# *Doing Science or Doing a Lab? Engaging Students with Scientific Reasoning During Physics Lab Experiments*

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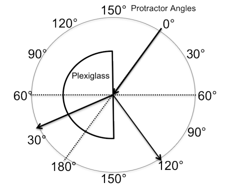
## THE LAB: CONTEXT

This study involved 136 students in a two-semester first-year physics lab course at the University of British Columbia. The learning goals in the course focus exclusively on developing "skills at acquiring data, understanding the nature of uncertainty in measurements, and developing statistical and graphical methods for evaluating the data" (p. 2).[1]

A series of studies had previously been conducted in the lab to target how students learn particular data handling skills. There had been little explicit instruction, however, on evaluation of higher level scientific reasoning skills. This study was conducted to assess whether students were engaging in authentic scientific sensemaking when confronted with disagreements between different measurements of the same quantity.

## THE LAB: INDEX OF REFRACTION



Orientation of the plexiglass prism (semicircle) and the fixed protractor angles can be seen on the left. The incident beam (fixed) entered along the 0° line and the prism was rotatable to orient the position of the normal and, hence, the angle of incidence.

### Snell's Law (SL)

Using an incident angle of 60°, measure the refracted angle and determine *n* from Snell's Law:

$$n = \frac{\sin(\theta_{incident})}{\sin(\theta_{refracted})}$$

### Total Internal Reflection (TIR)

Measure the critical angle of incidence beyond which the incident beam is totally reflected with no refracted beam and determine *n* from:

$$n = 1/\sin(\theta_{critical})$$

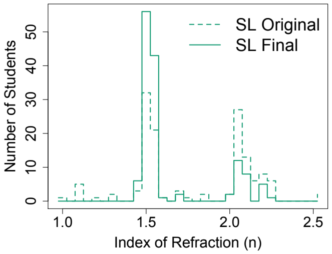
### Brewster's Angle (BA)

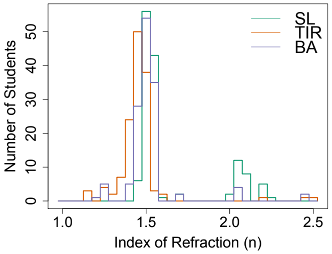
Use a polarizer to determine *n* using Brewster's angle (BA), the angle of incidence at which the reflected beam is completely polarized:

$$n = \tan(\theta_{Brewster's})$$

| | Expert | | Systematic Error | |
|---|---|---|---|---|
| | Measurement | Calculated n | Measurement | Calculated n |
| Snell's Law | $\Theta_{refracted}$ = 35.7°±0.5° | n = 1.48±0.02 | $\Theta_{systematic}$ ≈ 24° | n ≈ 2.13 |
| TIR | $\Theta_{critical}$ = 42.5°±0.5° | n = 1.48±0.01 | $\Theta_{systematic}$ ≈ 45° | n ≈ 1.41 |
| Brewster's Angle | $\Theta_{brewster's}$ = 56°±1° | n = 1.48±0.06 | | |

## WHAT STUDENTS DID



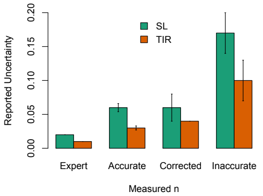


We extracted students' values from their lab books for analysis, including original and final values if changes were made to measurements during the lab.

- •49% of students made the SL systematic error
- •58% of the students who made the SL error corrected it
- •20% of students reported the systematic error as their final value
- •60% of students made the TIR systematic error
- •Only 2 students corrected the TIR systematic error

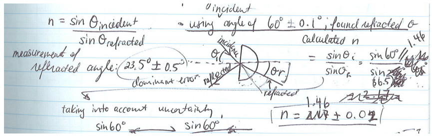
The difference between reflecting in TIR and SL may simply be due to the relative sizes of the disagreements.

In fact, students greatly inflated their uncertainties (at least twice as large as the precision obtained by TAs), especially if their values were inaccurate (about twice as high as accurate or corrected measurements). This inflation often meant that the TIR measurement agreed with the other two within uncertainty ranges.



## HOW THEY REFLECTED

In many cases, students changed their values of *n* during the lab, often to correct systematic errors. Rather than explaining how or why they changed their measured values, students crossed out the initial value and replaced it with the new one. No students provided clear and distinct descriptions of how they managed to correct their errors.



n = sin θincident / sin θrefracted

θincident
- using angle of 60° ± 0.1°; found refracted θ

measurement of refracted angle: 23.5° ± 0.5°

dominant error

incidence

θi

reflected

θr

refracted

Calculated n = sinθi / sinθR = sin60° / sin 36.5° 1.46

1.46 ~~2.17~~

taking into account uncertainty

sin60° ↔ sin60°

n = ~~2.17~~ ± 0.0~~4~~2

✳ Comparing all three measurements and checking agreement
✳ Talking to other groups and comparing values
✳ Calculating the expected angle using *n* from a previous measurement
But many students thought that this was cheating!

## WHY THEY DIDN'T REFLECT

A possible explanation is that students did not have enough time to complete the lab and reflect on their results. This was not the case for this lab, though. In fact, 75% of students had left the lab with 45 minutes remaining and no students stayed working for the full 3 hours. Previous labs were often short on time, however, and interviews suggested that students may have gotten used to rushing their work. Other explanations for why students did not reflect elicited from student interviews and in-class observations include:

✳ Habits of not reflecting due to previous time crunches

*"Stop thinking and write something down"*

✳ Following algorithms for assessing agreement between values[3]

*Procedure did not involve reflecting on what it means for nominally equivalent values to disagree*

✳ Inflated uncertainties hide inaccuracies

*Student Uncertainties >> TAs Uncertainties*

*Uncertainties for Inaccurate Measurement >> Accurate Measurements*

✳ Value agreement over quality measurement

*"Didn't try to be accurate, tried to be safe"*

✳ Student error

*"Surprised by how close the values were"*

*The plexiglass was just "a lump of acrylic"*

✳ Lack of value for reflection

*All students tried to hide the original mistakes, rather than focusing on how they managed to correct them.*

## MAKING THE LAB MORE SCIENTIFIC

✳ Experiments use high-quality equipment capable of accurate and precise measurements
✳ Ample time and support to reflect in each lab
✳ Experience where reflection improves measurement quality
✳ Placing assessment emphasis on lab process over final product and increased emphasis on quality of measurements and explanations
✳ Explicit support to develop different sensemaking strategies

## REFERENCES

[1]J. Day, and D.A. Bonn, Physical Review Special Topics – Physics Education Research **7**, 010114 (2011).

[2]T.S.Volkwyn, S.Allie, A.Buffler, and F.Lubben, Physical Review Special Topics – Physics Education Research **4**, 010108 (2008).

[3]B.M. Zwickl, N. Finkelstein, and H.J. Lewandowski, in *AIP Conference Proceedings*, **1513**, 442-445 (2012).