

Using facets in analyzing survey data from a project to investigate student concepts of quantization and the photon

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Categorization of ideas from survey:

Quantization - Energy levels

Quantization - Not energy levels

Photon vs. light

Photons are not real

Size

Shape

Producing photons

Color/frequency

Wave-particle duality

Observing/detecting photons

Photons as force carrier between objects

Slit experiments and “chopping off”

Shadows

Photons are protons (or another part of the atom)

Facets and Pprims

Facets are small ideas that describe an ordered sequence of ideas relating to a specific, larger, topic. These facets are descriptions of characteristic understanding and reasoning and are not intended to be used directly as a numerical scoring scheme.

Within a Facet Cluster, the codes ending in 9 are associated with the Facets that seem to be the most problematic. They are typically the ideas we choose to address first in our instruction. The codes ending in 0 or 1 for the units digit representing understandings that are probably okay at this introductory level. The others are roughly rank ordered between the 9 and 1. [idea from Jim Minstrell]

Pprims are the primitive student ideas underlying facets (and, as we will see, some are referred to in the facets). [idea from Andrea DiSessa]

We give below examples of facets and pprims. So far, most of the use of these has been in mechanics, but the concept is clearly expandable to other physics topics.

Facets: Minstrell's force facets

Pprims: a selection from Wittman's selection from DiSessa

Minstrel's Facets

Example—forces

400 Dynamics: Forces & Interacting Bodies

Identifying Forces (401 — 409)

Forces to Explain the At Rest Situation (410 — 419)

Forces to explain constant velocity (420 — 429)

Forces to Explain Linear Accelerated Motion (430 — 439)

Resistive Force by a Fluid Medium (440 — 449)

Rubbing Resistance by a Surface (450 — 459)

Vector Resolution of Forces (460 — 469)

Forces During Interactions

- 470 All interactions involve equal magnitude and oppositely directed action and reaction forces that are on the separate interacting bodies.
- 474 Effects (such as damage or resulting motion) dictate relative magnitudes of forces during interaction.
- 474-1 At rest, therefore interaction forces balance.
- 474-2 “Moves,” therefore interacting forces unbalanced.
- 475 Equal force pairs are identified as action and reaction but are on the same object.
- 476 Stronger exerts more force.
- 477 One with more motion exerts more force.
- 478 More active/energetic exerts more force.
- 479 Bigger/heavier exerts more force.

From **Table 4-1** of Michael Wittman's Ph. D. thesis. Primitives as defined by DiSessa in his monograph. For each primitive selected, a general definition is given, and an example is included.

Primitive	Definition	Example (mechanics related)
Working harder	“More effort or cues to more effort may be interpreted as if in an effort to compensate for more resistance.”	To make a box begin to move across the floor, a larger force needs to be exerted than to keep it moving.
Intrinsic Resistance	“Especially heavy or large things resist motion.”	Heavier boxes are harder to start moving across a floor (or lift up) than are lighter boxes.
	“An agent or causal impetus acts through a resistance or interference to produce a result. It cues and justifies a set of proportionalities, such as ‘increased effort or intensity of impetus leads to more result’; increased resistance leads to less result.’ These effects can compensate each other; for example, increased effort and increased resistance may leave the result unchanged.”	The speed of a coin tossed in the air depends on its mass and the force exerted on it to throw it in the air (see Force as Mover example).
Overcoming	“One force or influence overpowers another”	To get a box moving along a rough floor, the exerted effort must be larger than the resistance of the object (related to Ohm's in terms of competing proportionalities).

We ran surveys and found that our questions (taken from our interview transcripts) fell into categories already mentioned. We investigate one category in more detail.

Photon vs. light:

1	1	What are the images that come to mind when you hear the word PHOTON?
14	14	The photon is a part of light and quantization means the separating of these parts.
18	16 BC	A light wave produces photons as it travels.
26	21 A	“Quantization” means the partitioning of photons into parts.
41	31 A	Photons can produce light.
42	31 BC	Photons are not light, but can produce light.
44	33	The photon is not real, it is only a way of thinking about light and energy.
45	34	A photon is a particle that carries light.
46	35 A	A photon is a building block of light.
48	36 A	When you see the light coming out of a bulb, there’re millions and millions of little photon particles that come out that are bright, and that’s what makes you see the light.
49	36 BC	When you see the light coming out of a bulb, there’re millions and millions of little photon particles that come out.
50	37	There are particles of light inside the photon that move at the speed of light
59	41 BC	A photon is a building block of light.

