Supporting Online Material for

Improved Learning in a Large-Enrollment Physics Class

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This PDF file includes:

Materials and Methods
SOM Text
References

Improved learning in a large enrollment physics class


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1. Engagement measurements discussion.
2. Experimental section opinion survey and responses.
3. Test given to both sections on the material taught.
4. Slides shown in the three days of class in the experimental section. There is typically one question or task per slide, with about six slides per 50 minute class. Commentary on the design and preparation is inserted (in italics).
5. Learning objectives agreed upon by the two instructors.
6. Hawthorne effect comment, and discussion of engagement and attendance in courses with similar design over a full semester.
7. List of proven teaching practices used, with references.

1. Engagement measurements

The engagement measurement is as follows. Sitting in pairs in the front and back sections of the lecture theatre, the trained observers would randomly select groups of 10-15 students that could be suitably observed. At five minute intervals, the observers would classify each student's behavior according to a list of engaged or disengaged behaviors (e.g. gesturing related to material, nodding in response to comment by instructor, text messaging, surfing web, reading unrelated book). If a student's behavior did not match one of the criteria, they were not counted, but this was a small fraction of the time. Measurements were not taken when students were voting on clicker questions because for some students this engagement could be too superficial to be meaningful as they were simply voting to get credit for responding to the question. Measurements were taken while students worked on the clicker questions when voting wasn't underway. This protocol has been shown by E. Lane and coworkers to have a high degree of inter-rater reliability after the brief training session of the observers.
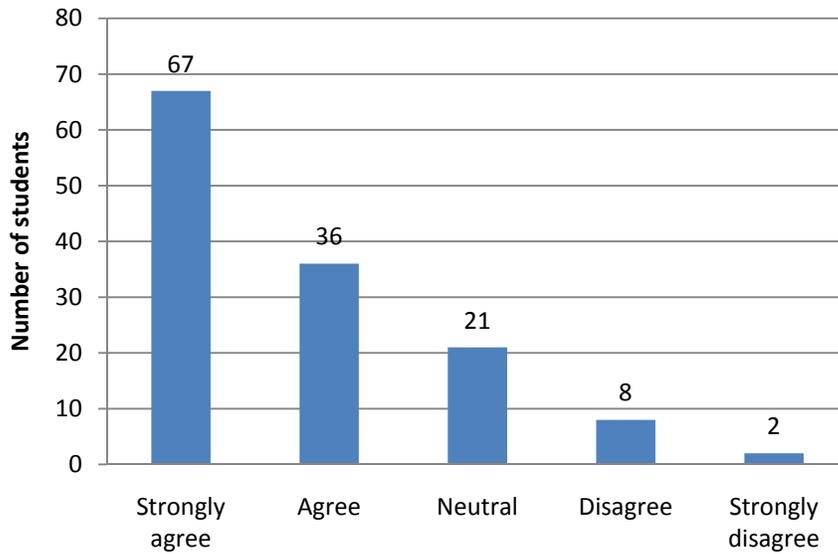
2. Opinion survey and responses given in the experimental section

Q1   *I really enjoyed the interactive teaching technique during the three lectures on E&M waves (Ch32):*
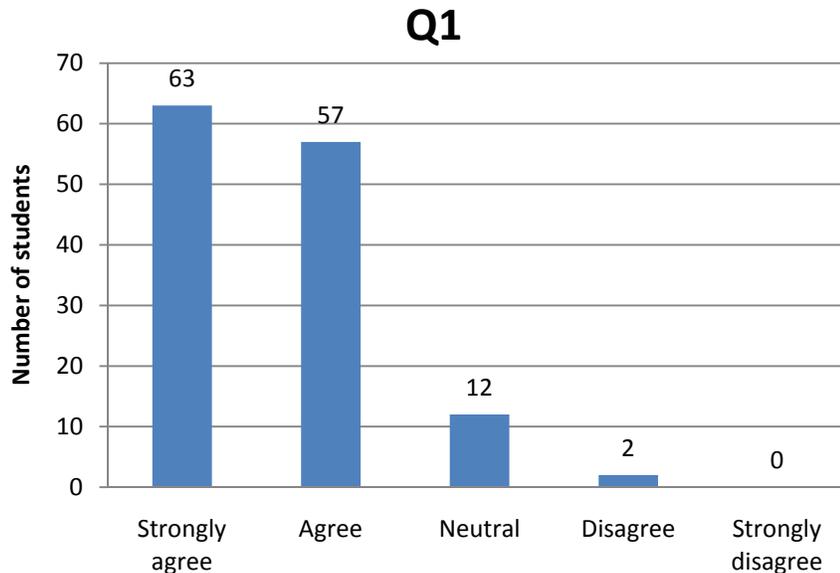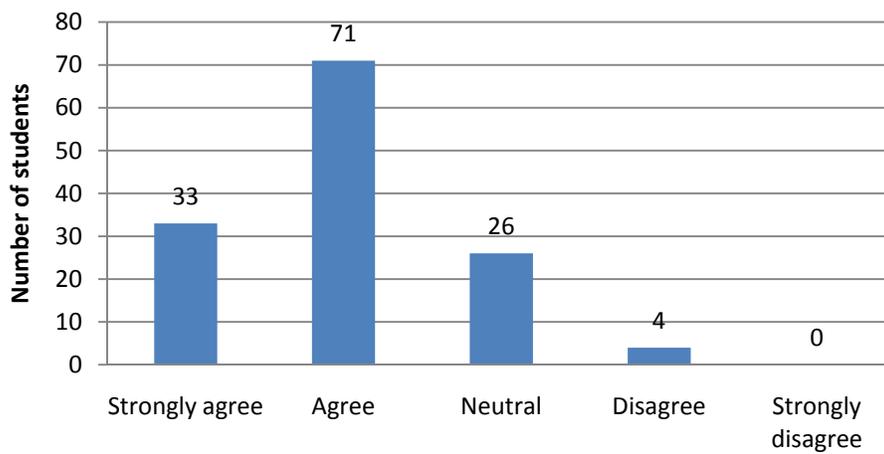
Q2   *I feel I would have learned more if the whole course (Phys153) would have been taught in this highly interactive style:*
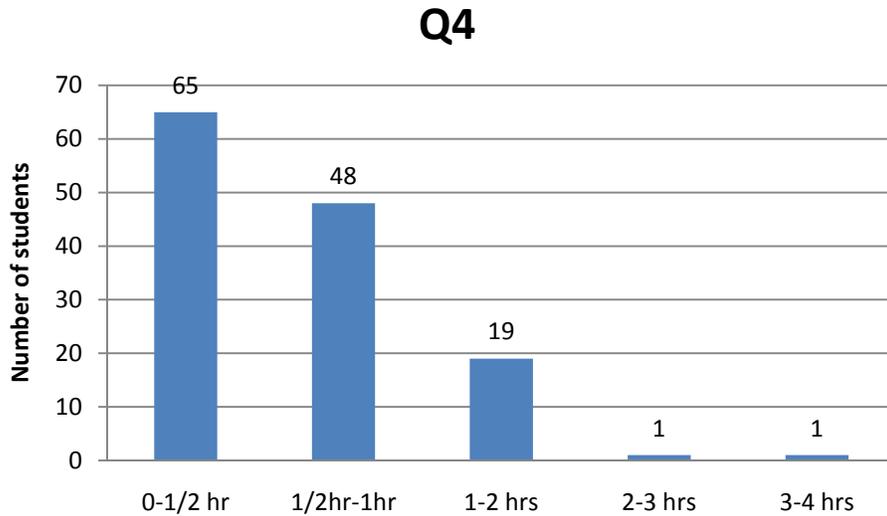
Q2

