Framing Geological Numeracy for the Purpose of Geoscience Education: The Geoscience Quantitative Preparation Survey

Victor J. Ricchezza

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Co-Major Professor: Jeffrey G. Ryan, Ph.D.
Committee: Jeffrey R. Raker, Ph.D.
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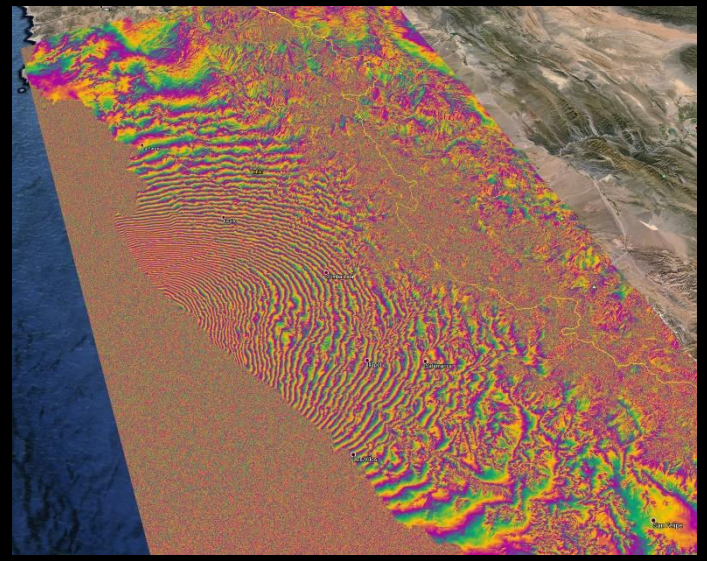
Jennifer M. Wenner, Ph.D.
External Chair: Luanna B. Prevost, Ph.D.

What do Geologists Study?



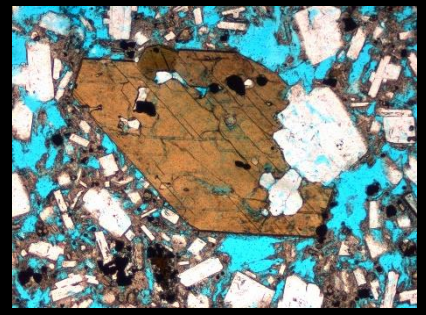
September 2015 Chile Earthquake By European Space Agency - http://www.esa.int/spaceinimages/Images/2015/09/Chile_earthquake_on_the_radar , CC BY-SA 3.0-igo, https://commons.wikimedia.org/w/index.php?curid=58544984

Astronaut Harrison Schmitt – an idiot re: global warming – collecting rocks on the goddamned moon, NASA, public domain

Valdez Glacier, Alaska, Public Domain, https://commons.wikimedia.org/w/index.php?curid=527732

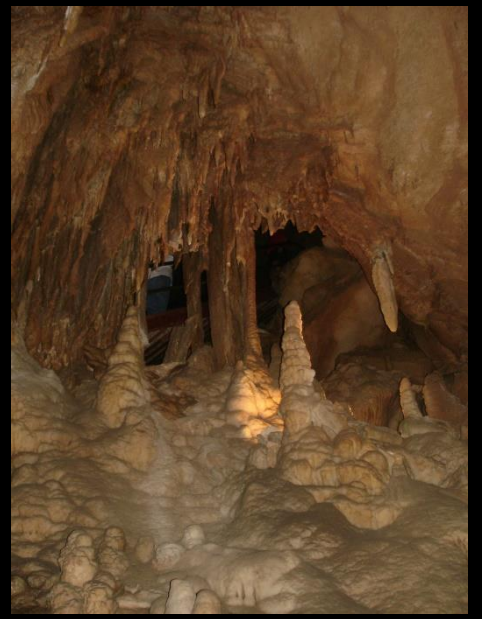
Rinjani 1994 by Oliver Spalt [CC BY 2.0 (https://creativecommons.org/licenses/by/2.0)]

Black Canyon of the Gunnison N.P. taken by Urban and put under the GNU FDL {{GFDL}} From : http://en.wikipedia.org/wiki/Image:Black_canyon_gunnison_20030921.4.jpg



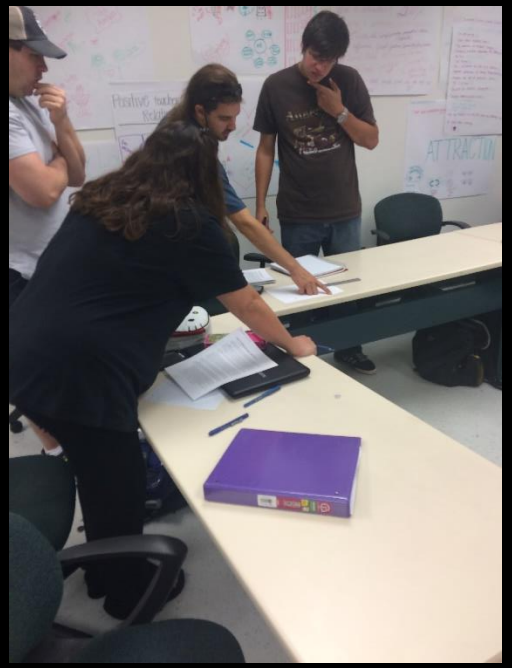
Andesite thin section, By Cheryl Cameron - https://www.usgs.gov/media/images/rock-thin-section-andesite , Public Domain, https://commons.wikimedia.org/w/index.php?curid=77508220

Eumorphocystis multiporata by Sarah Sheffield (used with permission)

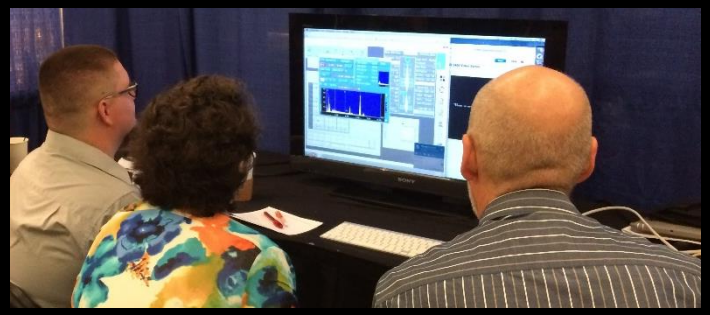


Mammoth Cave National Park By Navin75 - https://www.flickr.com/photos/navin75/162073106/ , CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=3676763

What do I Study?