The survey

We gave three versions of a survey to various groups of students—we will characterize them as

engineers

technical students

non-science, non-engineering students

The **engineers** and **non-science, non-engineering students** (we'll abbreviate this as **ns-ne** below) were students at Ohio State University, respectively students taking the second quarter of the engineering sequence and students in Physics by Inquiry courses (electric circuits) and “World of Energy” courses (liberal arts or preteaching students).

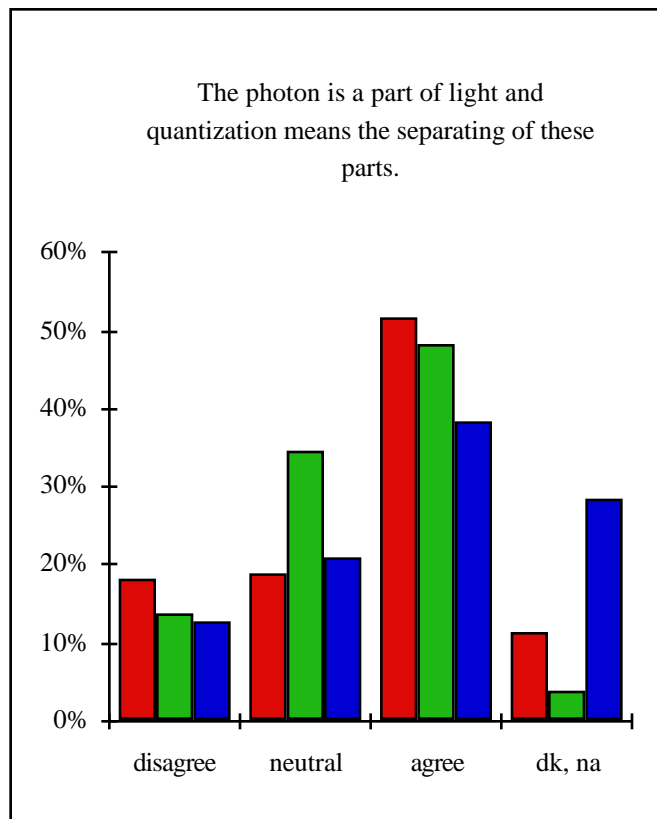
The **technical students** attended the Ohio Mechanical Institute of the University of Cincinnati (many thanks to Prof. James Sullivan for his help).

The multiple choice item has:

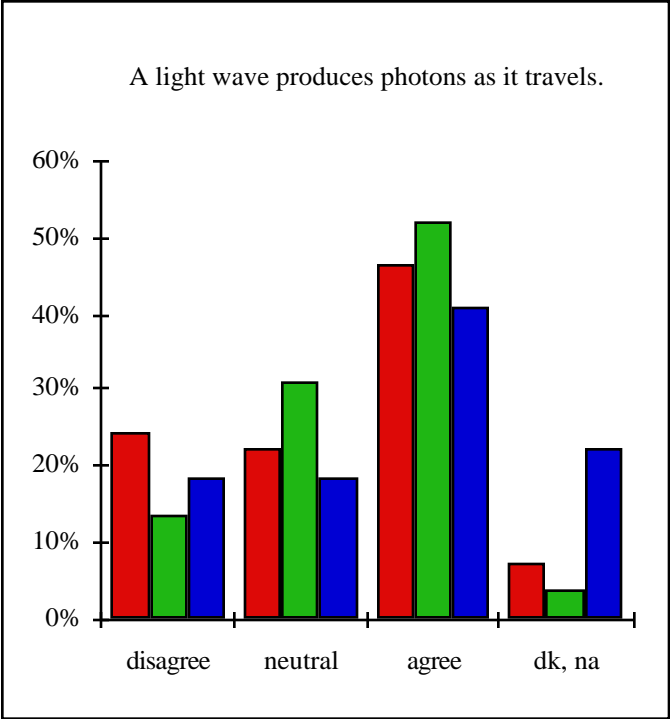
	engineers	tech students	ns-ne
1 What are the images that come to mind when you hear the word PHOTON?			
a. a particle	72%	77%	60%
b. a wave	46%	13%	22%
c. a packet of energy	62%	46%	53%
d a small, round, positively charged object	18%	40%	36%
e. a high-energy bullet	25%	13%	13%
f. quanta of electromagnetic radiation	29%	2%	15%
g. an extremely small particle in an atom	16%	29%	32%
h. beams of light	51%	21%	37%
i. something very small	47%	44%	36%
j. a ball of light	26%	15%	21%
k. a disk about the size of a dime	0%	0%	3%
l. rod-shaped particles	2%	6%	10%
m. a ball of some kind that's always white in color	4%	2%	4%