Q3   *I thought the 30 min exam on E&M waves did a very good job at measuring how much I know about E&M waves and photons:*
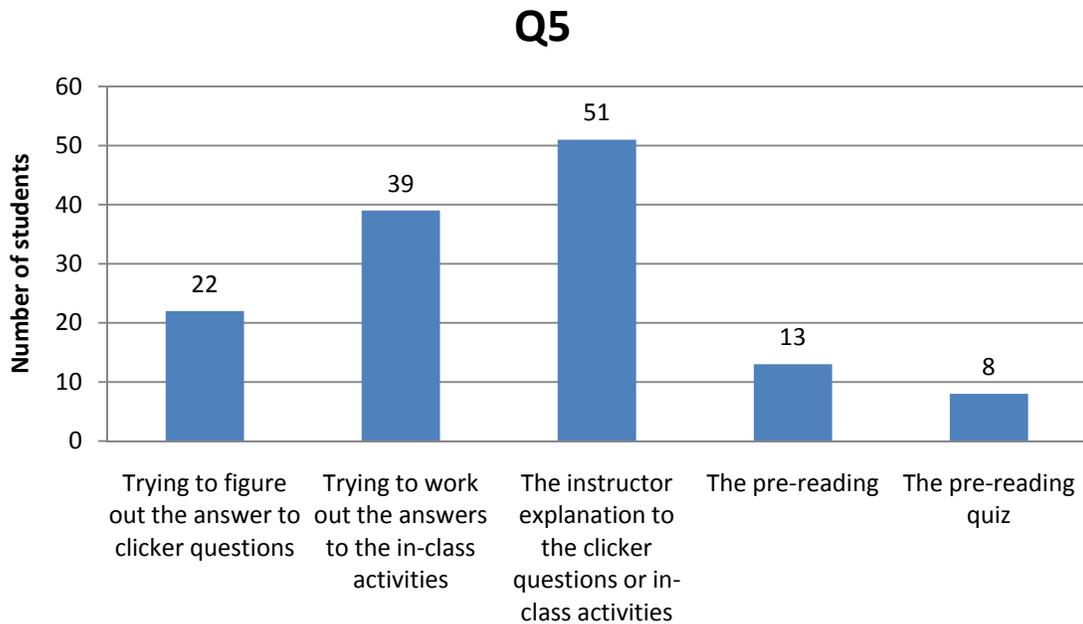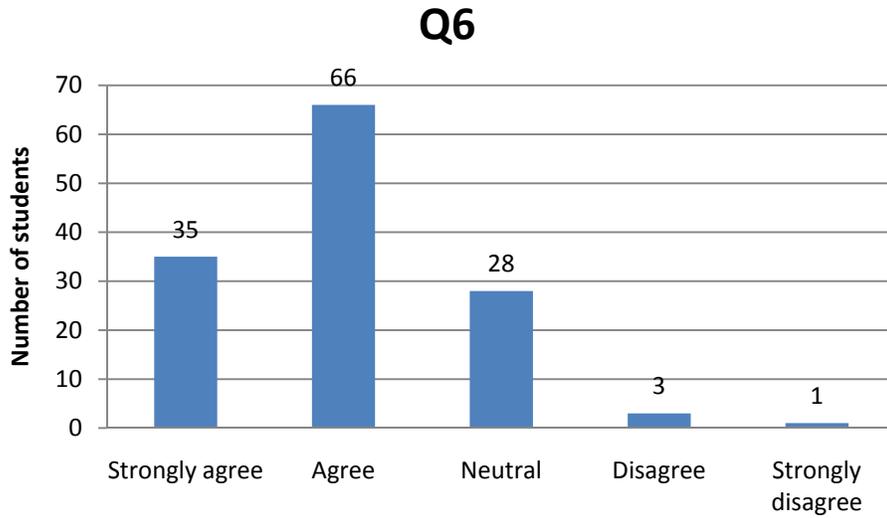
Q3