Computational Geology lab (me)



Jeff Ryan demonstrating remote microprobe project at SEGSA (me).

USF volcanology field camp students (left), photo by USF staff

Left and below, computational geology students at lab (me)

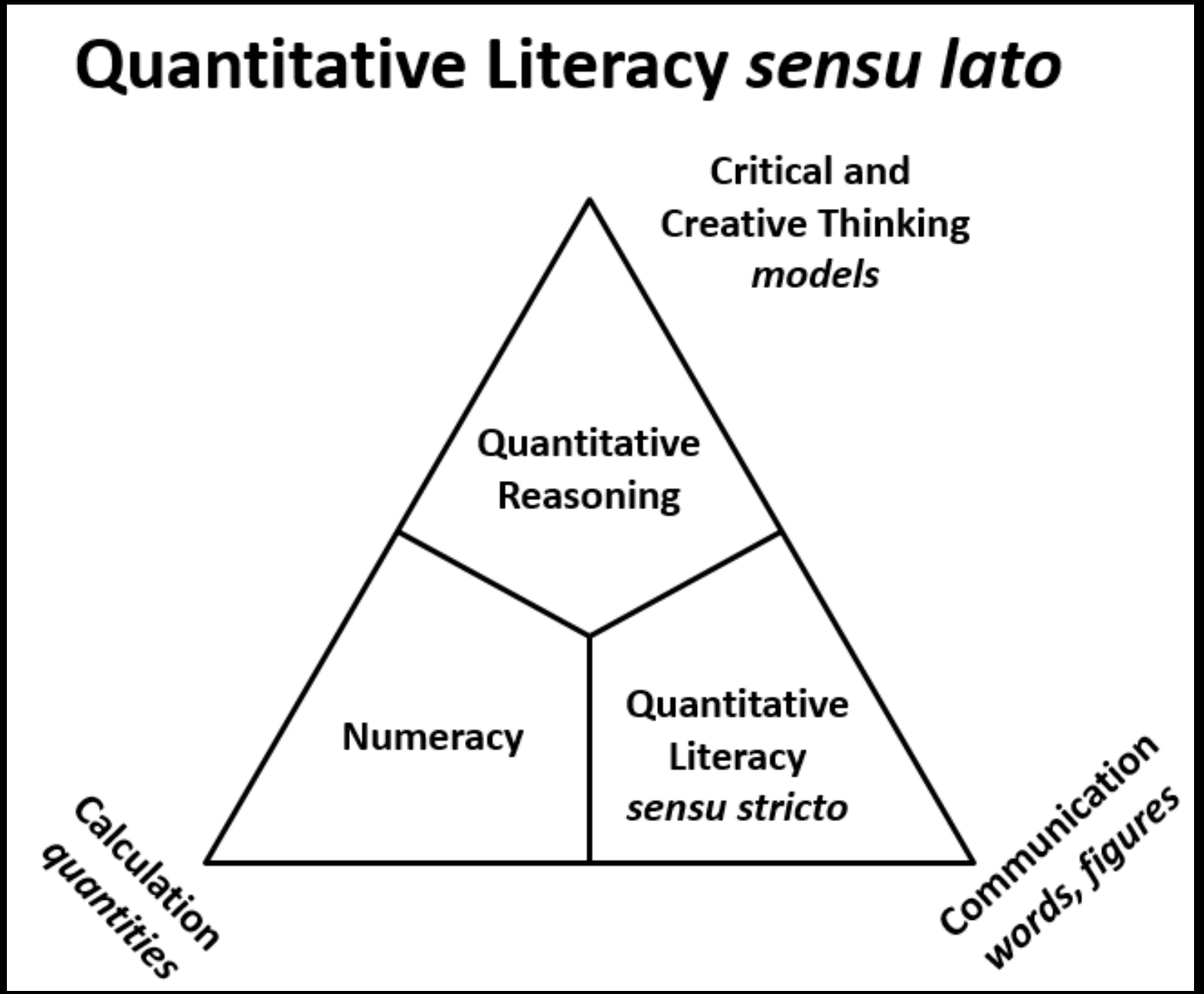
USF Field Camp students and a beaver, by E. Gallant.

Dr. Bright smells her finger, photo by E. Gallant.

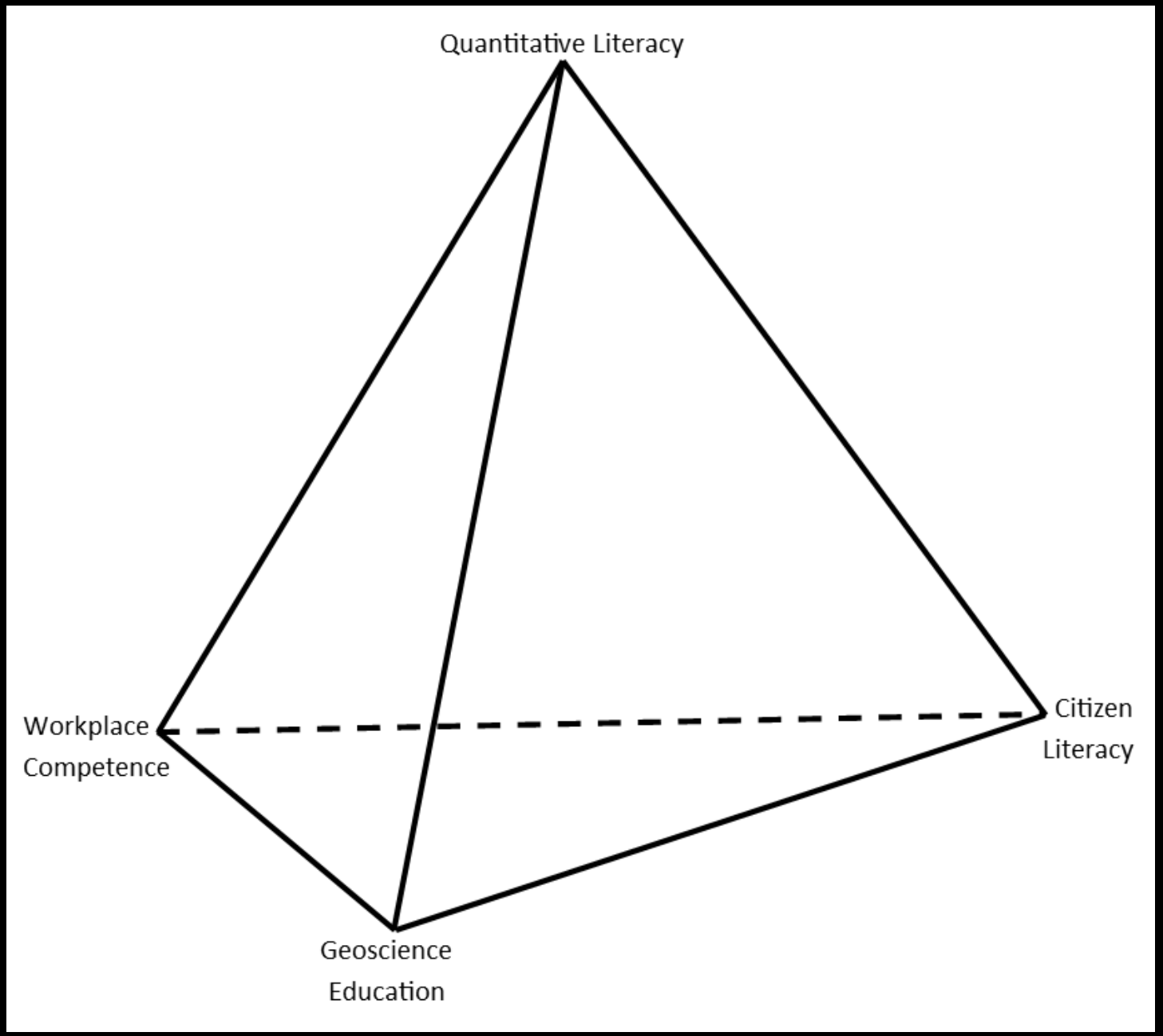
Me at field camp badly crossing a shitty wire bridge (photographer unknown)