We pick out those items having to do with light:

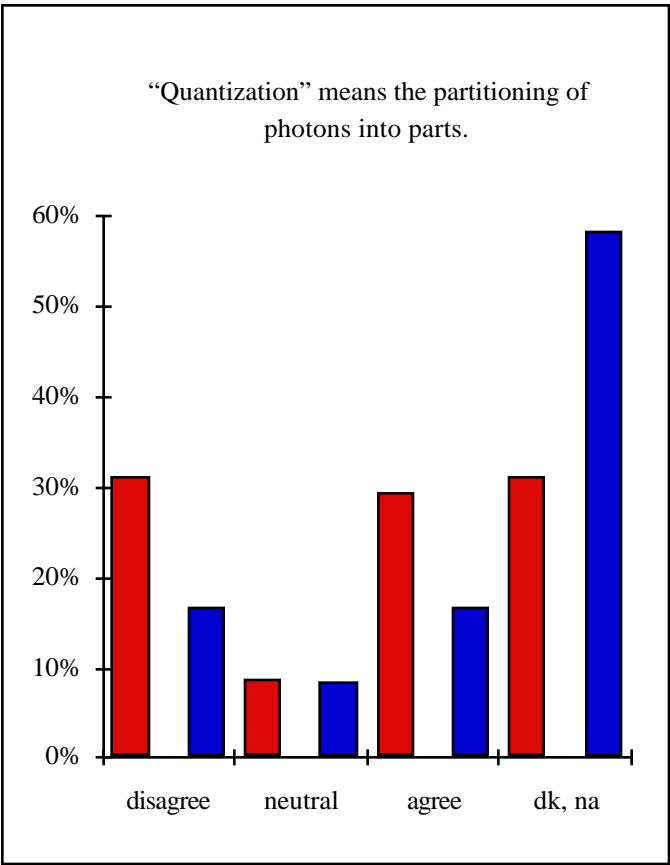
	engineers	tech students	ns-ne
1 What are the images that come to mind when you hear the word PHOTON?			
b. a wave	46%	13%	22%
h. beams of light	51%	21%	37%
j. a ball of light	26%	15%	21%
m. a ball of some kind that's always white in color	4%	2%	4%



	N	disagree	agree	asa
		strongly disagree	strongly agree	-dsd
14 The photon is a part of light and quantization means the separating of these parts.				
engineers	170	18%	52%	34%
tech students	52	13%	48%	35%
ns—ne	120	13%	38%	26%
total	342	15%	46%	31%