Q4   *I studied for the E&M test/quiz for:*

Q4

Q5   *What contributed most to my learning during these three lecture on E&M waves:*

Q5

Q6   I found the pre-reading to be very helpful to my learning:

Q6

Q7   I found the pre-reading quiz to be very helpful to my learning:

Q7
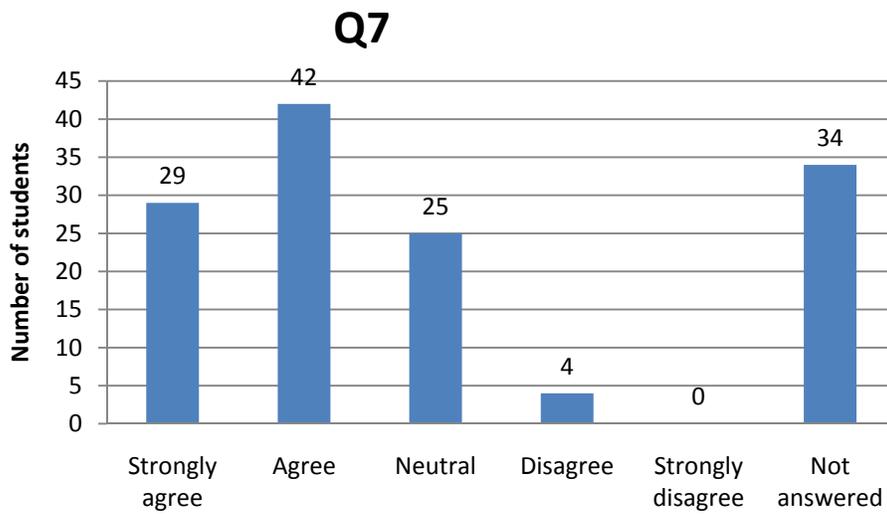
Q8   In class, the group discussions with my neighbors were very helpful to my learning:

Q8
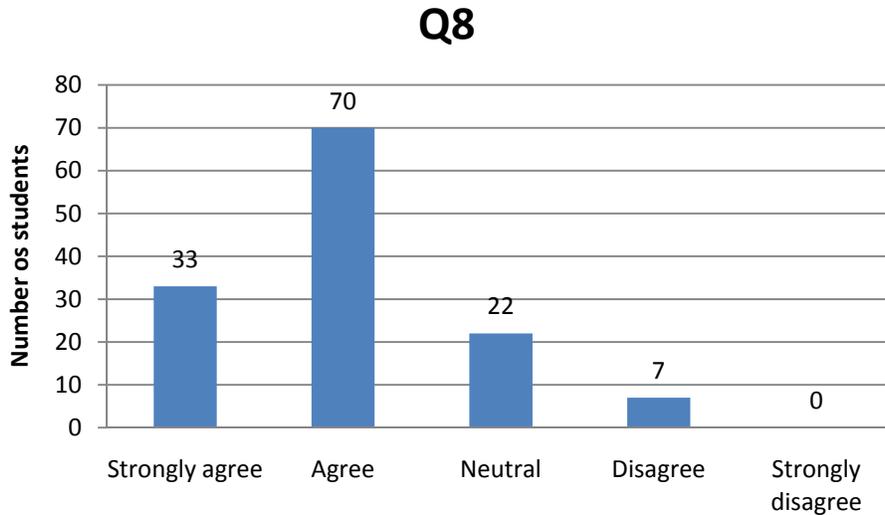
3. Test given to both sections on the material taught

Question 1

The amplitude and frequency of 4 E&M waves are shown below. The waves are representative of one instant in time and are all travelling in vacuum. Which wave travels the fastest?

a) 1   c) 3

b) 2   d) 4   e) All 4 waves travel at same speed

Question 2

An Electromagnetic wave is traveling along the negative x-direction.
What is the direction of the Electric field vector E at a point where the Magnetic field vector B is in the positive y-direction?