At this point I'm really wondering what's on Jen's finger. What the hell, Jen? Photo by E. Gallant.

Quantitative Literacy *sensu lato*

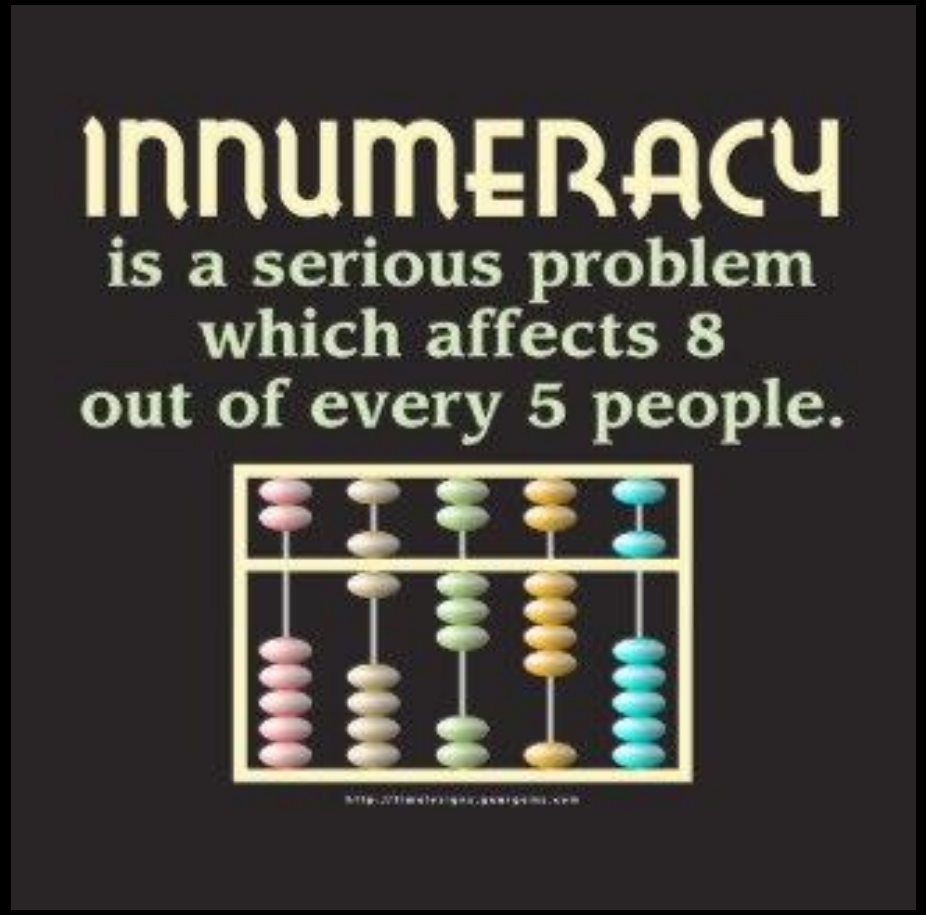


From Vacher, unpublished. Used with permission.


Quantitative Literacy
Workplace Competence
Citizen Literacy
Geoscience Education

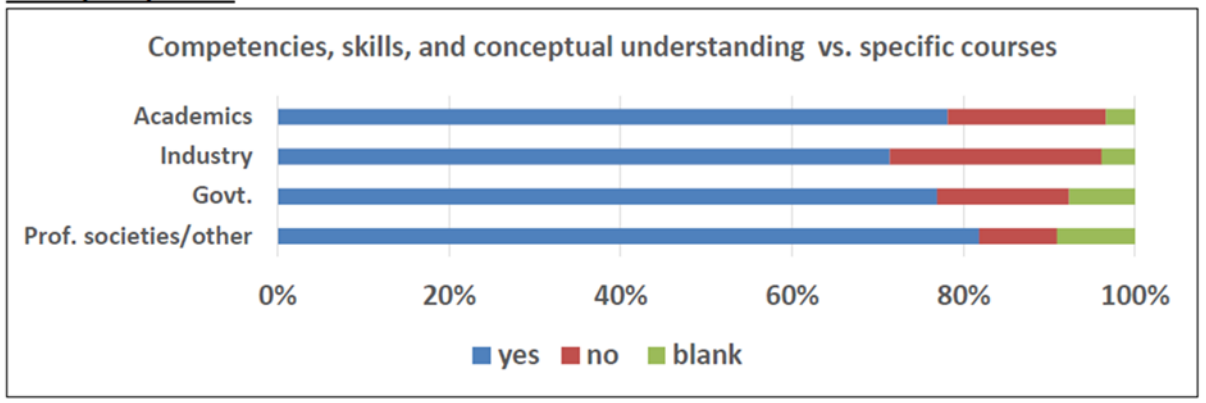
Why Do Geoscientists Need QL?