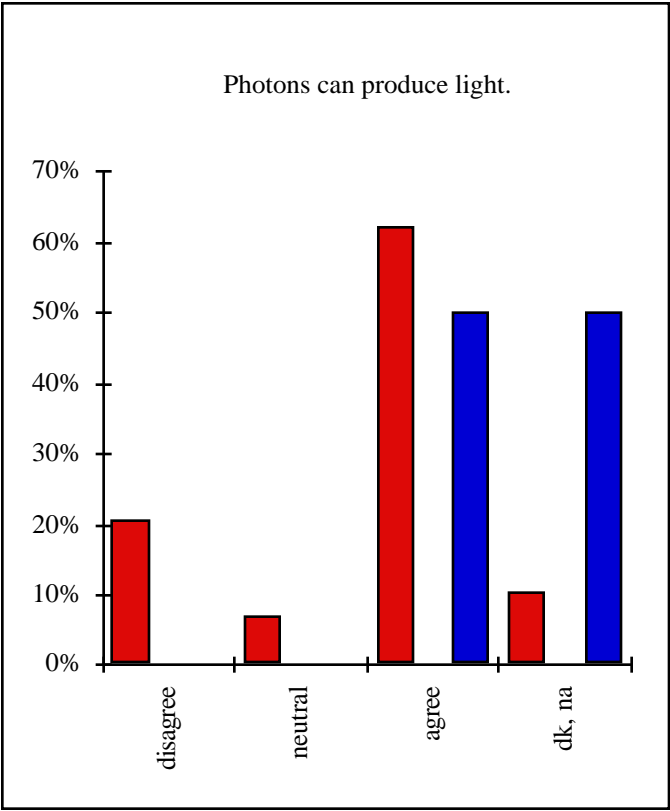


	N	disagree strongly disagree	agree strongly agree	asa -dsd	
16 A light wave produces photons as it	engineers	112	24%	46%	22%
BC travels.	tech students	52	13%	52%	38%
	ns—ne	108	19%	41%	22%
	total	272	20%	45%	25%

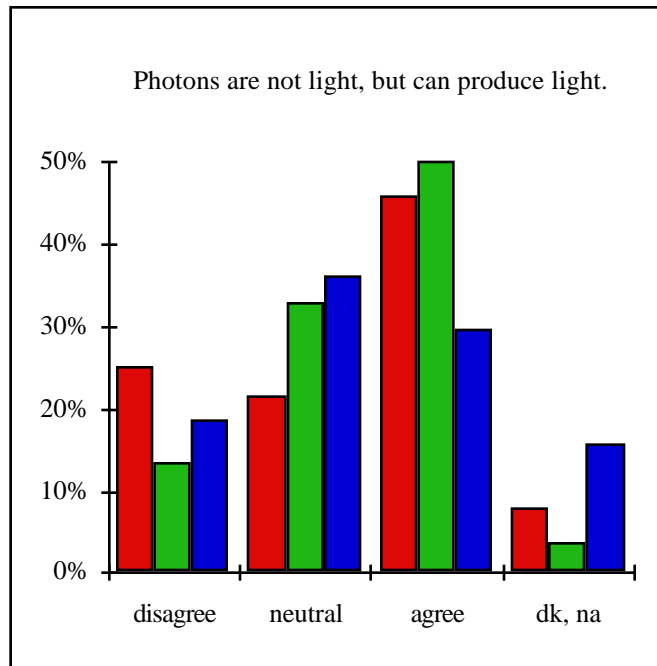


21 A “Quantization” means the partitioning of photons into parts.

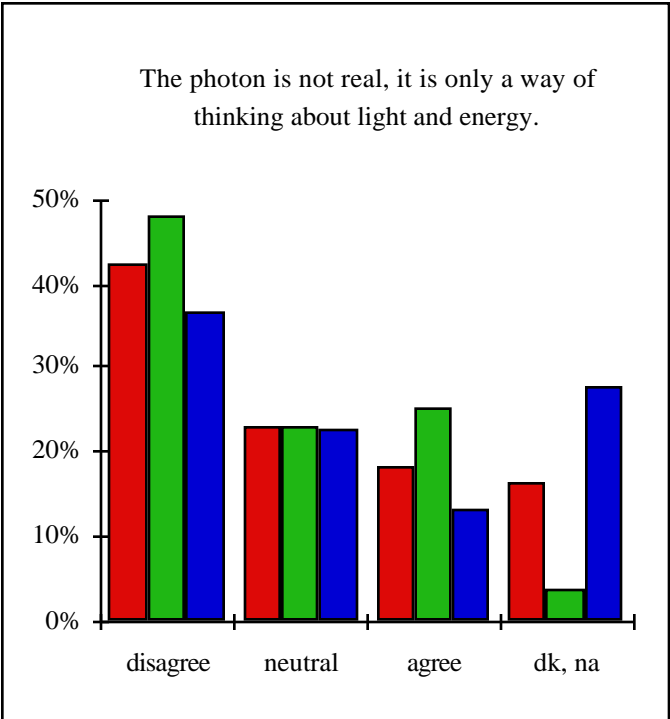
	N	disagree strongly disagree	agree strongly agree	asa -dsd
engineers	58	31%	29%	-2%
tech students	0	0%	0%	0%
ns—ne	12	17%	17%	0%
total	70	29%	27%	-1%