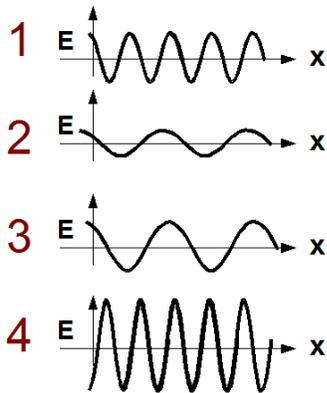   (a) The E field points along the positive x-direction

    (b) The E field points along the negative x-direction

    (c) The E field points along the positive z-direction

    (d) The E field points along the negative z-direction

    (e) The E field points along the negative y-direction

Question 3

An electromagnetic wave is propagating along the positive x-direction with a magnetic field pointing along the z-direction:

$$B_z(x,t) = 3 \cdot 10^{-4} \sin(2\pi \cdot 10^6 x - \omega t)\ Tesla$$

What is the wavelength of this EM wave?
(*Note: 1 nanometer= 10^{-9} meter*)?

    a) 10^4 nanometers

    b) 10^3 nanometers

    c) 100 nanometers

    d) 10 nanometers

    e) 1 nanometers

Question 4

An electromagnetic wave is propagating along the positive x-direction with a magnetic field pointing along the z-direction:

$$B_z(x,t) = 3 \cdot 10^{-4} \sin(2\pi \cdot 10^6 x - \omega t)\ Tesla$$

What is the strength of the Electric field E?

a) 3×10^{-4} V/m

b) 9×10^{-8} V/m

c) 3 V/m

d) 9×10^{4} V/m

e) Not enough information is given

Question 5

An electromagnetic wave is propagating along the positive x-direction with a magnetic field pointing along the z-direction:

$$B_z(x, t) = 3 \cdot 10^{-4} \sin(2\pi \cdot 10^6 x - \omega t) \; Tesla$$

How will the intensity of the EM wave change if you increase the strength of the Magnetic field B_z by a factor of 4?

a) The intensity will increase by a factor of 16

b) The intensity will increase by a factor of 8

c) The intensity will increase by a factor of 4

d) The intensity will remain the same

e) Not enough information is given

Question 6

An electromagnetic wave is propagating along the positive x-direction with a magnetic field pointing along the z-direction:
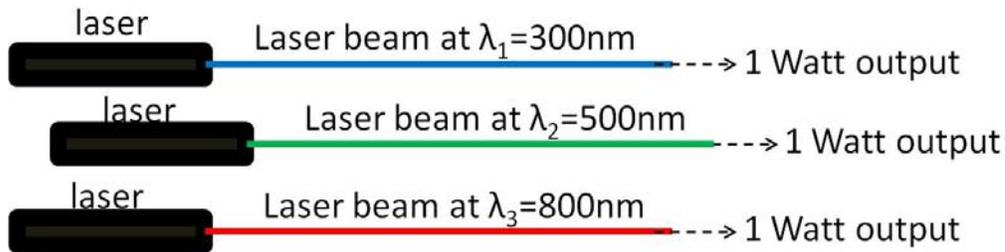
$$B_z(x, t) = 3 \cdot 10^{-4} \sin(2\pi \cdot 10^6 x - \omega t) \; Tesla$$

How will the intensity of the EM wave change if you decrease the *wavelength of the EM wave by a factor of 4*?

a) The intensity will decrease by a factor of 16

b) The intensity will increase by a factor of 16

c) The intensity will decrease by a factor of 4

d) The intensity will increase by a factor of 4

e) The intensity will remain the same

Question 7

laser
Laser beam at λ_1=300nm
---> 1 Watt output

laser
Laser beam at λ_2=500nm
---> 1 Watt output

laser
Laser beam at λ_3=800nm
---> 1 Watt output

Three laser beams have wavelengths λ_1=300nm, λ_2=500nm, and λ_3=800nm. The output power of all three lasers is **precisely 1Watt**.
Which laser emits the most energetic photons?

a) The Laser at λ_3=800nm

b) The Laser at λ_2=500nm

c) The Laser at λ_1=300nm

d) All three lasers emit photons with the same energy

Question 8

Laser beam
---> 1 Watt output
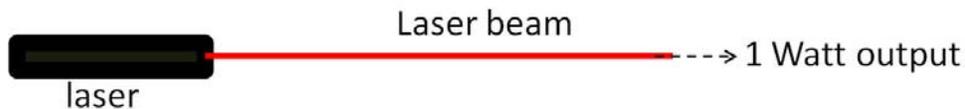
laser

The output wavelength of a laser is slowly changed from 450nm (Blue color) to 750nm (red color). While the wavelength is changed, the output power of the laser is kept precisely to 1Watt.
What can we say about the number of photons that are emitted by
the laser every second?

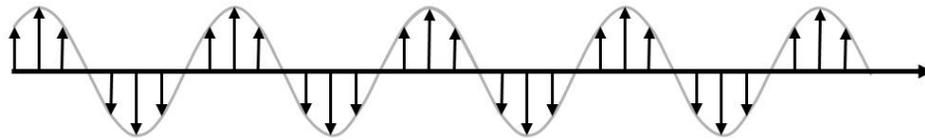a) Number of photons leaving the laser each second *decreases* as we increase λ
b) Number of photons leaving the laser each second *stays the same* as we increase λ
c) Number of photons leaving the laser each second *increases* as we increase λ
d) Not enough information is given

Question 9

$E(x,t) = E_{max}\sin(kx-wt)$ E_{max}=peak amplitude

What quantity best characterizes the energy/sec carried by the Electromagnetic wave?

