reflections based on short conceptual and important items. The goal was to have students reflect, write what they understood, and explain what they learned in their own words. They were required to reflect on their own learning as well as the results of their group discussions. The instructor read and provided feedback in the following session. Our results show that the most important aspects of the reflection process is to provide timely, encouraging, and careful feedback.

To be effective, reflection has to be followed with a few similar activities with reflections and then perhaps a longer assignment. Our observations showed that the more students in the technological literacy classes reflected by drawing, making equations into special figures of their own imagination, and by owning the equations and concepts, the more they could remember.
them. Of course this is well known and many active learning activities and cognitive psychology learning ideas verify that. These goals and methods have to be clearly communicated to the students for them to engage confidently.

The question is how can this reflective thinking be used in the engineering classes? The technological literacy classes do not delve deeply into many concepts yet students seemed to have better connectivity between major concepts. They also demonstrated a special passion to follow up their learning and take actions based on advancing their knowledge in their research and creating their projects in upper level classes. This is interesting, in particular when one thinks about how they clearly did not like the subject to begin with. With all this in mind, we decided to see how we could bring the same concepts and use of reflective thinking into the engineering classes. There were challenges, but the effort showed successful results.

The results of the three classes show interesting trends.
1. The thematic reflective thinking approach for helping students in non-engineering classes works. As a result those students do have a better understanding of the concept and related them to basic equations.
2. When asking engineering students to learn the concepts, with applications and visualization approaches, and asking them to reflect by writing what is in their mind, not only we help engineering students have a better mental picture of the concepts but also help them understand the equations better. This shows in our experience.
3. The more advance-engineering students (the non-electrical engineering students) have general engineering approach, as a result with the new system they do excel reasonably faster. However, for all engineering students the process of reflection does work

Example: Reflecting on Demonstrations of Faraday’s and Lenz’ Law

We are introducing few examples of the work done by the students. The three classes saw the same demonstrations. They would see a strong magnet dropped in a copper tube, they would get a strong magnet to move next to a Aluminum plate, and they would see different videos describing how strong magnet next to a conductor would impede the magnets motion. Then as a part of the lecture, we would talk about electromotive force (emf), Faraday’s law of induction, magnetic flux, and Lenz’s law based on the concepts and illustrated with the demonstrations and short videos that. Students would discuss in groups, and then each student would fill a reflection form. The results show interesting trends. Figure 1 shows select results from the non-engineering students. Figure 2 shows selected results from the freshman in electrical engineering class. Figure 3 shows the results for the 3rd year non-electrical engineering students.

Figure 1a: Electromotive force (EMF) demo and reflections by non-engineering students
Please reflect on what you observed with the magnets and the conducting material? Describe your experience.

\[ x m/s^2 < 9.8 m/s^2 \]

When the magnet dropped through the conductive copper tube, it fell slower than it would outside of the tube.

How do you explain this phenomenon occurs? Please discuss in words why this works, and how, you can use equations as well.

When the magnet falls through the tube, its magnetic flux changes. When the flux lowers, the tube tries to stop the magnet using eddy current to repel with electrons. The force of gravity, however, is too strong to stop the magnet.

\[ CmF = -A \frac{d}{dt} \]

What type of applications do you see for this? You have seen some and please reflect on what do you think can be done with this technology?

- I could see this technology being used with some type of elevator that doesn’t need cables.
- Making some sort of energy source using this on a large scale.
Figure 1b: Electromotive force (EMF) demo and reflections by non-engineering students

Please reflect on what you observed with the magnets and the conducting material? Describe your experience

The magnet drops through the copper pipe without touching any of the sides, it slows down as well.

How do you explain this phenomenon occurs? Please discuss in words why this works, and how, you can use equations as well.

This phenomenon is magnetic flux between the pipe and the magnet.

\[
\Delta \Phi = \Delta \int B \cos \theta \Delta s = \Phi B \frac{A}{2} \text{(magnetic flux)}
\]

What type of applications do you see for this? You have seen some and please reflect on what do you think can be done with this technology?

Or as little - Frictionless turbines that can create electricity, such as the bike light. Some concept could be used on greater scale if it is as efficient as it looks.
Figure 1c: Electromotive force (EMF) demo and reflections by non-engineering students

Please reflect on what you observed with the magnets and the conducting material? Describe your experience.

The magnet was rolling inside of the copper pipe without touching the sides.

How do you explain this phenomenon occurs? Please discuss in words why this works, and how, you can use equations as well.

