In-between Multiple-Choice and Free-Response: Large-scale Assessment for Upper-division Physics?

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Outline

• The Colorado Upper-division Electrostatics Diagnostic (CUE)
  o Outcomes
  o Limitations

• The Multiple-choice CUE
  o Motivation
  o Development

• Preliminary Results

• Future work
Conceptual Assessment in Upper-division Physics

- Challenges
  - Increased importance of mathematical content
  - More focus on reasoning & problem-solving skills

The Colorado Upper-division Electrostatics Diagnostic\(^5\) (CUE)

Do **NOT** solve, but “give the **EASIEST** method you would use to solve” and “why”

Q1. An insulating sphere with radius R, with a voltage on its surface \(V(\theta) = k \cos(3\theta)\). Find \(\vec{E}\) or \(V\) inside the sphere at point P.

The CUE is sensitive to different types of instruction

- **Traditional Lecture** (N=259, 9 Courses)
- **Interactive Engagement** (N=265, 10 Courses)
Conceptual Assessment in Upper-division Physics

Limitations of the CUE

- Complex grading rubric
- Graders training required
- Time consuming and impractical for most faculty
- Limits scalability

Q1. **5 points total.**

<table>
<thead>
<tr>
<th>Correct Answer</th>
<th>3 points</th>
<th>Correct answer is separation of variables. Full credit for Laplace’s Equation +2.5 for “Legendre polynomials” +2 point if implies sep. of var. without being explicit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation</td>
<td>2 points</td>
<td>Typically give full credit.</td>
</tr>
<tr>
<td>Mistake Code</td>
<td></td>
<td>A – integrate or direct integration \nB – Gauss \nC – N/A \nD – E = -grad V \nX – Blank \nZ – “Don’t know”</td>
</tr>
</tbody>
</table>

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Developing a Multiple-choice CUE

- **Standard multiple-choice**
  - 1 unambiguously correct response
  - 3-5 clearly incorrect (though tempting) distractors

- **Multiple True/False**
  - 4-6 statements per question
  - Each statement marked True or False

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Developing a Multiple-choice CUE

The free-response rubric\(^5,7\)
Many common student responses

Student responses
Additional common responses
Wording of the distractors

Student Interviews
Students correctly interpreting the questions
Refined phrasing of the distractors

Q1. An insulating sphere with radius $R$, with a voltage on its surface $V(\theta)=k \cos(3\theta)$. Find $\vec{E}$ or $V$ inside the sphere at point $P$.

The easiest method would be ... because... (select ALL that support your choice of method)

Select only one:

A. Direct Integration
B. Gauss’s Law
C. Separation of Variables
D. Multipole Expansion
E. Ampere’s Law
F. Method of Images
G. Superposition
H. None of the Above

- a. $\blacksquare$ you can calculate $\vec{E}$ or $V$ using the integral form of Coulomb’s Law
- b. $\blacksquare$ symmetry allows you to calculate $\vec{E}$ using a spherical Gaussian surface
- c. $\blacksquare$ the boundary condition is azimuthally symmetric (i.e., symmetric in $\phi$)
- d. $\blacksquare$ there is not appropriate symmetry to use other methods
- e. $\blacksquare$ you can use $\vec{E}(\vec{r}) = -\nabla V(\theta)$ and evaluate this at point $P$
- f. $\blacksquare$ $\nabla^2 V=0$ inside the sphere and you can solve for $V$ using Legendre Polynomials

If you would like to elaborate further, please do so below.
Q1. An insulating sphere with radius R, with a voltage on its surface $V(\theta) = k \cos(3\theta)$. Find $\vec{E}$ or $V$ inside the sphere at point P.

**The easiest method would be ...**

Select only one:

A. Direct Integration  
B. Gauss’s Law  
C. Separation of Variables  
D. Multipole Expansion  
E. Ampere’s Law  
F. Method of Images  
G. Superposition  
H. None of the Above

**because...** (select ALL that support your choice of method)

a. ☐ you can calculate $\vec{E}$ or $V$ using the integral form of Coulomb’s Law  
b. ☐ symmetry allows you to calculate $\vec{E}$ using a spherical Gaussian surface  
c. ☐ the boundary condition is azimuthally symmetric (i.e., symmetric in $\phi$)  
d. ☐ there is not appropriate symmetry to use other methods  
e. ☐ you can use $\vec{E}(\vec{r}) = -\nabla V(\theta)$ and evaluate this at point P  
f. ☐ $\nabla^2 V = 0$ inside the sphere and you can solve for $V$ using Legendre Polynomials

If you would like to elaborate further, please do so below.
Q1. An insulating sphere with radius R, with a voltage on its surface \( V(\theta) = k \cos(3\theta) \). Find \( \vec{E} \) or \( V \) inside the sphere at point \( P \).

**The easiest method would be ...**

Select only one:

A. Direct Integration
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G. Superposition
H. None of the Above

**because...** (select ALL that support your choice of method)

a. \( \square \) you can calculate \( \vec{E} \) or \( V \) using the integral form of Coulomb’s Law
b. \( \square \) symmetry allows you to calculate \( \vec{E} \) using a spherical Gaussian surface
c. \( \square \) the boundary condition is azimuthally symmetric (i.e., symmetric in \( \phi \))
d. \( \square \) there is not appropriate symmetry to use other methods
e. \( \square \) you can use \( \vec{E}(\vec{r}) = -\nabla(k \cos 3\theta) \) and evaluate this at point \( P \)
f. \( \square \) \( \nabla^2 V = 0 \) inside the sphere and you can solve for \( V \) using Legendre Polynomials

If you would like to elaborate further, please do so below.
Preliminary Results

How do the free-response and multiple-choice versions compare?

- 1 upper-division electrostatics course
- Half took the free-response version, half took the multiple-choice, (N=25 each)

<table>
<thead>
<tr>
<th></th>
<th>Multiple-Choice</th>
<th>Free-Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score (%)</td>
<td>58.9 ± 3.5</td>
<td>60.5 ± 2.8</td>
</tr>
<tr>
<td>Time (min)</td>
<td>35 ± 1.6</td>
<td>37 ± 1.6</td>
</tr>
</tbody>
</table>

(Student’s t-test, p=0.7)
Future Work

• Further testing at additional institutions (You can help!)
  - Increased statistical power
  - More robust measures of validity and reliability
  - MC CUE’s sensitivity to different types of instruction (i.e., Traditional lecture vs. Interactive engagement)

• Insight into student thinking with the new format
Questions

For more information
or to give the MC CUE,

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