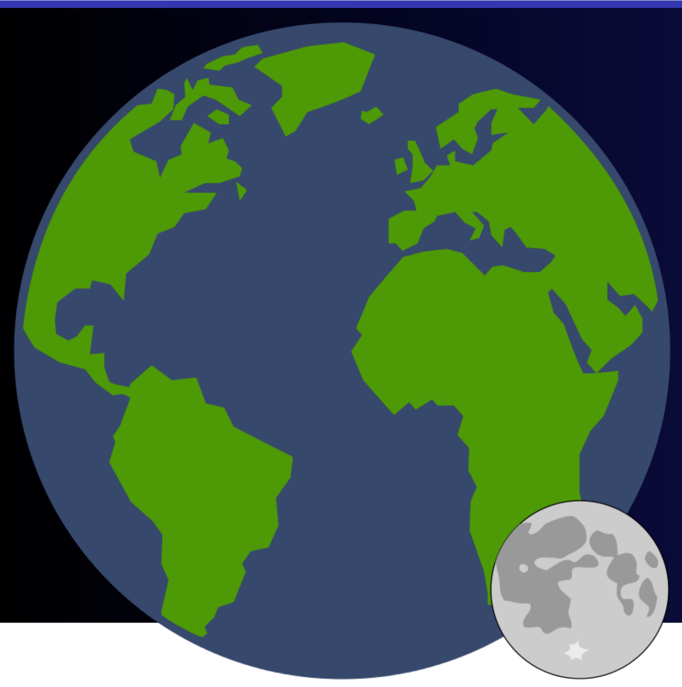

Probing student understanding of size and distances in the universe

Vinesh Rajpaul,*
Christine Lindstrøm, Megan C. Engel

* PhD student in astrophysics @ University of Oxford; vinesh.rajpaul@astro.ox.ac.uk

(I) Introduction

We adapted and translated the Introductory Astronomy Questionnaire (IAQ) into Norwegian. (IAQ reference: PRST-PER, **10**, 020126.)

Our instrument, the Norwegian IAQ (hereafter NIAQ), probed three main areas of interest, using a combination of free-response writing, multiple-choice responses, and ranking tasks:

- student motivation and views on astronomy and physics;
- astronomy content;
- worldview and scientific thinking.

The NIAQ was targeted at:

- 41 pre-service teachers at the largest teacher education institution in Norway, before and after astronomy instruction;
- 922 students from eight middle schools in Norway, before ($N = 535$) and after ($N = 387$) astronomy instruction.

We focus here on a ranking task that sought to probe student understanding of sizes and distances in the universe.

(II) A distance ranking task

In one question, students were asked to rank the following items in terms of their distance from the *Earth's surface*: center of the Milky Way; edge of the observable universe; the asteroid belt; edge of the Solar System; the Moon; the Sun; the star Polaris; the ozone layer; center of the Earth; Neptune.

This distance ranking task's design was informed by a similar question piloted and then used in an introductory, undergraduate astronomy course at the University of Cape Town.

(Another question in the NIAQ, not considered here, asked students to rank the following in terms of *size*: galaxy; planet; star; universe; solar system.)

(III) Why might such a task be useful?

Students cannot rely strictly on memorized answers, formulae substitutions, etc.

One can obtain a wealth of information from a seemingly-simple task: for a 10 item ranking task, there is one correct solution, and approximately 3.6 million possible incorrect solutions → broad spectrum of possible responses.

One can analyse the spectrum of responses from thousands of students very quickly (using fairly simple computer code), e.g. to:

- identify most problematic items (in isolation);
- identify most problematic relationships (via pair-wise comparison).

Similar methodology could be used to probe students' understanding of:

- sizes and distances on various scales, e.g. microscopic rather than astronomical;
- different topics involving categorization, e.g. energy scales in physics;
- process sequences, e.g. stellar evolution, evolution of the early Universe.

(IV) Illustrative results: middle school students

Below: results for $N = 766$ middle school students (448 before and 318 after instruction; combined here, given similarity of the results) on the distance ranking task. All items were to be ranked in terms of distance from the Earth's surface. The upper table shows, for each item, student ranks vs. correct ranks (independent of other items); the lower table enumerates specific errors for *pairs* of items.