- Better preparation for modern careers.
  (Kastens, et al., 2018)
- There is no field of geoscience that doesn't include some quantitative material.
  (Manduca et al., 2008)
- Everyone needs QL in a functioning democracy.
  (Steen, 2001)

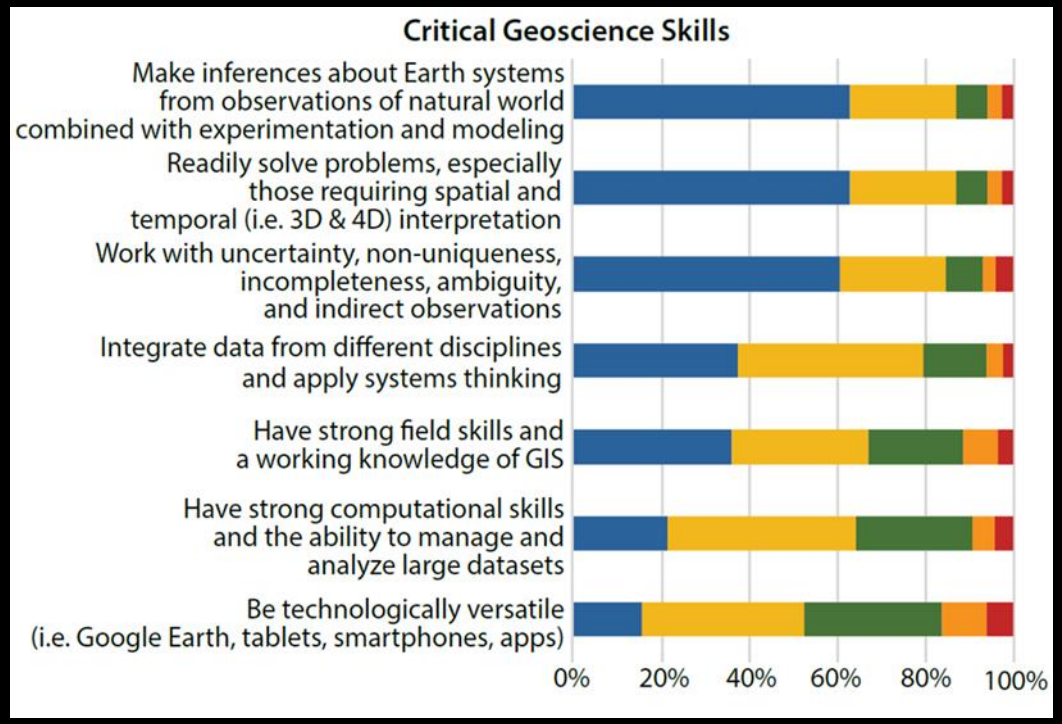


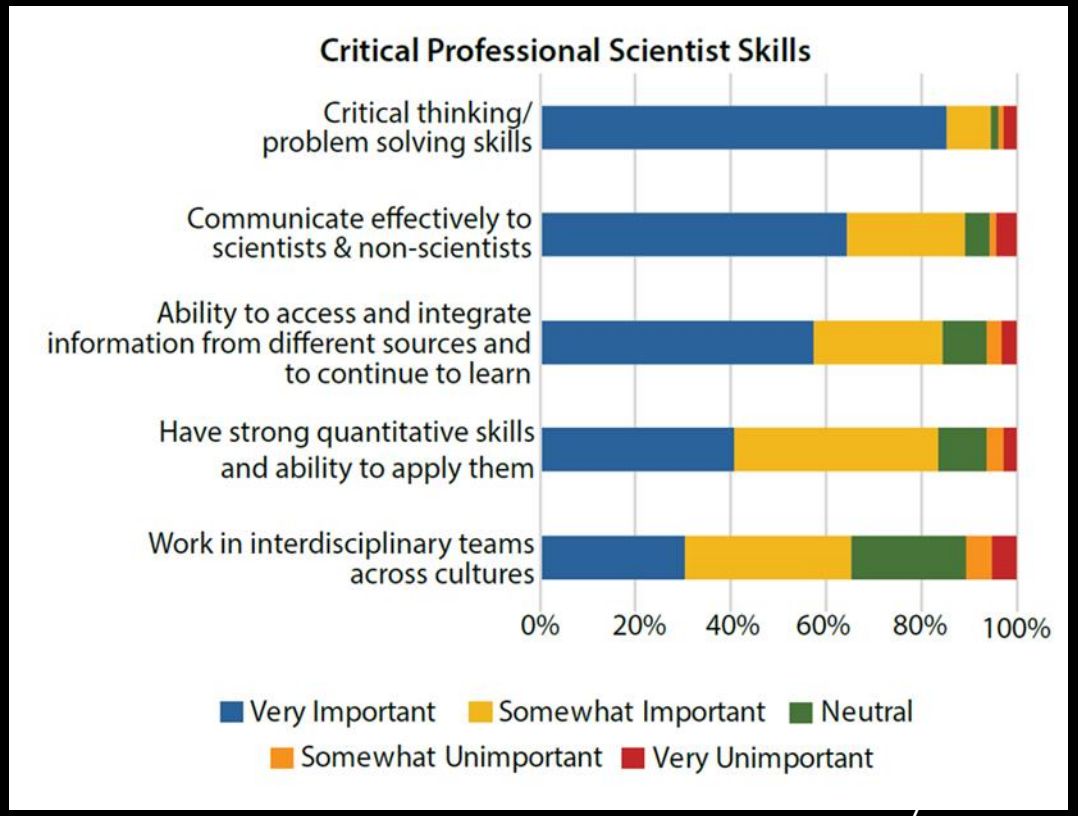
Major conclusion of Summit: Developing competencies, skills, and conceptual understanding is more important than taking specific courses

Survey Responses:



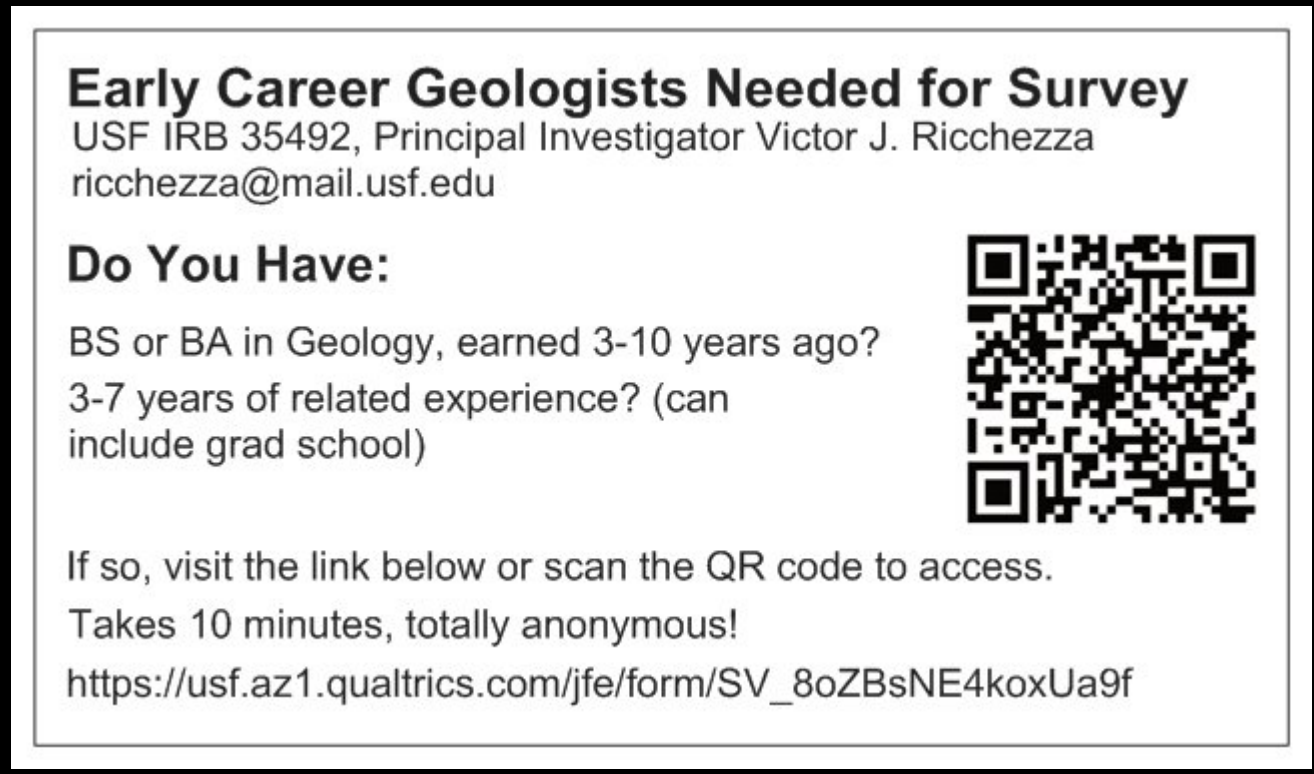
Summit survey report/Mosher 2015
Used with permission





Geoscience Quantitative Preparation Survey

- National Survey of Early Career ~~Geoscientists~~ Geologists
- Online, anonymous
- 8/20/18 – 11/30/18
- Early career
  - 3-10 years time
  - 3-7 years experience



Subjective Numeracy Scale to GQPS

- SNS: 11 Q, all general confidence
- GQPS: 4 sections
  - 1. Confidence, based on SNS.
    - 5Q on HOW
    - 11Q on Skills
  - 2. Use. Work/Non-work. Yes/No.
  - 3. Satisfaction w/ undergrad preparation (dept/uni).
  - 4. Demographics

Cognitive abilities (1 = *not at all good*, 6 = *extremely good*)
- How good are you at working with fractions?
- How good are you at working with percentages?
- How good are you at calculating a 15% tip?
- How good are you at figuring out how much a shirt will cost if it is 25% off?

Preference for display of numeric information
- When reading the newspaper, how helpful do you find tables and graphs that are parts of a story?* (1 = *not at all*, 6 = *extremely*)
- When people tell you the chance of something happening, do you prefer that they use *words* ("it rarely happens") or *numbers* ("there's a 1% chance")?* (1 = *always prefer words*, 6 = *always prefer numbers*)
- When you hear a weather forecast, do you prefer predictions using *percentages* (e.g., "there will be a 20% chance of rain today") or predictions using only *words* (e.g., "there is a small chance of rain today")? (1 = *always prefer percentages*, 6 = *always prefer words*; reverse coded)
- How *often* do you find numerical information to be useful? (1 = *never*, 6 = *very often*)

SNS (Fagerlin et al., 2007), used with permission

GQPS Research Questions

To what extent do early career geologists self-identify as quantitatively literate relative to the demands of their careers?

To what extent are early career geologists satisfied with the quantitative preparation they received as undergraduates relative to the demands of their careers?

Theoretical Framework: Social Cognitive Career Theory

(Lent, Brown, & Hackett, 1994)