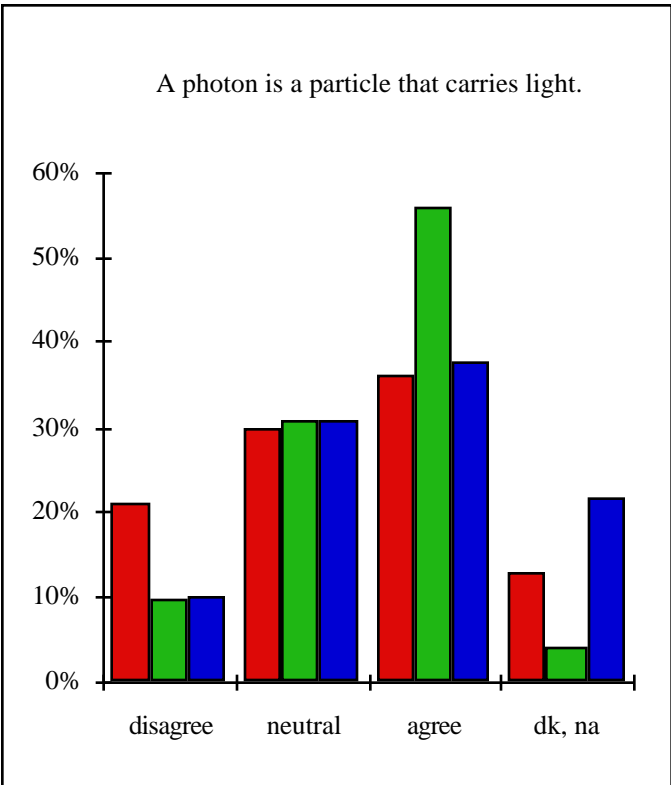
	N	disagree strongly disagree	agree strongly agree	asa -dsd
31 A Photons can produce light.				
engineers	58	21%	62%	41%
tech students	0	0%	0%	0%
ns—ne	12	0%	50%	50%
total	70	17%	60%	43%



	N	disagree strongly disagree	agree strongly agree	asa -dsd
31 Photons are not light, but can produce BC light.				
engineers	112	25%	46%	21%
tech students	52	13%	50%	37%
ns—ne	108	19%	30%	11%
total	272	20%	40%	20%