a) frequency
b) wavelength (color)
c) E_{max}
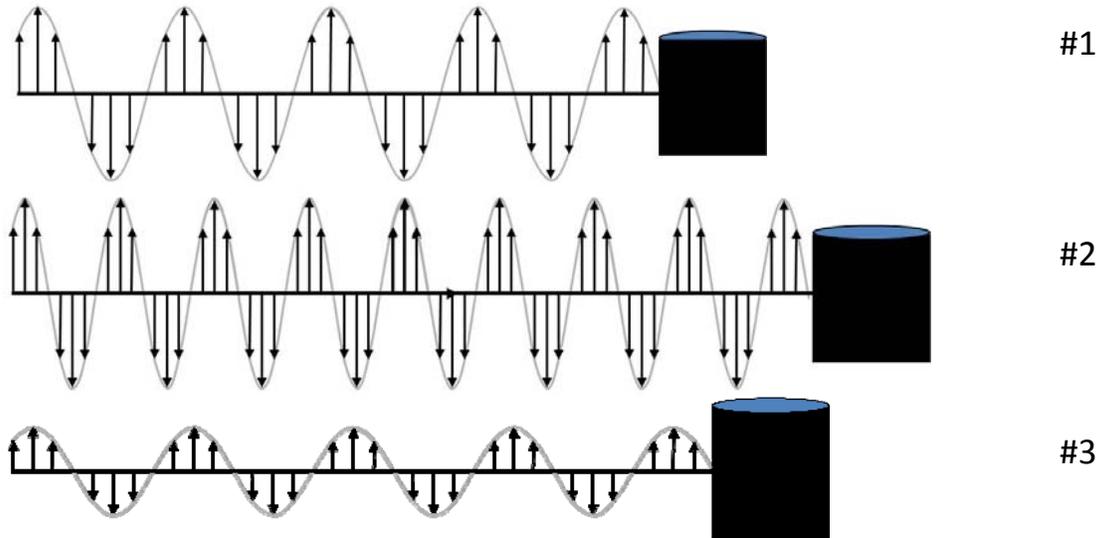d) $(E_{max})^2$
e) frequency^2

Question 10

True or False: In the absence of external forces, photons move along sinusoidal paths.

1) True
2) False

Question 11

3 Electromagnetic waves are absorbed by a dark object:

#1

#2

#3

Which barrel will heat up the fastest?

a. 2>1>3   b. 1>2>3   c. 1=2>3

d. 1=3>2   e. 2>1=3

Where, E_{max}=peak

$$E_{1max}=E_{2max}>E_{3max}$$

Question 12

Light from the sun or from a light bulb appears to be constant (i.e. the rate at which the energy reaches your eyes doesn't appear to change in time). But we know that the strength of electromagnetic waves oscillates in time. So why do we see "steady" light? Pick the best answer.

a) The oscillations of the E and B fields cancel out so it looks like the rate of energy is constant

b) The oscillations in the rate of energy flow happen so quickly that we see an average energy which is steady

c) The maximum E and B fields are <u>constant</u>

d) You are looking over a large area so all the light combined will be constant

4. In-class activities used in the experimental section for the three days

 The preparation of the in-class activities was based upon a "cognitive task analysis" of how physicists think about this material in terms of the mental models, multiple representations, related associations, and specific metacognitive processes they use with the different particular aspects of the material. The design of the activities also take into account known "naïve" student understandings or interpretations of particular aspects of this material that we were aware of from published literature or that LD and ES have observed in physics students. A full discussion of both these aspects is beyond the scope of this paper, but we have provided a brief annotation after each activity in italics to provide some guidance as to what expert-like thinking the activity is intended to stimulate the students to practice. This practice is primarily happening as the students formulate their answers and discuss the questions and answers with their fellow students and the instructor. As noted in the main text, the student questions and discussion often resulted in the coverage of material beyond what is shown in the activities presented here. There was also a few minute introduction to each class which is not reflected in the class notes shown here. We do not intend to imply that these activities are optimum. They were created by relatively inexperienced teachers as described in the main text, and with more experience with the course and the students these instructors could improve these activities.

The preparation of the experimental classes, which include class activities and reading quizzes, took roughly 20 person hours for the first class, dropping to 10 hours by the third class. Much of this preparation time was spent becoming familiar with the course material and, due to inexperience, designing activities for which there was not sufficient class time to utilize. The decrease in time required from the first to the third class is a reflection of increasing familiarity with the material and more experience with what these students could accomplish in a one hour class.

We estimate that under normal circumstances a moderately experienced instructor would require about 5hrs of preparation time per one hour class in this format. This includes: 3hrs to come up with clicker questions, activities, and reading quiz, 1hr of interview testing with one or two students, and 1hr to implement changes based on the student interview(s). Of course such material can be readily reused, in which case the preparation time would be far less.

Physics 153 Class Activities

CQ = Clicker Question
GT = Group Task

Day 1
CQ1
Which of the following is NOT one of Maxwell's Equations?

a) Gauss's Law for magnetism

b) $\dfrac{d^2 E_y(x,t)}{dx^2} = \dfrac{1}{c^2} \dfrac{d^2 E_y(x,t)}{dt^2}$

c) $\oint \vec{E} \cdot d\vec{l} = -\dfrac{d\Phi_B}{dt}$

d) Ampere's Law

Commentary: Largely factual review, but does practice expert distinction and relationship between Maxwell's equations and combination of Maxwell's equations that is the wave equation.

CQ2
Labelled 1-4 are Maxwell's equations in integral form. Labelled i-iv are the names of Maxwell's equations. Which of the following is the correct match?