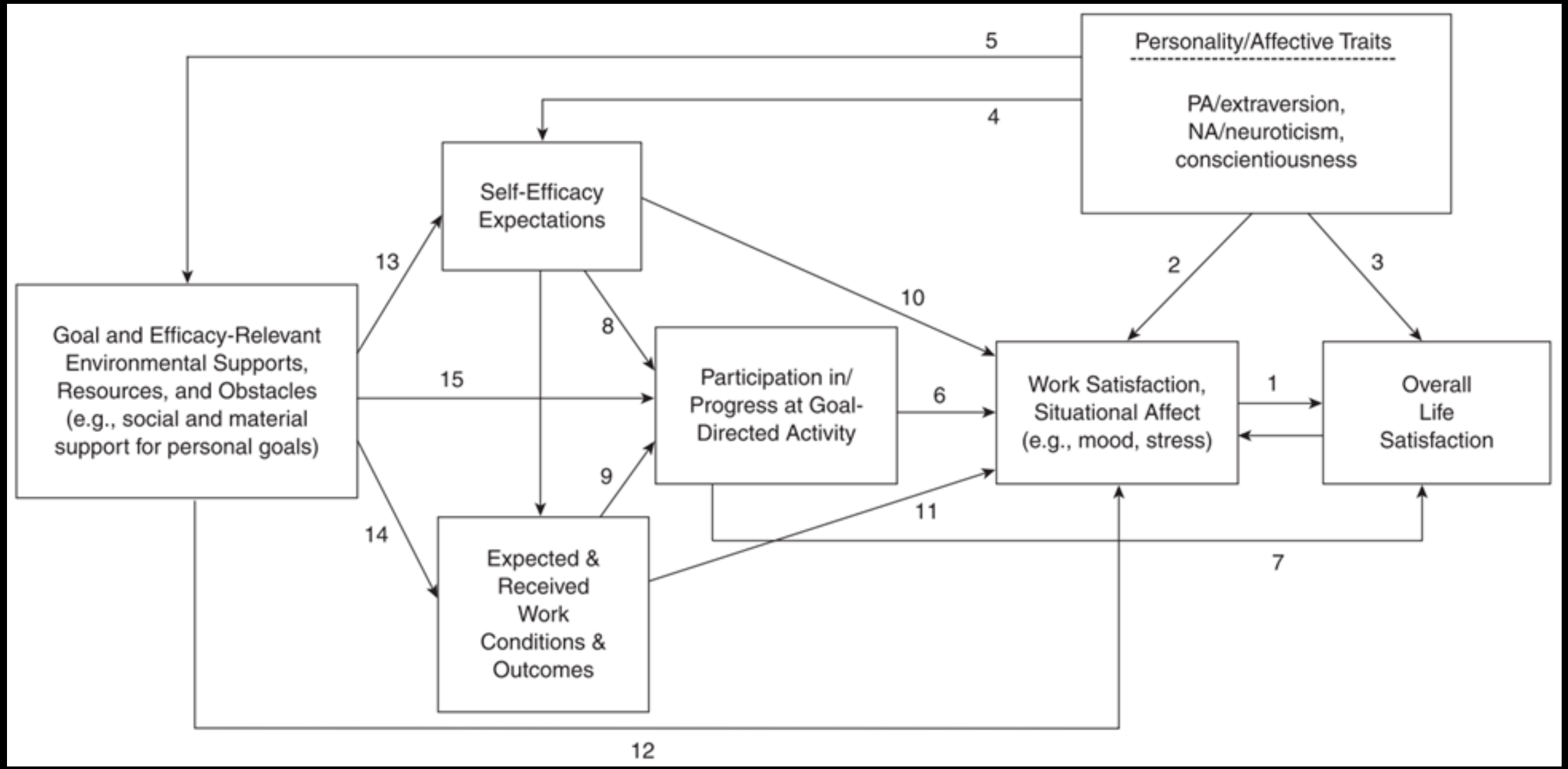


Figure 1 from Lent & Brown, 2008, used with permission.

Validation

- Panel of three survey experts:
  - J. Raker, USF Chemistry/ACS Exams
  - J. Wenner, UW-O Geology – TMYN
  - H. Houlton, (formerly) AGI
- Reviewed and revised iteratively
- Tested by 10 graduate students in think-aloud protocol
- Notes on confusing items, wording
- Final changes after grad student testing
- IRB 35492

Distribution and Collection

- Initial plan – email to a set list
  - Only one AGI list used, less than 250 names
- Issues: impossible to locate ECP in numbers
- Moved to social media – Facebook & Twitter
- Distributed via cards at GSA
- Survey open August 20 – November 30, 2018
- Entirely online via Qualtrics

Raw Data

- 377 complete surveys received
- 178 in target range – all further discussion is for target data

Level	Count	Percent
Bachelors	43	24%
Some Graduate	27	15%
Masters	94	53%
Doctorate	14	8%
Total	178	100%

Field	Count	Percent
2 year college	2	1%
4 year college	41	23%
Construction	8	4%
Environmental Serv.	33	19%
Federal Gov.	7	4%
Information Serv.	1	1%
K12 Education	3	2%
Manufacturing/Trade	2	1%
Mining	14	8%
Nonprofit/NGO	4	2%
Oil/Gas	11	6%
"Other"	14	8%
Other Education	1	1%
Research Institute	20	11%
State/Local/Tribal Gov.	17	10%
Total	178	100%

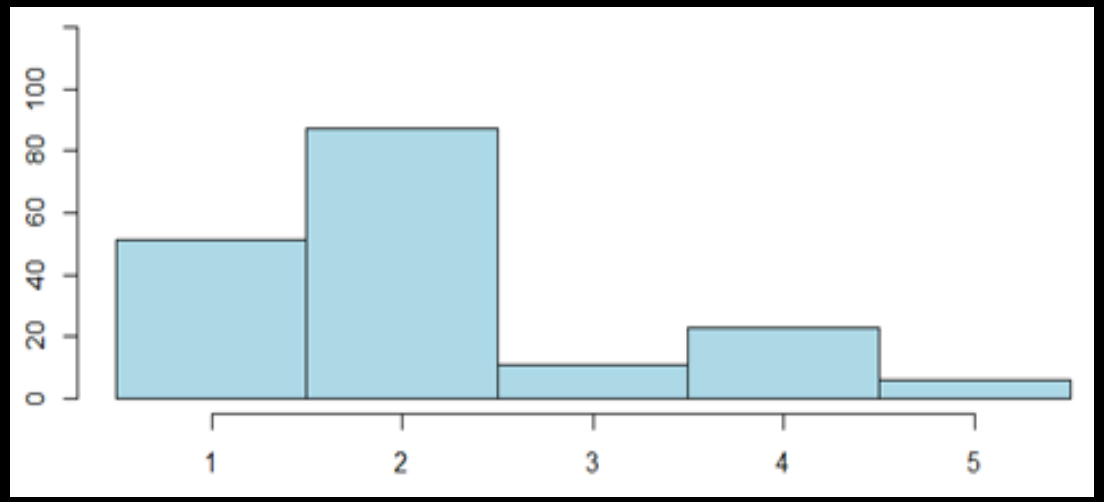
GQPS Research Questions

To what extent do early career geologists self-identify as quantitatively literate relative to the demands of their careers?