Items vs. student-assigned ranks (%)

	1 (Ozone layer)	2 (Center of Earth)	3 (The Moon)	4 (The Sun)	5 (Asteroid belt)	6 (Neptune)	7 (End of Solar System)	8 (Pole star)	9 (Centre of Milky Way)	10 (End of Universe)
Ozone layer	**38**	42	4	2	2	3	3	2	3	1
Center of Earth	52	**34**	5	3	2	2	1	0	1	0
The Moon	4	11	**62**	12	5	3	1	1	1	0
The Sun	1	4	6	**30**	28	14	8	5	2	1
Asteroid belt	1	2	4	13	**14**	15	19	17	13	2
Neptune	1	2	6	16	24	**26**	12	9	3	1
End of Solar System	0	0	1	2	3	14	**23**	21	32	4
Pole star	1	2	8	15	11	11	15	**21**	14	1
Centre of Milky Way	1	2	3	8	10	11	16	20	**25**	3
End of Universe	0	0	1	0	1	1	1	3	6	**86**

Examples to help interpret table:

the correct item to be ranked as 7th closest to the Earth's surface: end of the Solar System

1% of students ranked the ozone layer as the most distant item from the Earth's surface

23% of students correctly ranked the end of the Solar System as the 7th closest item to the Earth's surface

Specific errors: item in row more distant than item in column (%)

	Ozone layer	Center of Earth	The Moon	The Sun	Asteroid belt	Neptune	End of Solar System	Pole star	Centre of Milky Way	End of Universe
Ozone layer		59	17	14	9	12	8	13	10	3
Center of Earth			12	7	5	5	2	5	5	2
The Moon				7	10	10	3	14	9	2
The Sun					32	34	8	33	23	3
Asteroid belt						62	31	52	43	4
Neptune							9	37	30	4
End of Solar System								62	56	7
Pole star									37	4
Centre of Milky Way										6
End of Universe										

Examples to help interpret table:

59% of students said the ozone layer is further from the Earth's surface than is the center of the Earth (regardless of the absolute ranks assigned to each item)

9% of students said Neptune is more more distant from the Earth's surface than is the end of the Solar System

(V) Highlights from full results

Both before and after instruction, a significant fraction of middle school students appeared to think that:

- the radius of the Earth is smaller than the height of the Earth's atmosphere ($> 55\%$);
- the Pole star is contained within the Solar System ($> 60\%$), or is closer to the Earth than the Sun ($> 30\%$);
- the center of the Milky Way Galaxy is closer to Earth than the end of the Solar System ($> 55\%$);
- (from a different ranking task, it also emerged that $> 40\%$ of middle school students thought that planets are larger than stars).

Female middle school students performed significantly worse (made 15-20% more errors) than male middle school students, both before and after instruction.

No normalized gains were observed pre- to post-instruction for middle school students!

Pre-service teachers fared better than the middle school students pre-instruction (making approximately only half as many mistakes), and also showed nontrivial normalized gains (~30%) post-instruction.

(VI) Future work (and preview of other results)

Which teaching interventions might be useful, based on our findings?

How to address the gender stratification observed in our results?

Could collaborative ranking tasks offer potential for greater learning gains?

The ranking task (and NIAQ) has room for iterative improvement: e.g. asteroid belt was determined to be a bad choice, given its similar distance to Sun, and that this topic was not explicitly addressed in the middle school students' astronomy curricula.

Sneak-peak of a few other (preliminary) findings from the NIAQ:

- Following instruction, improvements were seen in pre-service teachers' ability to explain simple astronomical concepts (stars, planets, etc.). No improvements were seen for the middle school students.
- Astronomy instruction appeared to make no difference to the middle school students' or pre-service teachers' opinions on (i) how interesting, and (ii) how important to society physics and astronomy are, and (iii) how much there is left to discover in these fields (but these opinions did start from high baselines).
- Following instruction, pre-service teachers exhibited a shift from pedagogical, 'teacher-like' behaviour to authoritative, 'expert-like' behaviour, when prompted to provide responses to hypothetical students.

Oxford Physics · University of Oxford · The Rhodes Trust · Merton College Oxford