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Concept Paper

An Extended Constructive Alignment Model in Teaching Electromagnetism to Engineering Undergraduates

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Abstract: Introducing abstract concepts to students from applied fields can be challenging. Electromagnetics is one of those courses where abstract concepts are introduced. This work presents a conceptual model which defines learning objectives in three levels for Engineering Electromagnetics. Each level is aligned with its own assessment and evaluation methods. The advantage is that the three-level learning objectives can be extended as student self-assess and instructor assessment rubrics, and a detailed implementation is presented here. This model gives students more accessibility to the learning objectives and increases the transparency of the learning and grading processes. The main goal of this conceptual model is to make students learn with the end in mind.

Keywords: engineering education; engineering classroom practices; learning objectives; student-centered learning; assessments and evaluations; rubrics; constructive alignment

1. Introduction

Electromagnetism is one of the critical fields in physics. It discusses the inter-dependence of electric and magnetic fields and how they behave under certain conditions [1]. Electromagnetism spans across a wide range including but not limited to communication systems (wireless, satellite, global navigation), space weather monitoring, and bio-medical applications such as body area networks, glucose monitoring using micro-strip patch antennas, hyper/hypo thermic applications, and the list continues. In today's world where everything is wireless, knowing the fundamentals of electromagnetics is essential for both physics and electrical engineering students. Based on the major the depth covered may differ. Teaching electromagnetic theory for engineering students is challenging since engineering students like to apply the knowledge to real-world scenarios, but the subject itself contains abstract mathematics. Therefore, it is a daunting task for the teachers to find the right balance between the theory and examples, given the limited time.

Electromagnetism, especially at its initial stages, requires visualization. Since most of the concepts such as "an electric charge in free space" cannot be seen, students have to imagine it in their mind. This issue together with the complexity of mathematics make students demotivated at the beginning of the semester. To avoid that issue, students need to be involved in the teaching and learning process since the beginning of the course. The more abstract a course can be the more student engagement is needed to keep the interest and the intensity of the subject [1–3]. Students should know what is expected from them and the process of achieving those. The assessment and evaluation criteria should be available to them to make the grading process transparent. This is where a constrictive alignment approach can be used.

Constructive alignment is an approach used to match the evaluation methods with the learning objectives [4–11]. In constructive alignment, students are aware of the expectations at the beginning

of the semester. This process makes the teaching and learning process transparent to the students. Students know that each assessment or evaluation method is aligned with a course objective. Many universities have applied this method successfully to their courses [1,10,12–14]. Learning objectives, assessment, and evaluation methods are essential in the accreditation process. Nevertheless, average undergraduate students have less knowledge on learning objectives. The efficiency of the learning process will increase to a great extent if the students raise the concern about the learning objectives and use those to assess them.

In this work, the author presents a model where students can self-assess whether they have met the learning objectives. This model differs from the existing ones since, instead of defining a single set of learning objectives, those are given in three levels for each chapter covered. The author also suggests proper assessment and evaluation methods for each level of learning objectives. The advantage of this three-level constructive alignment model is the learning objectives can be extended to be the assessment rubrics for both students and the teacher. This approach makes the learning objectives more visible to the students and the learning process more transparent. Although this paper uses engineering electromagnetics as an example, this model can be used in teaching any major course (for example, electromagnetics) to students from an applied field (for example, electrical engineering).

2. Proposed Model

The extended constructive alignment model I am presenting here contains the following main points.

2.1. Entry Survey

At the beginning of the semester, the teacher is supposed to give the students and the entry survey. Appendix A shows a sample questionnaire prepared by the author for this paper This step builds the rapport between the teacher and the students and provides a rough understanding of the group of learners.

Knowing the plans of the students helps decide the extent of the material needing to be covered, assign reading and homework problems, and extra homework.