1 $\oint \vec{E} \cdot d\vec{l} = -\dfrac{d\Phi_B}{dt}$ i) Ampere's Law

2 $\oiint \vec{E} \cdot d\vec{A} = \dfrac{Q_{enc}}{\epsilon_0}$ ii) Gauss's Law

3 $\oint \vec{B} \cdot d\vec{l} = \mu_0 i_{enc} - \dfrac{1}{c^2} \dfrac{d\Phi_E}{dt}$ iii) Gauss's Law for magnetism

4 $\oiint \vec{B} \cdot d\vec{A} = 0$ iv) Faraday's Law

a) 1i, 2ii, 3iv, 4iii   b) 1iv, 2ii, 3i, 4iii
c) 1ii, 2i, 3iii, 4iv   c) 1i, 2ii, 3iii, 4iv

Commentary: Factual memorization/review, not practicing expert thinking except small amount involved in translating between different mathematical representations.

CQ3
Which of the following best expresses what Gauss's Law describes?
   a) The net electric flux through an enclosed surface is proportional to the net amount of charge inside the enclosed surface.
   b) If you integrate over the electric field inside a box you get charge.
   c) The net magnetic field along a closed path is proportional to the current flowing through the closed loop.
   d) If you integrate the electric field over two parallel planar surfaces you get the charge enclosed between the two planar surfaces.

Commentary: Development of mental models of static electric and magnetic fields. Translation between representations, particularly between mathematical representation and physical models of electric and magnetic fields.

CQ4
Which of the following is true?
   a) For EM waves to exist, they must propagate in a medium with atoms. With no atoms present, the field cannot have any effect on the system and therefore can't exist.
   b) An EM wave can propagate through a vacuum.
   c) An EM wave is like a wave travelling along a rope in that it needs atoms to move up and down.
   d) An EM wave can *only* propagate in a vacuum since any medium would get in the way of its propagation.
   e) More than one of the above is true.

Commentary: Develop and test mental model of EM wave. Practice metacognitive thinking in this context.

CQ5
Which of the following are forms of the wave equation for an EM wave propagating in vacuum along the x direction?

i)
$$\frac{d^2 E_y(x,t)}{dx^2} = \epsilon_0 \mu_0 \frac{d^2 E_y(x,t)}{dt^2}$$

ii)
$$\frac{d E_y(x,t)}{dx} = \epsilon_0 \mu_0 \frac{d E_y(x,t)}{dt}$$

iii)
$$\frac{d B_z(x,t)}{dx} = \epsilon_0 \mu_0 \frac{d B_z(x,t)}{dt}$$

iv)
$$\frac{d^2 B_z(x,t)}{dx^2} = \epsilon_0 \mu_0 \frac{d^2 B_z(x,t)}{dt^2}$$

a) i and iv
b) ii and iii
c) ii
d) i
e) None of the above

Commentary: Practicing translation between mathematical representations and physical phenomena.

GT
A friend of yours reminds you that en EM wave consists of both an E and B field.

She asks you if the following electric field
$E(x,t)=100x^2 t$ Volts/m could be that of an EM wave.
Can you help? Be quantitative in your answer.

[*Hint*: Is there an equation that the electric field portion of an electromagnetic wave, E(x,t), must satisfy?]

Commentary: Recognize relationship between form of solution and its origin.

Day 2
CQ1
Which of the following are types of electromagnetic waves, just like the light coming from our sun?

    a) FM radio (i.e. Signal picked up by your car)
    b) Microwave (i.e. Popcorn)
    c) Infrared (i.e. Night vision goggles)
    d) X-rays (i.e. I just broke my leg)
    e) all of the above

BONUS: ⬤ Can you see with your eyes all EM radiation?

Commentary: Links to prior knowledge and building expert associations among previously encountered phenomena. Connect class material to real world phenomena.

CQ2
Could the following E wave function describe the electric field portion of a propagating EM wave?

$$E_y = E_{max} \cos(kx)$$

    a) Yes
    b) No
    c) Not enough information to determine this

        BONUS: ⬤ What about cos(kxt)?
                     ⬤ What about cos[k(x-vt)]?

Commentary: Translating between representations. Explicitly testing mathematical representations of physical phenomena.

GT
PhET Simulation: Radio Waves and Electromagnetic Fields
http://phet.colorado.edu/en/simulation/radio-waves
Observe the simulation of an EM wave being generated.

    1. What do the arrows show?
    2. A classmate tells you, "If I place a charge right there (see picture), the wave will pass over it and it won't affect it or apply a force on it". Do you agree with your classmate? Explain.

Point charge
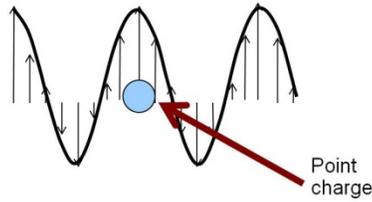
Commentary: Developing mental model, understand and apply expert representations and models to make predictions. Develop metacognitive capabilities.

CQ3

What is a source of EM waves?

a) A static charge distribution
b) A static current distribution
c) Charges moving at a constant speed
d) Accelerating charges
e) none of the above

Commentary: Developing and testing mental model, make explicit and provide feedback on known naïve interpretation.

CQ4

Someone has told you the maximum electric field strength and the electric field polarization of an electromagnetic wave. What do you know about the magnetic field?

i. Its maximum strength
ii. Its polarization
iii. Its propagation direction

a) i
b) i and ii
c) i and iii
d) ii and iii
e) all of the above
f) none of the above

Commentary: Sophisticated development and refinement of mental model, likely calling on multiple representations and self-checking in the process.