This phenomenon occurs because of the magnetic flux between the copper pipe and magnet.

\[ - \frac{\Delta}{\Delta t} \text{ (Magnetic Flux)} \]

\[ \Phi = B \cos \theta \Delta s_i \]

EMF creates current to oppose the magnet.

What type of applications do you see for this? You have seen some and please reflect on what do you think can be done with this technology?

- Frictionless Turbines that can create electricity
  (as close as you can get to frictionless)
Figure 2a: Electromotive force (EMF) demo and reflections by freshman electrical engineering students

Please reflect on what you observed with the magnets and the conducting material? Describe your experience.

when the magnet was dropped, it was drag by some kind of force and was slowing down but still fall steadily. When move the copper bar upward after dropping the magnet, the magnet fall slower.

when I spun the bar (clockwise), the magnet also spinning inside.

How do you explain this phenomenon occurs? Please discuss in words why this works, and how, you can use equations as well.

as the magnet move (the flux's movement has to be parallel to the direction of moving), the flux which was release on the source of the metal is trying to pull the magnet back (thus slow it down).

What type of applications do you see for this? You have seen some and please reflect on what do you think can be done with this technology?

bike light
91 what about you idea?
Figure 2b: Electromotive force (EMF) demo and reflections by freshman electrical engineering students

Please reflect on what you observed with the magnets and the conducting material. Describe your experience.

We experienced the concept of eddy currents that can be generated by inducing a magnetic field on a metal which is nonmagnetic.

Magnet

Copper pipe

Experienced resistance to natural movement from generated electromotive force.

How do you explain this phenomenon occurs? Please discuss in words why this works, and how, you can use equations as well.

This occurs when a magnetic field is induced on a nonmagnetic metal.

What type of applications do you see for this? You have seen some and please reflect on what do you think can be done with this technology.

Some applications could involve accessing or moving a nonmagnetic metal from behind a barrier.

Movement from one will induce similar movement on the other.

Another application is to set it up as a bumper of sorts for heavy objects.
Please reflect on what you observed with the magnets and the conducting material? Describe your experience.

When the magnet was placed on the aluminum and then lifted slightly from the surface and moved vertically across the plate, there was a slight resistance present. Similarly when the magnet being dropped down the copper tube it almost felt as if there was a slight vibration. I think that it could be from the eddy currents.

How do you explain this phenomenon occurs? Please discuss in words why this works, and how, you can use equations as well.

I am not quite sure how this works, but I think it has something to do with the electrons in both of the objects. I think that the magnet draws the electrons closer to itself, creating an electrical current. The electric current then causes the magnets "falling" motion to be slowed.

What type of applications do you see for this? You have seen some and please reflect on what do you think can be done with this technology?

I'm not really sure what applications this could be used for other than trying to slow the falling of a magnetic object, or pinning something between two magnetic surfaces. Often times magnets are being used everyday in your home. People will use them to hold documents on the fridge, or to keep paper clips or sewing needles neatly stored.

There are variations exists among different groups and classes, there is a trend that shows the different content and approach in these classes, while the demonstration, and the discussion by
the faculty has been the same and the videos were the same, there are interesting differences between the groups.

Figure 3a: Electromotive force (EMF) demo and reflections by in 3rd and 4th year non-electrical engineering students

Please reflect on what you observed with the magnets and the conducting material? Describe your experience.

I saw the phenomenon of Eddy Currents in action. The Eddy currents are induced and attempt to prevent the change. This is illustrated by the dropping of a magnet through a copper pipe or the sliding of a magnet over a copper plate. The eddy current tries to counteract this change in magnetic field by creating another induced by the current to stop it. I believe this is also an illustration of Len's law, attempting to prevent the change.

How do you explain this phenomenon occurs? Please discuss in words why this works, and how, you can use equations as well.

\[ \frac{\partial V}{\partial t} = \text{EMF, Faraday’s law.} \]

What type of applications do you see for this? You have seen some and please reflect on what do you think can be done with this technology?

Anything that uses has a rotating body around a point. So there could be car tires to create light like the bike application. Could also be used to create electricity in remote areas for wilderness application. What if you had it attached to bike to get it hot, then use that hot “thing” to cook something. Like dip it into a can of soup and will heat it by conduction.
Figure 3b: Electromotive force (EMF) demo and reflections by 3rd and 4th year non-electrical engineering students

Please reflect on what you observed with the magnets and the conducting material? Describe your experience.

Magnets and conducting materials can create an electromotive force (EMF) that can be used in a variety of circuit applications. The magnetic field creates an EMF which in turn creates a current.

How do you explain this phenomenon occurs? Please discuss in words why this works, and how, you can use equations as well.