By identifying the preferred learning style, the teacher can adjust the course material to cater for all students. The learning style can change from topic to topic. But each person has a dominant learning style. These are diverging (learning by watching and feeling), assimilating (learning by watching and thinking), converging (learning by doing and thinking), and accommodating (learning by doing and feeling). Although some students might categorize themselves as a hybrid, it is important to know the preferred learning style of the students. When assigning students for group projects, the teacher can assign students such that each group contains one student from each learning style. The projects usually include an equal amount of workload from each learning category, and in this case workload can be successfully distributed, and students can learn from each other creating a collaborative learning environment.

Appendix A shows an entrance survey designed for an undergraduate electromagnetic course. But a revised version can be used for any subject. It is essential to keep the language of the questionnaire friendly and straightforward since this is the first written communication between the teacher and the student. For a course such as electromagnetics, students might have already heard the toughness of the class from their peers, hence it is crucial to building the rapport between the students and the teacher by using friendly language.

The entry survey also serves the purpose of making the minds prepared to absorb the complicated material by giving them a “heads-up”.

2.2. The Three-Level Learning Objectives

The main difference between this proposed model and the current outcome-based education is that the current models contain only one set of learning objectives for each lesson. Whereas in this

proposed model, we are introducing three levels of learning objectives. These learning objectives must be made visible to the students at the beginning of each chapter.

The learning objectives are designed as low, medium, and high. The low-level learning objectives target the basic understanding of the course material. The wordings are selected based on Bloom's taxonomy [4–9,13], and sample learning objectives for a typical undergraduate electromagnetic course is given in Table 1.

For illustration, we have selected the topics covered in a 30 credit hours undergraduate electromagnetic course. The topics covered are:

1. Gauss's Law for electrostatic fields and Maxwell's first equation.
2. Gauss's Law for magnetostatic fields and Maxwell's second equation.
3. Faraday's Law for time-varying electric fields and Maxwell's third equation.
4. Ampere's Law for time-varying electromagnetic fields and Maxwell's fourth equation.
5. Plane wave solution.
6. Poynting theory, electromagnetic power, basic electromagnetic radiation principles, and their applications.

Depending on the university, there are variations of these topics and instructors would breakdown the above topics to chunks. But the above are considered mandatory.

The learning objectives are designed on three levels for all chapters. In a course such as engineering electromagnetics, students might have different goals. If a student is planning on going to graduate studies, he or she may want to learn more in-depth physics content whereas if someone wants to join the industry wants to know just enough material. With this method, the student can decide whether he or she has achieved the required learning objective.

Table 1. Three level learning objectives and the suggested assessment and evaluation methods (Bloom's taxonomies are in bold face).

Topic	Learning Objective(s)	Assessment Method(s)	Evaluation Method(s)
1. Gauss's Law for electrostatic fields and Maxwell's first equation.	Low: By the end of this chapter students are expected to **explain** Maxwell's first equation and its implications.	Conference, Self-assessment	A quiz Presentation, Case study
	Medium: By the end of this chapter students will be able to **apply** Maxwell's first equation to solve real-world physics problems.	Self-assessment quiz, Question and answer, I am in the fog about . . .	Exam problem, Quiz
	High: By the end of this chapter students are expected to **design** a basic static charge dust collector using Maxwell's first equation.	Chart it out, Concept map	Group project (2-3 students), A term paper Project report
2. Gauss's Law for magnetostatic fields and Maxwell's second equation.	Low: By the end of this chapter students will be able to **discuss** the practical implications of Maxwell's second equation.	Discussion, Conference	Short presentation, Quiz, Short essay
	Medium: By the end of this chapter students will be able to **solve** problems related to Maxwell's second equation.	Self-assessment quiz, I am in the fog about, Operation outline	Exam questions, Quizzes
	High: By the end of this chapter students will be able to **create** a computer software model of Earth's magnetic system.	Chart it out, Ticket out the door, Concept map	Problem based project, Research report, Research paper

