# The relationship between visual skill and student difficulty expressing a distance in terms of wavelength


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## Introduction

Waves are a fundamental topic in introductory physics and understanding wave properties (frequency, velocity, wavelength, amplitude) and wave phenomena (reflection, refraction, superposition, interference) are important for more advanced study in physics.

Previous work revealed that students have difficulty expressing a physical distance in terms of wavelength (λ).[1] This is a basic skill without which students cannot successfully complete interference tasks, but a main reason for this difficulty has not yet been identified.

We hypothesize that students' visual-spatial skills may underlie the difficulty expressing distance in terms of wavelength because (1) waves are an abstract concept and (2) waves are in motion and can change shape.

Visual-spatial skill is the ability to understand, create, and manipulate mental images.[2,3] While it is known that on average physicists have higher visual skills than the general population, little work has been done on how visual ability affects performance on specific tasks or topics in physics.[2,3]

## Objectives

1. Examine impact of visual-spatial skills on ability to express distance in terms of wavelength.
2. Develop methodology which can be used to determine whether a problem or topic requires application of visual-spatial skills.

## Methods

**Student population:** Calculus-based introductory physics students at NDSU or UW.

**Paper Folding Test (PFT):** Twenty-item assessment used to measure a student's visual-spatial skills.[4] It measures the capacity of a student's visuo-spatial sketchpad, the part of their working memory that processes visual information.[2]

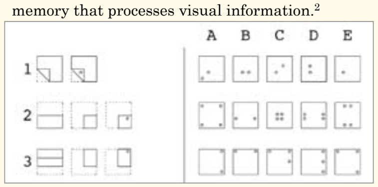
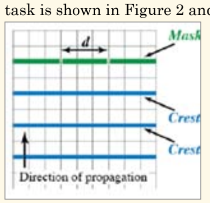



**Figure 1: Portion of the Paper Folding Test** Students are asked to choose the picture on the right (A-E) that represents what the paper on the left would look like when unfolded.

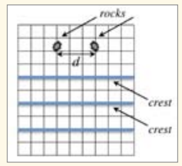
## Objective 1: Tasks

All four tasks pictured below were given to students on pre-tests. The question accompanying each picture was presented in multiple choice format (eight answer options given), but students were also asked to explain their answer choice. The original slit separation task is shown in Figure 2 and Figures 3-5 are variations on the original task. Correct answer for Fig 2-4 is d=1.5λ; for Fig 5 AB=2.5L.



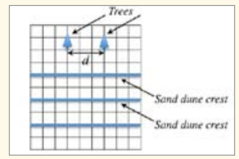

Correct reasoning: 38%

**Figure 2: Slit Separation Task** A dowel moves up and down in a tank of water creating a periodic wave. Students are asked to: *Determine the distance between the slits , d, in terms of the wavelength λ.*



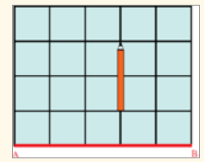

Correct reasoning: 55%

**Figure 3: Rocks Task** A pilot measures the distance between the rocks in a bay that has parallel rows of waves. Students are asked to: *Determine the distance between the rocks, d, in terms of the wavelength λ.*




Correct reasoning: 53%

**Figure 4: Dunes Task** A pilot measures the distance between two trees in a desert that has rows of parallel sand dunes. Students are asked to: *Determine the distance between the trees, d, in terms of the spacing of the sand dune crests, s.*




Correct reasoning: 85%-95%

**Figure 5: Pencil Task** Students are asked to: *Determine the width (AB) of a piece of paper in terms of the length, L, of the pencil.*

## Objective 1: Results

All tasks require the same skills. Students:

- successfully answer the *Pencil* task, yet they perform much worse on the *Slit Separation* task.
- are more successful on the *Rocks* and *Dunes* tasks which are asked in a more everyday context than the original *Slit Separation* task.
- perform similarly on tasks with and without motion (*Rocks* and *Dunes* tasks, respectively).

There is a statistically significant difference in the PFT scores between the students who had correct reasoning on the original slit separation question and those who had incorrect reasoning.

| | | |
|---|---|---|
| <PFT Score>: Correct Reasoning | 15.97 | P-value: |
| <PFT Score>: Incorrect Reasoning | 14.91 | 0.02 |
| Difference in <PFT Scores> | 1.06 | |

**Table 1: PFT scores and t-test result for the original slit separation task**

## Objective 2: Tasks

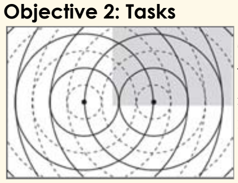


**Figure 6: Two-Source Task** Given to students on final exam.

**Question Sequence**:
Two point sources in phase generate water waves in a big tank of water. The solid circular lines represent crests; the dashed lines, troughs.