The phenomenon works because of the basic magnetic and electric field properties. A magnetic field created a variety of wires creates a magnetic flux through a conducting surface. The magnetic flux change with respect to time creates an EMF. The EMF creates a current when a conductor or resistive element is shown.

\[ \text{EMF} = \frac{\Delta \Phi}{\Delta t} \]

\[ I = -\frac{1}{R} \cdot \frac{d \Phi B}{dt} \] (different resistive change current)

What type of applications do you see for this? You have seen some and please reflect on what can be done with this technology?

With electric cars:

- Car lights change color
- Car battery that recharges itself throughout a drive by receiving EMF from the spinning motor which drives the EMF. Increase MPHs & distance.
Challenges and actions for engineering classes

Our experience shows that due to the phenomenon known as a packed syllabus, most engineering students will forget many key issues and concepts unless they are creatively repeated.
four to five times throughout the curriculum. Many faculty are aware of this and try to overcome the issue by reviewing important material. However, there is little connection from the students’ perspective. The facts, equations, and manipulations are presented to the students with many different nomenclatures. The loads of the engineering classes are heavy and there are many problem sets, laboratory reports and other activities during the week. Students claim that they just move into a problem solving mode and make sure they do what has to be done. This was true for the freshman engineering class (EE1) as well as for the electromagnetism class (EE3).

In the engineering classes, when we focused on reflective learning and provided fast feedback, and connected the material and concepts with many iterations and constructive assignment activities, the students remembered and connected the concepts much better. The key issues were to encourage the engineering students to also draw and reflect on how they think. Many of them still thought in terms of equations, but they were encouraged to use the equations as conceptual drawings. After all, equations (such as Faraday’s Law) are pictures, and each picture is worth a thousand words! The connection between reflections, writing, group reflections, drawing and active learning did become very successful. It should be noted that by adding these activities we needed to reduce the number of items that we cover in the typical syllabus.

This approach has been successful in our freshman engineering, and EE3 classes. Consequently, in fall 2013 semester we tried the same approach in a senior class (High Speed Systems Engineering) and students did communicate a better-connected understanding and better integration of their knowledge. We are in the process of analyzing those results more carefully.

Students in the EE3 class strive to get a better understanding of the electromagnetic fields areas. They are encouraged to read more in-depth technical material and do major final projects. The projects seem to be very successful for students’ knowledge interactions. However, it is the discussions, reflections and connected homework related to the reflection topics that students say they remember the most from the class.

**Interesting outcomes and findings**

Here are a couple of key findings from our study

1. We need to encourage all students to reflect and create narratives for equations. While equations are figures and pictures, the reflection-derived narrative for each student is the most important items that really tell us if they understand the essence of the concept. This is true for the technological literacy students, as well; they need to treat equations as figures and create their narrative.

2. Many engineering students can manipulate equations well, but when it comes to develop their reflective narratives and show interconnections of the concepts they do not seem to be tooled appropriately. We have found out that those students tend to forget the material much faster.

3. The development of narratives through reflection and understanding of the equations and their treatments need to be monitored regularly and fast feedback provided to help them correct their conceptual aspects of the reflections narratives and keep progressing.

4. Instructors need to provide the following: A set of key items, upon which to reflect, that we would like them to know, problems that they need to be able to solve, concepts that they need to be able to talk about. This is essential. If we know what they need to accomplish, if it can
come into a set of test-like questions and essays, and if that can be available to the students from the first day, the iterations to conceptualize the subjects as well as the skills to solve problems will be much more meaningful. It may sound that we are teaching for a test, but if the problems are conceptual with applications in mind that is fine.

5. Teaching engineering needs to be connected to the philosophical basis of engineering and reflect on this connection. We need to teach within the pragmatic and ethical framework of engineering". The instructor needs to have strong connection to historical events and relevant applications and encourage reflection on these aspects. The concepts specifications, what is a good solution, practical approaches, and ways to deal with constraints are important aspects of engineering and engineering practice and design. This needs to be emphasized in our engineering as well as our technological literacy classes.