Table 1. *Cont.*

Topic	Learning Objective(s)	Assessment Method(s)	Evaluation Method(s)
3. Faraday's Law for time-varying electric fields and Maxwell's third equation.	Low: By the end of this chapter students are expected to **describe** Faraday's law and its implications.	Discussion, Conference	Quiz Short, presentation
	Medium: Upon completing this chapter students are expected to **compute** values for real-world problems based on Faraday's law.	Self-assessment quiz, I am in the fog about, Operation outline	Exam questions, Quizzes
	High: By the end of this chapter students will be able to **build** an electromagnetic inductor to **demonstrate** Faraday's law.	Ticket out the door, Concept map	Experiment, Prototype building
4. Ampere's Law for time-varying electromagnetic fields and Maxwell's fourth equation.	Low: By the end of this chapter students are able to **define** Ampere's law and its implications.	Ticket out the door	Presentation, Short quiz answers, Short essay
	Medium: By the end of this chapter students are able to **calculate** values for a real-world application using Ampere's law.	Self-assessment quiz, I am in a fog about, Question and answer	Exam questions, Quizzes
	High: by the end of this chapter students are expected to **construct** an electromagnet with given specifications based on Ampere's law.	Conference, Ticket out the door, Concept map	Short project, Live demonstration, Presentation of a prototype
5. Plane wave solution.	Low: By the end of this chapter students are able to **state** the plane wave solution.	Ticket out the door	Presentation, Short essay, Short quiz
	Medium: By the end of this chapter students are able to **manipulate** the plane wave solution and apply it in a real-world problem.	Self-assessment quiz, Questions and answers, Operations outline	Exam questions, Quizzes
	High: By the end of this chapter students will be able to **synthesize** plane wave electromagnetic propagation in computer software.	Chart it out, Ticket out the door, Concept map	Project, Demonstration, Video presentation
6. Poynting theory, electromagnetic power, basic electromagnetic radiation principles, and their applications.	Low: By the end of this chapter students will be able to **identify** the appropriate concepts used in real-world EM wave propagation applications.	Ticket out the door, Discussion	Presentation, Essay
	Medium: By the end of this chapter students will be able to **analyze** the real-world EM applications using appropriate concepts.	Self-assessment quiz, I am in the fog about, Operations outline	Exam questions, Long answer quizzes, Summary paper
	High: By the end of this chapter students are expected to **integrate** EM concepts and **implement** a solution to a real-world problem.	Conference, I am in the fog about, Concept map	Prototype building, Video presentation, Term paper, Presentation

2.3. Three-Level Assessment and Evaluation Methods

In this paper, the author suggests assessment and evaluation methods for each level of learning objectives. The teachers can pick a process that they might think suits the class environment to add a variety and build a collaborative environment. In Table 2 below the author shows a standard grade break down. Depending on the class performance and average, the teacher is free to make necessary adjustments. This is the "judgement" component since it determines the final grade based on the performance.

Since this course is targeting towards engineering students, the highest percentage is allocated for projects. Hence the majority of the course percentage is for the application or projects. Projects can be assigned individually or as groups since there are five projects within about 14–16 weeks. Hence, appointing group projects will expedite the submissions. The statistics collected from the entry survey can be used here for assigning groups. It is preferred that each group contains at least one member from each learning style. Also, students get to know each other by changing the groups for each project.

Most of the faculty is familiar with the evaluation methods. But some of the assessment techniques are unfamiliar to most of the instructors. But assessment techniques are necessary because those give students an opportunity to determine whether they have met the learning objectives. Appendix B shows a sample self-assessment quiz for chapter 1; Appendix C is a concept map for Section 2 and Appendix D illustrates an operations outline for topic 6.

Table 2. Standard grade breakdown.

Evaluation Method	Percentage
Quizzes	10%
Homework	15%
Exams (3 including the finals)	25%
Projects (6 mini projects)	50%

2.4. Student Self-Assessment and Instructor Assessment Rubrics

Tables 3 and 4 show the student self-assessment and instructor assessment rubrics. The importance of these rubrics is that these are directly aligning with the learning objectives. Therefore, this is an extended model. With this model, students can determine where they are in the rubric, and the instructors can assess where each student is in the performance chart. The alignment between the learning objectives and the assessment rubrics extends this model and increases the visibility of the learning objectives. It also increases the transparency of the teaching-learning process.

