Motivation of Physics Students’ Self-Checking Behavior

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ABSTRACT

For an investigation into physics students' mathematical difficulties, we have administered written diagnostic tests to over 4000 students. Students' responses to elementary questions on trigonometry, algebra, and graphing reflected a large number of operational errors, to a degree that could significantly interfere with success in an introductory physics course. However, individual problem-solving interviews with students revealed that, when simply asked to explain their solutions to the problems, students would very frequently discover and correct a large proportion of their errors with no additional input from the interviewer. Consequently, we propose that integrating multiple "self-checking" steps into guided quantitative problem-solving exercises may help habituate students to perform simple checks that could significantly impact their problem-solving success.

PHYSICS STUDENTS’ PERFORMANCE ON MATHEMATICS PROBLEMS

- We administered and analyzed a written mathematics diagnostic, given to over 4000 students in algebra- and calculus-based physics classes over seven semesters at Arizona State University during 2016-2019.
- We carried out individual interviews with 75 students enrolled in those or similar courses during the same period. (Primary interviewer: Matthew Jones.) Error rates observed during interviews were *significantly lower* than average values observed on written diagnostics.
- We found that 35-70% of students were confused on basic trigonometric relationships, and up to 90% (in the first-semester algebra-based course) made significant errors on algebra problems with simultaneous equations.
- The various errors observed could severely impact students’ performance in physics courses, depending on how heavily the courses weight quantitative problem-solving skills.

PRIMARY SOURCES OF DIFFICULTIES

- Skill-practice deficit: Insufficient repetitive practice with learned skills
- Inability to efficiently access previous learning
- Carelessness: Critical errors due to inadequate attention to detail, momentary forgetfulness, intermittent confusion

KEY INTERVIEW FINDINGS

- Nearly half (26/56) of students’ algebra errors were self-corrected by students following minimal (or no) prompts by the interviewer.
  - 20% of errors were auto-corrected with *no* specific instructor prompts
- More than 70% of students’ trigonometry errors were self-corrected.

Trigonometry Questions

with samples of correct student responses

(interview questions were slightly different)

Correct Response Rate, #1-3 combined

ASU Polytechnic campus, Spring + Fall

Algebra-based course, 1st semester, (N = 116): 37%

Algebra-based course, 2nd semester, (N =79): 48%

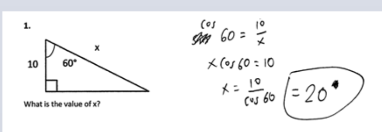
ASU Polytechnic campus, Spring

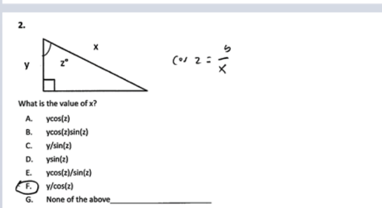
Calculus-based course, 1st semester, (N = 146): 66%

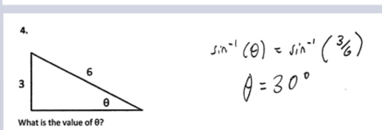
Errors observed:

(i) use of incorrect trigonometric function (e.g., cosine instead of sine), or misunderstanding of definition;

(ii) unaware (or forgot) about inverse trigonometric functions, e.g., arctan, arcsin, arccos [$\tan^{-1}$, $\sin^{-1}$, $\cos^{-1}$]







STUDENT SELF-CORRECTION OF ALGEBRA ERRORS

Our Interview Findings: Almost half of students’ errors on algebra problems were self-corrected by students during interviews, as a consequence of interviewer prompts or unprompted auto-correction.

Prompts Leading to Self-Correction

- *“Explain that step”*
- *“Clarify what you mean.”*
- “*What does the problem ask you to do?”*
- *[No specific prompt: Students asked to explain all work]*

Algebra: Simultaneous Equations

Interview Results; N = 53

Numerical Version

$3x = 2y$

$5x + y = 26$

What are the values of x and y? Show all your steps. For example, $x = 2$, $y = 5$ (These are NOT the correct answers).

Correct:	**83%**
Error, Self-corrected:	**9%**
Error, Uncorrected:	**8%**

“Semi-Symbolic” Version

$x \cos(20°) = y \cos(70°)$

$x \cos(70°) + y \cos(20°) = 10$

What are the values of x and y? Show all your steps. Note: The value for x should NOT include y, and the value for y should NOT include x.

Correct:	**57%**
Error, Self-corrected:	**19%**
Error, Uncorrected:	**25%**

Symbolic Version

ax = by

bx + ay = c

a, b, and c are constants.

What are the values of x and y in terms of a, b, and c? Show all your steps. Note: The value for x should NOT include y, and the value for y should NOT include x.

Correct:	**55%**
Error, Self-corrected:	**21%**
Error, Uncorrected:	**25%**

Almost 50% of algebra errors were self-corrected.

Over 70% of trigonometry errors were self-corrected!

Common Errors with Mathematical Operations (see Booth et al., 2014)

Negative Sign, e.g., moving a term without changing its sign; deleting or adding a negative sign;

Equality, e.g., performing operations without maintaining balance on both sides of an equals sign;

Mathematical Property, e.g., inappropriately applying the distributive property;

Fraction, e.g., moving a term from the numerator to the denominator or vice versa.

All of these observed in our investigation

Why the Difficulties with Symbols? Some Hints From the Interviews

- In elementary math courses, “simplified forms” of equations are emphasized (i.e., few messy symbols and functions)
- Students get “overloaded” by seeing all the variables, and are unable to carry out procedures (e.g., multiplying each term in an expression by a constant [symbol]) that they do successfully with numbers (e.g., multiply through by a number)
- Other procedural failures that occur more often with symbols: cancellation, factoring out a constant, retaining coefficients from one line to the next

MOTIVATIONAL ISSUES

- Many, if not most, introductory physics students have little experience and skill with consistent, systematic self-checking behaviors.
- The potential for performance improvements is great if instructors can find ways of stimulating self-checking behaviors and motivating students to practice and sustain these behaviors.

SUMMARY AND IMPLICATIONS FOR PHYSICS INSTRUCTORS

- Some mathematical difficulties relate to relatively narrow, well-defined procedures and *may* be subject to significant improvement by short-term, targeted instruction (e.g., trigonometry).
- Other difficulties (e.g., algebraic operations) are likely to be more long-standing, resistant to quick improvement, and not easily addressable within college physics courses themselves.
- An alternative approach, potentially yielding high return (on improvements in student performance) relative to input (of targeted instruction): Guidance to strengthen physics students’ self-checking, “care-taking” skills, with various prompts directing them to restate, review, and re-think key steps in their work.

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