Findings, reflections, and final remarks

When teaching engineering to non-engineering students one realizes that the first item that needs to be taken away from the lectures are the focus on mathematical treatment of all subjects. While essential to engineering, mathematical concepts need to be developed constructively in correct contextual and/or application oriented approaches. Our effort in teaching some of the most difficult concepts of engineering such as Faraday’s Law to three classes, clearly indicate that our goal should be:

1. Repeat the major important concepts in creative and constructive narratives emphasizing opportunities for reflective thinking.
2. Have students reflect and make their own narrative, write, draw, and get comfortable with treating equations as figures; that there is conceptual narrative associated with that
3. Provide many applications, designs, and historical connections to concepts. For instance discussions of historical narratives of the difficulties that Michael Faraday and others had with this equation known as Faraday’s Law, their important contributions, then the fascination of J.C. Maxwell with the equation together with how it ended up in the late 1800s and early 1900s to development of the dynamo, motors, and power systems as well as being an inspiration for Einstein in his special theory of relativity can all be useful narratives for students to reflect upon and remember what this law is all about.
4. We cannot get too carried away with historical narratives. While important, they are not sufficient. Students need to really connect them to how things are done, how they are used in design, applications, and how by knowing them they will be enable do things and understand them. This is important for both engineering and non-engineering students. It is the level of detail and the focus of the activities that distinguishes the engineering and non-engineering students.

Connecting the two technological literacy classes (ENG1 and ENG2) with this methodology emphasizing reflection has resulted in some instances of the students’ self-confidence and passion to continue their own learning. Many of the students, independent of any classes, decided to learn Arduino to impact third and fourth year projects. They approached our team about how they would learn about Arduinos and we just provided them some information on how they can learn. They did the rest on their own.
It is not hard to imagine how such approaches using frequent opportunities for reflective thinking, together with creative and constructive curricular connectivity, can help engineering students. In more than a few cases some of the technological literacy students did take the EE3 class, and did go through the steps with engineers. They seemed to go through the difficult tasks as long as they had the hope to learn and be able to apply their knowledge.

What about integrating the students of these classes? Can engineering and non-engineering students reflect and learning together. We think this is a necessary future activity

1. Perhaps if we can mix the students of the engineering and technological literacy classes in special projects and or designs, we would benefit from the interaction and help each side find special angles and perspective that they were missing.

2. Our studies show that a select group of the technological literacy class students (the industrial design students) have performed well as team members in multidisciplinary senior design project. Sharing a common experience of reflection, they bring about new questions that make challenging perspectives for the engineering students; they can help the background research and also help with iteration of the final project with their sketching, drawings and fresh verbalization.

3. When groups of engineering students joined the senior portfolio development of the industrial designers as well as special projects, the synergy was also beneficial to both sides. Such integration has been successful and encouraged. In these cases the engineering students do bring a new perspective of design, implementation, and specification related constraints that is of great help to the technological literacy students.

4. When mixing the two different groups, each introduces a felt difficulty to the other team. This happens to be the first step and the seed of the reflective thinking. It results in discussion, debates, and collaborations that reach beyond having just one of the groups working within their discipline. However, effective reflection needs to be monitored and mentored by mature faculty at the beginning.

Finally, it should be noted that the goal of all these classes and practice with reflection is to develop critical thinking capabilities and skills. There is a balance between doing, playing, engaging, learning, and rigorous drilling. While they are all important, too much focus on one is note desired. Depending on the level of the students and the class expectations our activities need to be adjusted.

Teaching engineering and technology to non-engineers reminds us that we need to be conceptual, practical, pragmatic, start from basics, create reflections, build on them, and develop connections. We need to be showing students how engineering is done from concepts to things. Sometimes this is not clearly obvious in our engineering classes, since we as engineering educators value mathematical manipulations to be more important than conceptual development. But our students need to play, make things, fail, be aware of the tools, be pragmatic, ethical, and understand the design aspects of engineering. Reflection promotes this process. Our engineering students need to be empowered and tooled to understand, manipulate, design, and enable progress that has direct relevance to people’s lives, needs, and advances societal and technological achievements. The non-engineering student need to understand the concepts, and
be empowered to realize technological and methodological relevant implications, understand who engineers are, and how they can work together to make things happen. Our experience has shown that creating opportunities for reflection are useful for both engineering and non-engineers.

Future plan for the project

As engineering educators, we know that the value of quantitative data is of great importance to most engineering faculty. Consequently, The most important challenge for understanding the data remains to be the answer to the questions: “How to create a quantitative measure of what we are seeing?” or “Is it possible to create meaningful quantitative data for this type of work?” Our goal will be to do a systematic analysis that would help us understand ways to have meaningful quantitative assessment of the student’s critical thinking growth, depth, and capabilities. The research approach on this subject is still open and being discussed extensively. Researchers have tried various ways, including creating rubrics that would try to quantify levels of thinking and in-depth critical analysis.\textsuperscript{18-25} Currently, our team is in the process of defining rubrics (with similar approaches to the CAT testing system and Professor Stein’s\textsuperscript{18} ideas on assessing critical thinking) to identify overall expectation, evaluations, and possibilities regarding realistic and meaningful quantitative results to support the current effort.

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