The three levels of Bloom's taxonomy [9] (low, medium, and high) and the model introduced by Biggs in 1996 [5] are closely related. In the Biggs model the term pre-structural was used to indicate the unsatisfactory performance. The low-level learning objectives in Bloom's taxonomy are similar to the unistructural performance in Biggs' model. If the student is at this level, here the student is categorized as "needs improvement". If the student has achieved medium-level learning objectives (multi-structural in Biggs' model), he or she will be categorized into the satisfactory level. If the student has achieved the high-level learning objectives (or the relational in the Biggs model) that student will be categorized as excellent.

Table 3. Student self-assessment rubric.

Topic	Unsatisfactory	Needs Development	Satisfactory	Excellent
Gauss's Law for electrostatic fields and Maxwell's first equation.	I can neither both explain, apply nor design an application based on Maxwell's first equation.	I can **explain** Maxwell's first equation. But I can neither apply nor design an application based on it.	I can **explain** and **apply** Maxwell's first equation. But I cannot design an application based on it.	I can **explain**, **apply** and **design** an application using Maxwell's first equation.
Gauss's Law for magnetostatic fields and Maxwell's second equation.	I can neither discuss the implications, solve problems nor create an application based on Maxwell's second equation.	I can **discuss** the implications of Maxwell's second equation. But I can neither solve problems nor create an application using it.	I can **discuss** and **solve** problems using Maxwell's second equation. But I cannot create an application based on it.	I can **discuss** the implications, **solve** problems and **create** an application based on Maxwell's second equation.

Table 3. *Cont.*

Topic	Unsatisfactory	Needs Development	Satisfactory	Excellent
Faraday's Law for time-varying electric fields and Maxwell's third equation	I can neither describe, compute nor build an application based on Faraday's law.	I can **describe** Faraday's law. But I can neither compute nor build an application based on it.	I can **describe** and **compute** values for a practical problem. But I cannot build an application.	I can **describe**, **compute** and **build** an application to **demonstrate** Faraday's law.
Ampere's Law for time-varying electromagnetic fields and Maxwell's fourth equation.	I can neither, define, calculate values nor construct an application using Ampere's law.	I can **define** Ampere's law. But I cannot calculate values or construct an application.	I can **define** and **calculate** values for problems, using Ampere's law. But I cannot construct an application.	I can **define**, **calculate** values and **construct** an application based on Ampere's law.
Plane wave solution.	I can neither state, manipulate nor synthesize plane wave solution.	I can **state** plane wave solution. But I cannot manipulate or synthesize it.	I can **state** and **manipulate** plane wave solution. But I cannot synthesize it.	I can **state**, **manipulate** and **synthesize** plane wave solution.
Poynting theory, electromagnetic power, basic electromagnetic radiation principles, and their applications.	I can neither identify, analyze nor integrate practical applications of EM wave propagation concepts.	I can **identify** EM concepts for real-world scenarios. But I can neither analyze nor integrate concepts.	I can **identify** and **analyze** EM concepts for real-world scenarios. But I cannot integrate those for implementations.	I can **identify**, **analyze** and **integrate** EM appropriate EM concepts to **implement** solutions.

Table 4. Instructor assessment rubric.