CQ5
Which of the following electromagnetic wave functions can describe a wave travelling in the negative y *direction*?

i) $\vec{E} = \hat{\imath}E_{max}\sin(ky + \omega t)$
    $\vec{B} = \hat{k}B_{max}\sin(ky + \omega t)$

iii) $\vec{E} = \hat{\jmath}E_{max}\sin(kx + \omega t)$
    $\vec{B} = \hat{\jmath}B_{max}\sin(kx + \omega t)$

ii) $\vec{E} = \hat{\imath}E_{max}\sin(ky + \omega t)$
    $\vec{B} = -\hat{k}B_{max}\sin(ky + \omega t)$

iv) $\vec{E} = \hat{\imath}E_{max}\sin(ky - \omega t)$
    $\vec{B} = \hat{k}B_{max}\sin(ky - \omega t)$

a) i   b) iii   c) iv   d) i,ii and iv   e) i and iv

Commentary: Translating between representations, relating mathematical representation to physical phenomena.

Day 3
CQ1
The frequency *f* of a laser pointer is increased but the light's *intensity* is unchanged. As a result, which of the following (perhaps more than one) are true? Explain.

i) The output power is increased
ii) Each photon has more energy
iii) There are fewer photons per second
iv) There are more photons per second

a) i
b) i and ii
c) ii and iii
d) ii and iv
e) iv

Commentary: Developing and testing mental models, building associations, confronting and providing targeted feedback on naïve understanding.

CQ2
Shown below are plots for the *energy density of an EM wave* vs. *frequency*. Think about how the energy density depends on the frequency of the wave. Which graph properly shows this relationship?

a) u, f

b) u, f

c) u, f
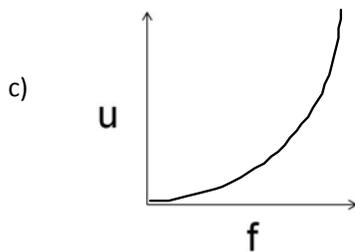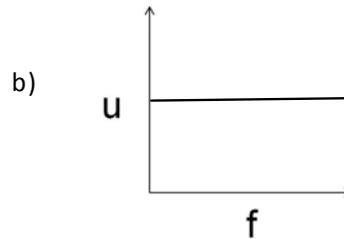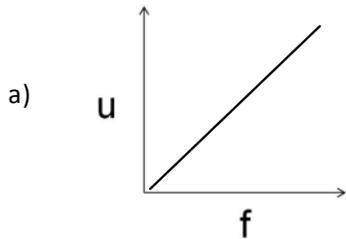
d) Not enough information to tell

e) None of the above

Commentary: Translating between representations, and in the process developing associations and refining mental model. Practicing metacognitive skill utilizing multiple representations.

CQ3
Many of you have learned in chemistry that photons are *quanta* of light. Which of the following best describes how photons and EM waves are related.

a) An EM wave is essentially made up of a single photon with frequency f; the size of which depends on the energy of the EM wave.
b) An EM wave is the sum of many photons that are all in phase.
c) An EM wave is composed of many photons where the strength of the wave depends on the energy of each photon and how many it is composed of.
d) The photons are what is moving up and down in an EM wave.
e) More than one statement is true

*Commentary: Developing mental model by addressing prior knowledge and known naïve models.*

GT

Three laser beams have wavelengths λ_1=400nm, λ_2=600nm and λ_3=800nm. The power (energy/sec) of each laser beam is the SAME at 1Watt. Rank in order, from largest to smallest:

a) The photon energies E_1, E_2, E_3 in these three laser beams. Explain your answer.
b) The maximum strength of the E fields, E_{max1}, E_{max2}, E_{max3}, in these three laser beams. Explain your answer.
c) The number of photons per second N_1, N_2, N_3 delivered by the three laser beams.

Commentary: A transfer task requiring recognition of relevant variables and use of mental model.

CQ4

Shown below are plots of energy density vs. electric field strength for an EM wave. Think about how the energy density depends on the electric field strength. Which graph properly shows this relationship?
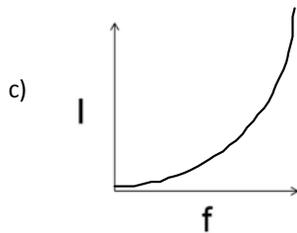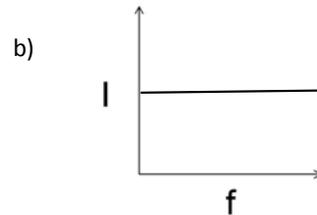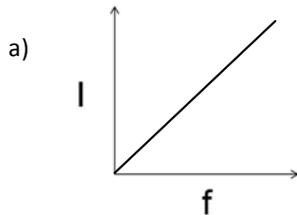
a)

b)

c)
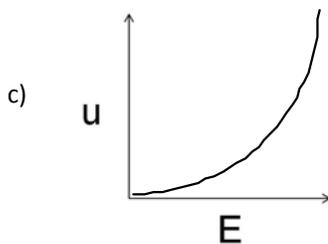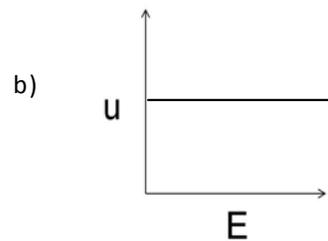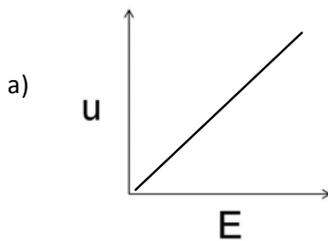
d) Not enough information to tell

e) None of the above

Commentary: Similar to CQ2

CQ5

Shown below are plots of intensity vs. frequency for a classical EM wave. Think about how the intensity depends on the frequency of the wave. Which graph properly shows this relationship?

a)

b)

d) Not enough information to tell

c)

e) None of the above

Commentary: Similar to CQ2, and addressing and providing feedback to correct known naïve thinking.