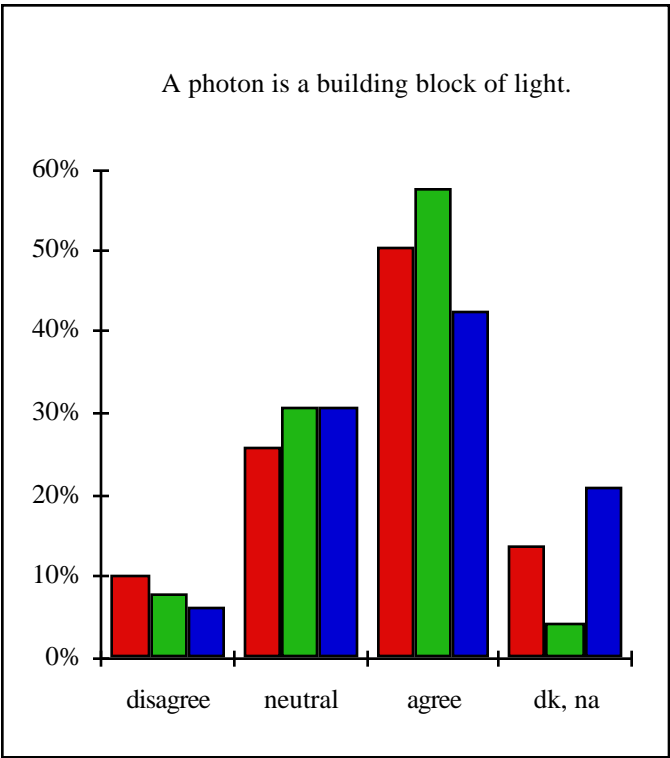


		N	disagree strongly disagree	agree strongly agree	asa -dsd	
33	The photon is not real, it is only a way of thinking about light and energy.	engineers	170	42%	18%	-24%
		tech students	52	48%	25%	-23%
		ns—ne	120	37%	13%	-23%
		total	342	41%	18%	-24%



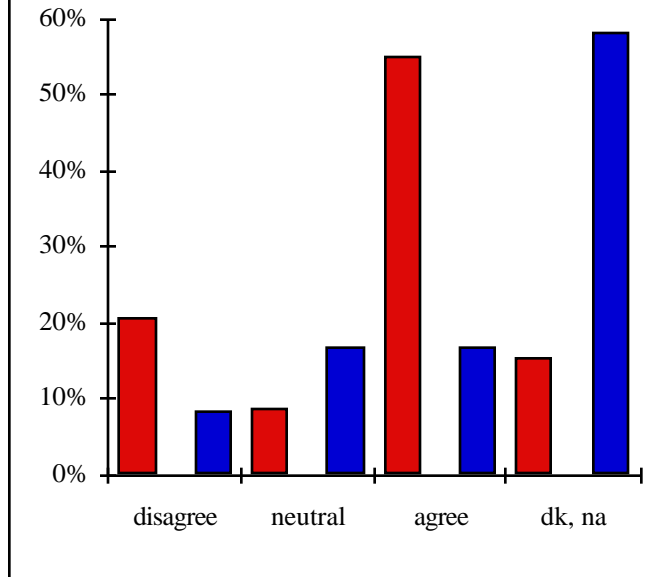
	disagree	agree	asa
N	strongly disagree	strongly agree	-dsd

34	A photon is a particle that carries light.	engineers	170	21%	36%	15%
		tech students	52	10%	56%	46%
		ns—ne	120	10%	38%	28%
		total	342	15%	39%	24%

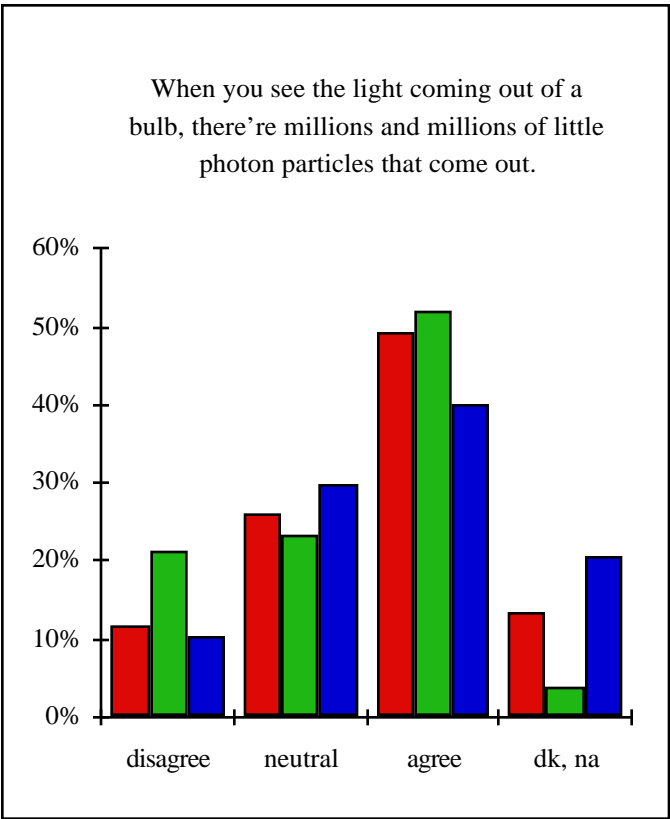


	N	disagree strongly disagree	agree strongly agree	asa -dsd
35 A A photon is a building block of light.	170	10%	51%	41%
41	52	8%	58%	50%
BC	120	6%	43%	37%
	342	8%	49%	41%

When you see the light coming out of a bulb, there're millions and millions of little photon particles that come out that are bright, and that's what makes you see the light.