Topic	Unsatisfactory	Needs Development	Satisfactory	Excellent
Gauss's Law for electrostatic fields and Maxwell's first equation.	Student can neither both explain, apply nor design an application based on Maxwell's first equation.	Student can **explain** Maxwell's first equation. But the student can neither apply nor design an application based on it.	Student can **explain** and **apply** Maxwell's first equation. But the student cannot design an application based on it.	Student can **explain**, **apply** and **design** an application using Maxwell's first equation.
Gauss's Law for magnetostatic fields and Maxwell's second equation.	Student can neither discuss the implications, solve problems nor create an application based on Maxwell's second equation.	Student can **discuss** the implications of Maxwell's second equation. But the student can neither solve problems nor create an application using it.	Student can **discuss** and **solve** problems using Maxwell's second equation. But the student cannot create an application based on it.	Student can **discuss** the implications, **solve** problems and **create** an application based on Maxwell's second equation.
Faraday's Law for time-varying electric fields and Maxwell's third equation	Student can neither describe, compute nor build an application based on Faraday's law.	Student can **describe** Faraday's law. But the student can neither compute nor build an application based on it.	Student can **describe** and **compute** values for a practical problem. But the student cannot build an application.	Student can **describe**, **compute** and **build** an application to **demonstrate** Faraday's law.
Ampere's Law for time-varying electromagnetic fields and Maxwell's fourth equation.	Student can neither, define, calculate values nor construct an application using Ampere's law.	Student can **define** Ampere's law. But the student cannot calculate values or construct an application.	Student can **define** and **calculate** values for problems, using Ampere's law. But the student cannot construct an application.	Student can **define**, **calculate** values and **construct** an application based on Ampere's law.
Plane wave solution.	Student can neither state, manipulate nor synthesize plane wave solution.	Student can **state** plane wave solution. But the student cannot manipulate or synthesize it.	Student can **state** and **manipulate** plane wave solution. But the student cannot synthesize it.	Student can **state**, **manipulate** and **synthesize** plane wave solution.

Table 4. *Cont.*

Topic	Unsatisfactory	Needs Development	Satisfactory	Excellent
Poynting theory, electromagnetic power, basic electromagnetic radiation principles, and their applications.	Student can neither identify, analyze nor integrate practical applications of EM wave propagation concepts.	Student can **identify** EM concepts for real-world scenarios. But the student can neither analyze nor integrate concepts.	Student can **identify** and **analyze** EM concepts for real-world scenarios. But the student cannot integrate those for implementations.	Student can **identify**, **analyze** and **integrate** EM appropriate EM concepts to **implement** solutions.

3. Discussion

This work presented an extended constructive alignment model for teaching engineering electromagnetics. The goal of this model is to relate learning objectives with the assessment rubrics, hence students become more familiar with the expectations. Because a typical undergraduate student would care about the course objectives if and only if it is related with the grade. Teaching electromagnetics is challenging for engineering students since most of the engineering students do not expect a course to be theoretical and mathematically complicated. But with electromagnetics being an essential field, those complex material needs to be introduced regardless of the challenges. Techniques such as the flipped classroom can be applied but those techniques might not have an effect given the work–life balance of students and the context of the course.

In this paper, the author presents a model which defines the learning objectives in three levels, hence it can be converted to assessment rubrics with minimal effort as illustrated later in this paper. Therefore, this model is an extended version of the existing constructive alignment concept. Initially, this might increase the workload of the instructor for course design, revisiting the learning objectives, preparation of assessments, and course material. But once the learning objectives are written the entire process will be much more apparent to the instructor as well as to the student. Instead of jumping right to the high-level learning objective, the students can self-guide themselves through each step of the learning process.

The difference between this model and the existing constructive alignment method is here course objectives are presented in three levels. Therefore, students know what is expected from them and the assessment and evaluation process become more transparent. As mentioned in this paper, this model has the advantage of directly converting the three-level course objectives into assessment rubrics.

Currently this model is structured in a way that everything is well defined and gives only little room for student's imaginative thinking. But as with every course, instructors have to fine-tune the model as it goes, keeping the core concepts intact. For example, if a student comes up with an alternative project instead of the one assigned, an instructor can compare the workload of the project and grant permission. And extra credit can be given if students perform beyond expectations. Another way to include creativity is the course objectives can be modified such that instead of the instructor assigning the projects students should come up with their own ideas. This second option might be better suited for an advanced undergraduate or a graduate level course where students have enough knowledge about the subject matter to challenge their creativity.

4. Conclusions

This paper presents an extended constructive alignment model for teaching electromagnetism to engineering undergraduates. Although the model is developed for electromagnetism, this can be applied when introducing any abstract field to undergraduates from an applied field. Currently this model is at a conceptual state and a follow-up paper will be published with the results of its implementation.

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Appendix A

Class entrance survey
I _____ answer these questions to the best of my knowledge.