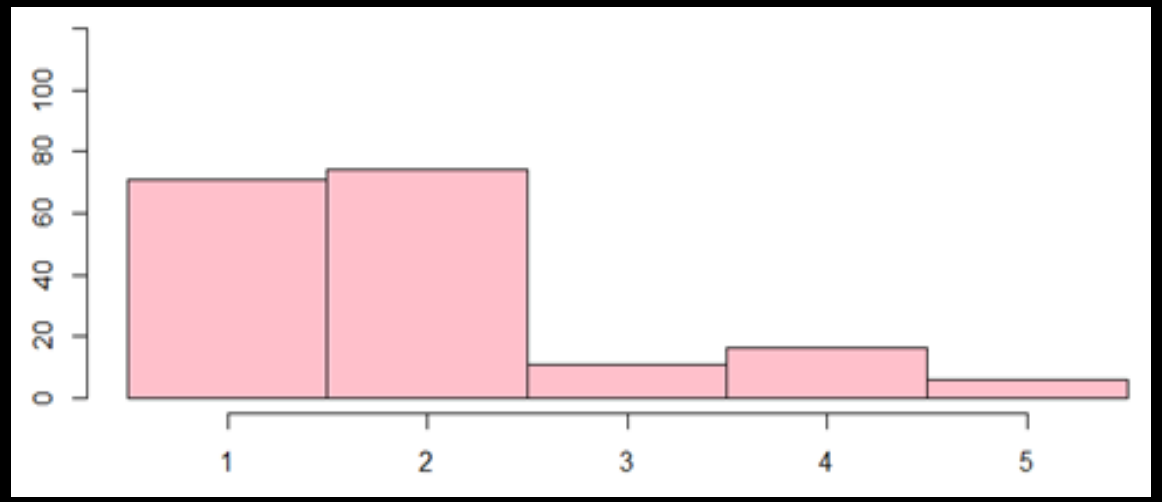
To what extent are early career geologists satisfied with the quantitative preparation they received as undergraduates relative to the demands of their careers?

Please rate your agreement regarding your undergraduate **geoscience program** (i.e., coursework, research, and learning specific to the geoscience department at the major level, not other coursework at your university, or any work afterward).

My undergraduate geoscience program gave me the **quantitative problem-solving skills** I need for professional success.



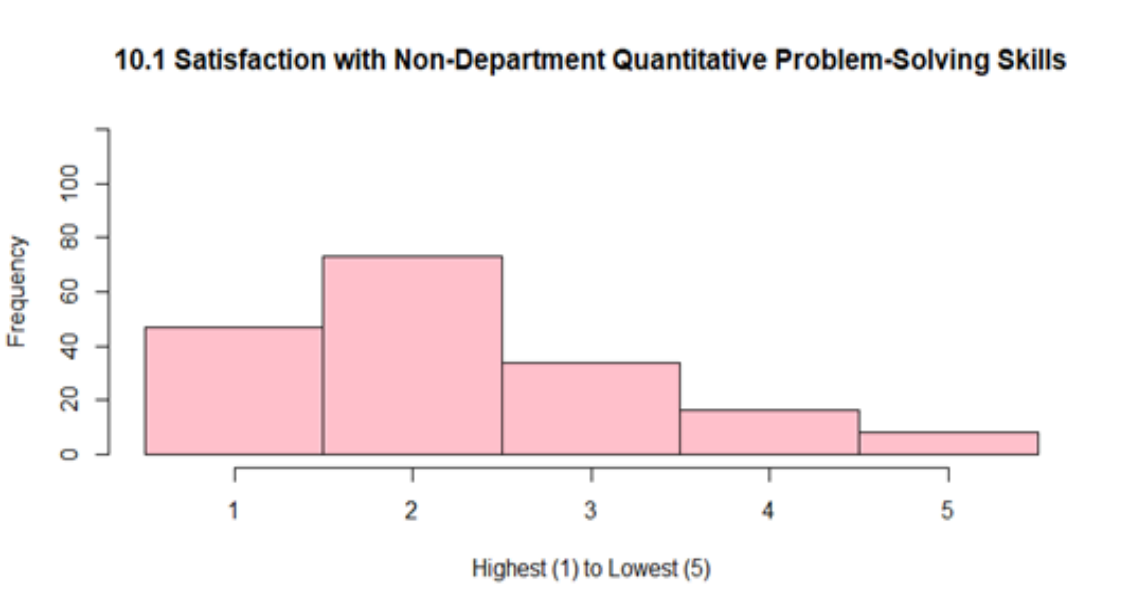
My undergraduate geoscience program gave me the **quantitative communications skills** (ability to read and write about quantitative material in both text and illustrations) I need for professional success.



Satisfaction: Higher ← Lower

Please rate your agreement regarding your overall undergraduate program **outside of the geoscience program** (i.e., coursework, research, and learning offered by any department other than the geoscience department, even if required for degree completion, not including graduate or other work done after undergraduate degree completion.)

The non-geoscience courses from my undergraduate program gave me the **quantitative problem-solving skills** I need for professional success