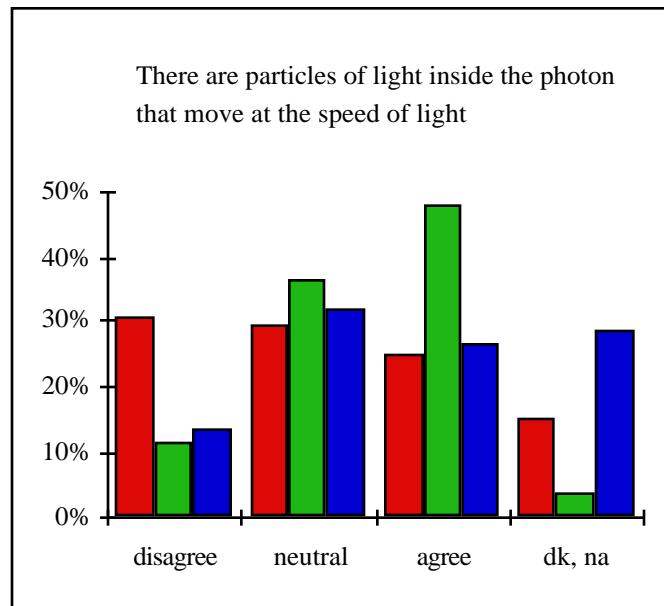


	N	disagree strongly disagree	agree strongly agree	asa -dsd
36 A When you see the light coming out of a bulb, there're millions and millions of little photon particles that come out that are bright, and that's what makes you see the light.				
engineers	58	21%	55%	34%
tech students	0	0%	0%	0%
ns—ne	12	8%	17%	8%
total	70	19%	49%	30%



		N	disagree strongly disagree	agree strongly agree	asa -dsd	
36	When you see the light coming out of	engineers	112	12%	49%	38%
BC	a bulb, there're millions and millions	tech students	52	21%	52%	31%
	of little photon particles that come	ns—ne	108	10%	40%	30%
	out.	total	272	13%	46%	33%

A surprise to us was the answer to the question of whether photons are composite or not. Most students (**engineers**, **tech students**, **ns—ne**) chose to be neutral or to agree than to disagree. **Engineers** do see photons slightly more as things in themselves than **ns—ne students** or, especially, **tech students**, having a flat distribution rather than one canted upward toward the right.



N	disagree	agree	asa
	strongly disagree	strongly agree	-dsd
37	31%	25%	-6%
	12%	48%	37%
	13%	27%	13%
	22%	29%	7%
			-42%

Some “conceptinos” gleaned from this group of answers that might turn into facets

Photons and light are the same thing.

Light is made up of photons; or, photons are the sole components of light.

- a) Light is made up of a very large number of photons leaving the light source simultaneously.
- b) Seeing photons is what makes you see light.

Photons are made up of light.

- a) Photons are made up of particles of light.
- b) Photons carry light.

Light produces photons.

A light wave throws or dribbles off photons as it travels.

Photons produce/emit light, or something that can be seen.

So, what are the facets here, and how do we organize them?

Most of this is work for the future.

Facets are context-specific. We must find the contexts in which to categorize our facets.

We are in the process of developing these “conceptinos” (perhaps pprims, which are neither wrong nor right, but simply exist) into a list of ideas that might, in context, be facets. We still have to categorize things. While this is simple for mechanics and student ideas, it is more difficult in the case of quantization and the photon.

A modest attempt for this category:

00 Photons and light

01 photons are defined in terms of QED creation & annihilation operators' actions on the vacuum

02 photons are building blocks of light

03 photons are the same as light

04 light is made up of photons

05 ...

06 ...

07 light dribbles photons off as it travels

08 photons emit light

09 photons are little particles traveling inside light waves

Much remains to be done!