**A.** For the region *far away* from the sources, determine the angle at which the *first* nodal line occurs. Explain your reasoning.
Correct answer: **$\Delta D = d \sin\theta$ ; $\Delta D = \lambda / 2$ ; $d = 2\lambda$ ; therefore $\theta = 14.5°$**

A **single** change is made to the **original** setup. After the change is made, will the first nodal line (at the location you determined in question A) become *a line of maximum constructive interference, a nodal line, or neither*? Explain.

**B.** The speed of the waves in the tank is decreased by a factor of 2 ($v_{modified} = v_{original}/2$).
Correct answer: **v decreases by 2, so does λ ; now $d = 4\lambda$ ; $\Delta D = 4\lambda \sin(14.5) = \lambda$ ; therefore it is now a line of maximum constructive interference**

**C.** The rate at which the sources tap the surface of the water is halved ($f_{modified}=f_{original}/2$).
Correct answer: **f decreases by 2, λ doubles; now $d = \lambda$ ; $\Delta D = \lambda \sin(14.5) = \lambda / 4$ ; therefore it is now neither**

## Objective 2: Results

| | Q. A | Q. B | Q. C |
|---|---|---|---|
| <PFT Score>: Correct Reasoning | 16.0 | 16.1 | 16.1 |
| <PFT Score>: Incorrect Reasoning | 14.9 | 14.8 | 14.4 |
| Difference in <PFT Scores> | 1.1 | 1.3 | 1.7 |
| P-Value | 0.01 | .006 | .0004 |

**Table 2: Average PFT scores and t-test results for each question in the two-source sequence**

For each question, there is a statistically significant difference in the PFT scores between *Correct reasoning* and *Incorrect reasoning* categories.

| Code Description | Avg PFT |
|---|---|
| Corr answer, used formula and drew no pic | 15. 5 |
| Corr answer, used formula and drew corr pic | 17. 7 |

**Table 3: Average PFT scores for two groups of student reasoning on question A**

Students who answered the question correctly by using the formula and drawing the correct picture had an average PFT score more than two points higher than the average score of students who answered correctly by using the formula alone.

| Code Description | Avg PFT |
|---|---|
| Corr answer, identify change in λ and how ΔD changes | 16.1 |
| Incorr answer, trouble with v, f, λ relationship ($v=f\lambda$) | 15.1 |

**Table 4: Average PFT scores for two groups of student reasoning on questions B and C**

The difference in average PFT scores between these two reasoning groups suggests that understanding the relationship between λ, v, and f may require higher visual-spatial skills.

## Conclusion

1. Our current methodology for determining whether a problem requires application of visual-spatial skills is to:
   - Code student responses by the reasoning used.
   - Compare the average PFT scores between the *Correct reasoning* and *Incorrect reasoning* categories.
   - Calculate and compare average PFT scores of the different reasoning groups.
2. We have **consistently** seen a statistically significant difference in PFT scores between students with correct reasoning and those with incorrect reasoning on a number of waves tasks. The differences in scores are between 5% and 8.5%. The instructional implications of these findings are still unclear.
3. Further examination of student difficulty expressing d in terms of λ reveals that students have the basic skills necessary to express d in terms of a non-standard unit (such as a pencil), but they do not spontaneously transfer those skills to tasks when the unit of measure is intangible.

## Future Directions

- Invention Tasks- have students draw out the situation described in the slit separation task rather than giving them the picture. This could help us gain further insights into the 1-2 point difference between groups on the PFT.
- Investigate the impact of spatial reasoning skills on student understanding of the relationship between λ, v, and f.
- Create tasks to explore further the effect of the intangibleness of a unit of measure and student difficulty expressing d in terms of λ.
- Use the proposed methodology in other contexts in order to refine it.

## References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4. R.B. Ekstrom, J.W. French, H.H. Harman, and D. Dermen, *Manual for Kit of Factor-Referenced Cognitive Tests* (Educational Testing Service, Princeton, NJ, 1976), p. 173-179.


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