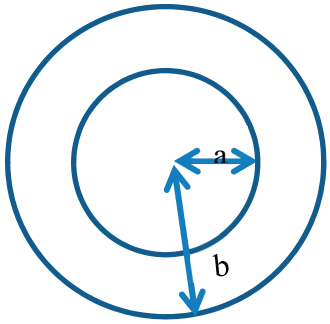
1. As of now, after completing my undergraduate degree, I am planning on:
   a. Doing graduate studies
   b. Working in the industry
   c. Doing my own thing, for example, painting, carving, sculpture
2. If I can get one thing out of this course it would be:
   a. Nothing, I registered just because it is required. I have a different subject interest.
   b. Try this subject and see whether I should pursue this for my graduate studies
   c. Learn how things work and apply it at work
3. While registering for this course
   a. I knew/heard this course it very mathematics and physics intensive
   b. Oops, I did not know that. But I can catch up quickly.
   c. Oh no, why? Engineers don't need math or physics.
4. We all learn in different ways. But if I have to choose one, that I learn quickly by
   a. Watching and feeling
   b. Watching and thinking
   c. Doing and feeling
   d. Doing and thinking
5. Knock on wood, but if my performances at exams are not satisfactory
   a. I will sue the instructor. I am exceptional, and it is always the instructor's fault.
   b. It might be a bad day. I want to write a make-up exam.
   c. I get nervous at exams. If so I will do an extra project or a presentation, whichever it takes to show my actual knowledge.

Appendix B

Self-assessment quiz: Gauss's Law or Maxwell's first equation

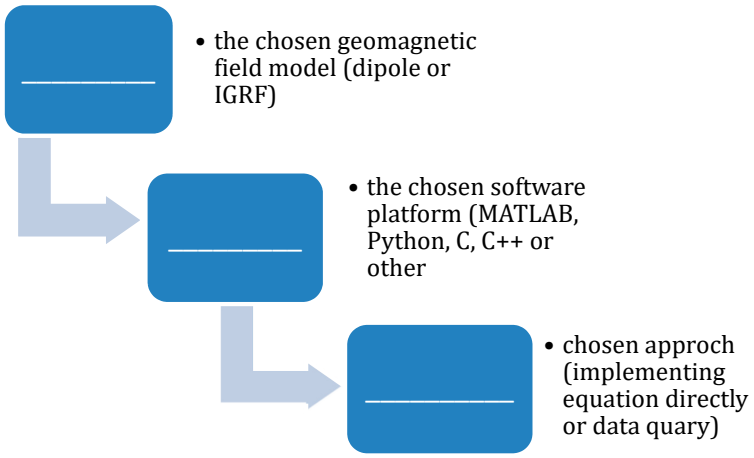
1. A spherical charge cloud with volume charge density ρ_v and radius a, is located at the origin of a spherical coordinate system. Determine the electric flux density and electric field intensity at a distance r such that,
   a. $r < a$
   b. $r \geq a$
2. An infinite length of a wire contains a line charge density of ρ_l. Choosing a suitable coordinate system, calculate the electric field intensity at a radial distance r from the wire.
3. Two hollow spheres are located at the origin of a spherical coordinate system. Surface of the inner sphere carries a total charge of $+Q$ and the surface of the outer sphere carries a total charge of $-Q$. The space between the spheres is filled with air.

a. Find the electric field intensity at a radial distance r : $a < r < b$
b. Calculate the potential difference between the two spheres
c. How much of a capacitance is developed between the two spheres?



Appendix C

Concept map: Creating a Computer Software Model of Earth's Magnetic System



Appendix D

Operations Outline: Basic EM Propagation Concepts

1. A 15W EM radiator is isotopically radiating energy equally in all directions. Your task is to calculate the surface area of a dish antenna located 15 m from the radiator to collect 1W of power.

a. What should be the radiating surface for the above radiator?

. . . . . .

b. Calculate the average power density 15 m from the radiator.

. . . . . .

c. If the goal is to collect 1W at the receiver, what should be the surface area of the receiver

. . . . . .

d. What should be the radius of the above dish

. . . . . .

e. If the above dish was replaced by a parabolic antenna with the same radius, will the power collected will increase or decrease?

. . . . . .

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