5. <u>Learning objectives agreed upon by the two instructors</u>

The learning objectives were categorized into levels of importance with A being the most important to C being less important. The test primarily covered the category A objectives. Although we believe it would be educationally beneficial to provide the students with such objectives in class before the unit, in deference to the wishes of the instructor of the control section, the students were not given the learning objectives.

After completing this module on EM waves the students should:

A

1) Be able to write down the wave equation for electric and magnetic fields.
2) Be able to describe the characteristics of a plane wave.
   a) Direction of propagation
   b) Polarization
   c) Planes of constant phase (C)
3) Be able to write the relationships between wavespeed, wavelength, frequency,

angular frequency and wave vector.

4)
   a) Given an analytical expression for an EM wavefunction (E or B), be able to represent it graphically
   b) Be able to correctly interpret all of the features of the representation when plotted as a function of time or space, *i.e.* Amplitude corresponds to field strength, being able to identify wavelength, frequency etc (see 3)
5) Be able to write down the relationship between polarizations of the E and B fields of an EM wave and its direction of propagation.
6) Be able to identify the equation of energy density of an EM waves in terms of E and B and in terms of just E, *i.e.* know that it goes at E^2 and doesn't depend on frequency
7) Be able to contrast EM waves with mechanical waves
   a) Compare how energy depends on critical parameters such as amplitude and frequency
   b) Compare physical interpretation of their oscillating amplitude
   c) Appreciate the fact that EM waves propagate in a vacuum.
8) Be able to give a basic description of how EM waves are related to photons.
   a) Be able to contrast the energy dependence on critical parameters for EM waves and photons.
   b) For an EM wave with a given intensity, be able to identify how many photons of a given frequency it is composed of.
9)
   a) Be able to write the Poynting vector in terms of E and B.
   b) Be able to describe how the intensity is related to the Poynting vector
   c) Be able to give a basic description of what the Poynting vector represents.

B

1) Be able to identify Maxwell's Equations by name.
2) Be able to test whether **scalar** E and B wavefunctions for an electromagnetic wave satisfy the wave equation.
   a) Given an E and B equation plug it into the wave equation and check that the sides of the equation equate.
3) Be able to identify a set of **vector** E and B wave functions that properly describe an EM wave propagating in a given direction.
   a) Use right hand rule

C

1) Qualitatively be able to explain the meaning of Gauss' Laws, Faradays Law and Ampere's Law
2) Be able to identify the terms in Maxwell's Equations that lead to the wave equation (*i.e.* Plane wave light propagation)

3) Be able to give examples of transverse waves. Contrast transverse waves with longitudinal waves.
4) Give examples of how we experience the energy of EM waves in everyday life.
   a) Ex. From the sun get: heat, can power solar cells etc
   b) Ex. Need batteries to power flashlight
   c) Etc.
5) Be able to identify points of equal phase along on a wave.

6. <u>Hawthorne effect discussion</u>

It is not the intention of this paper to review the Hawthorne effect and its history, but we comment on it only because this is such a frequent question raised about this work. It is not plausible that it resulted in a significant impact on the results reported here.   As discussed extensively in (*S1-S3*), analyses of the methodology and data used in the original Hawthorne plant studies reveal both serious flaws in the methodology, and an absence of statistically significant data supporting the existence of the claimed effect. Thus, the failure to replicate such an effect in an educational setting, as reported in (*S4*), is not surprising.

Even if the Hawthorne effect were true, namely that people engaged in routine tasks will improve performance when conditions are changed in any manner, it would not be very relevant to this experiment. If one examines the typical daily activities of these students, the differences introduced by this experiment are not a significant increase in the variety of their educational experiences. These students are going to a variety of classes every day. These classes incorporate both a wide variety of subjects and instructional styles. They have large and small lecture courses, seminar courses, instructional labs, recitation sections, and project lab courses, all with various types of individual and group assignments. So while this experiment is introducing change in the student experience in one particular course (3 total hours per week) it provides little incremental novelty to their overall daily educational experience.

Finally, there have been several other full length physics courses at UBC transformed following the same design as discussed here. Those courses had much higher attendance and engagement for the entire term than is typical for other UBC physics courses including previous offerings of those courses. The attendance was similar or higher than what was observed in the experimental section in this work, and the engagement appeared to be similar. There were no control groups for those courses that can be used for learning comparisons however. This indicates that the level of attendance and engagement reported here were due to the instructional design and not merely due to the one week novelty.

7. **List of proven teaching practices used**

The instruction in this experiment incorporates variants on many established active learning instructional techniques. These include Just In Time Teaching (*S5*), Peer Instruction (*S6)*, some elements of Scale Up (*S7*), use of clicker question practices to facilitate student thinking and effective feedback as discussed in (*S8*) and (*S9*), some elements of Interactive Lecture Demonstrations (*S10*), group work (*S11*) and numerous other references), and the use of interactive simulations (*S12*). See also (*S13*) for a more extensive set of references on these teaching practices.

Supplemental references

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