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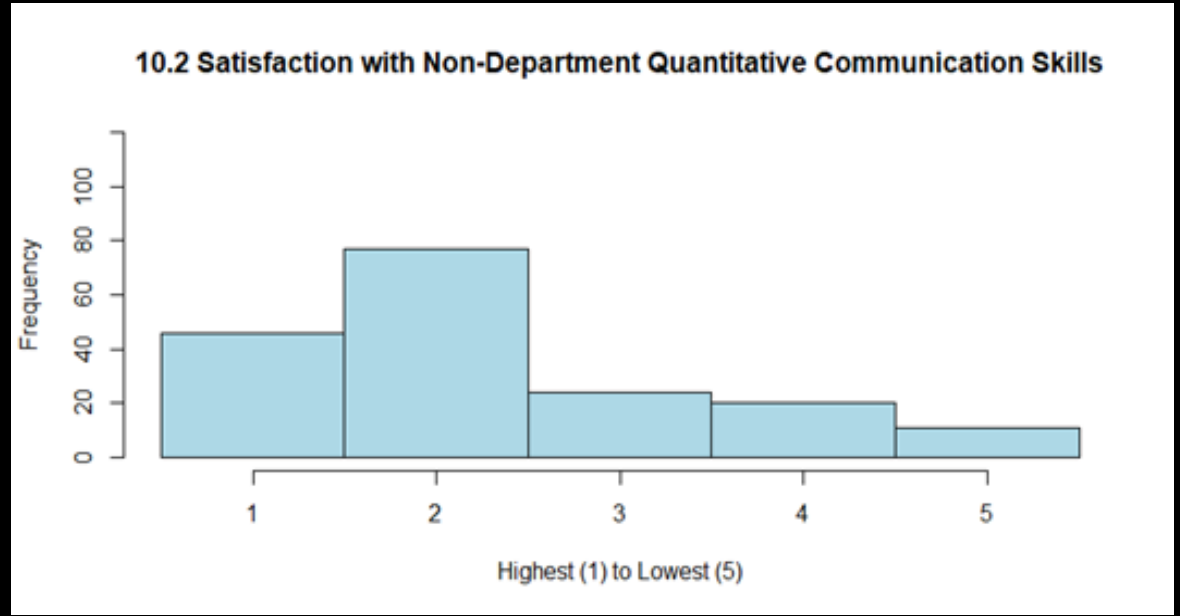
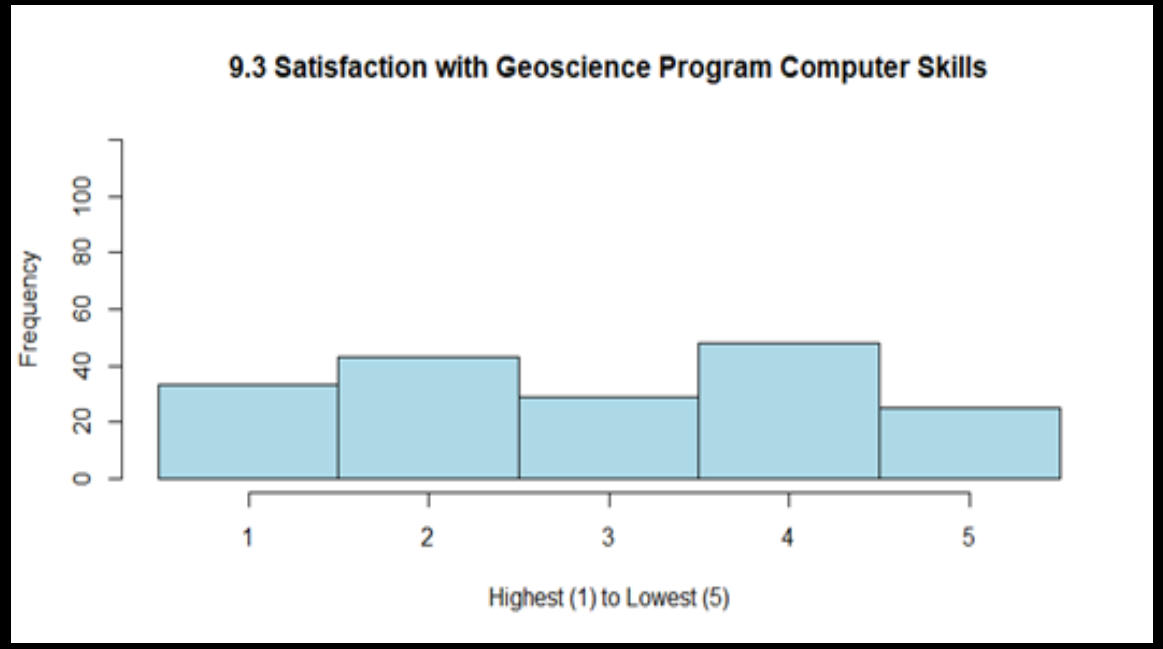


Frequency

Satisfaction: Higher ← Lower

Computer (not-so-)satisfaction

My undergraduate geoscience program gave me the **computer skills** I need for professional success.



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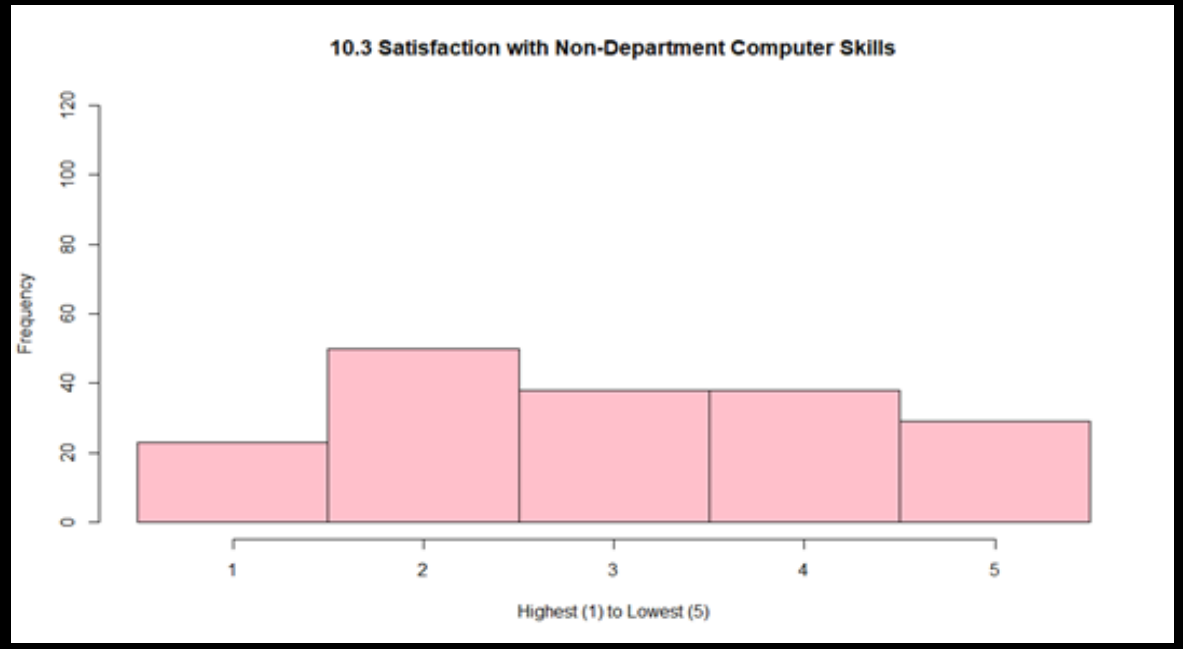


Frequency

Satisfaction: Higher ← Lower

To what extent are early career geologists satisfied with the quantitative preparation they received as undergraduates relative to the demands of their careers?

	Geoscience Median	University Median	Geoscience Skew	University Skew
Quantitative Problem-Solving	2	2	1.0142	0.8030
Quantitative Communication	2	2	1.2489	0.8527
Computer Skills	3	3	0.0018	0.0943

Satisfied?

Yes… and strongly…

Except for computers.

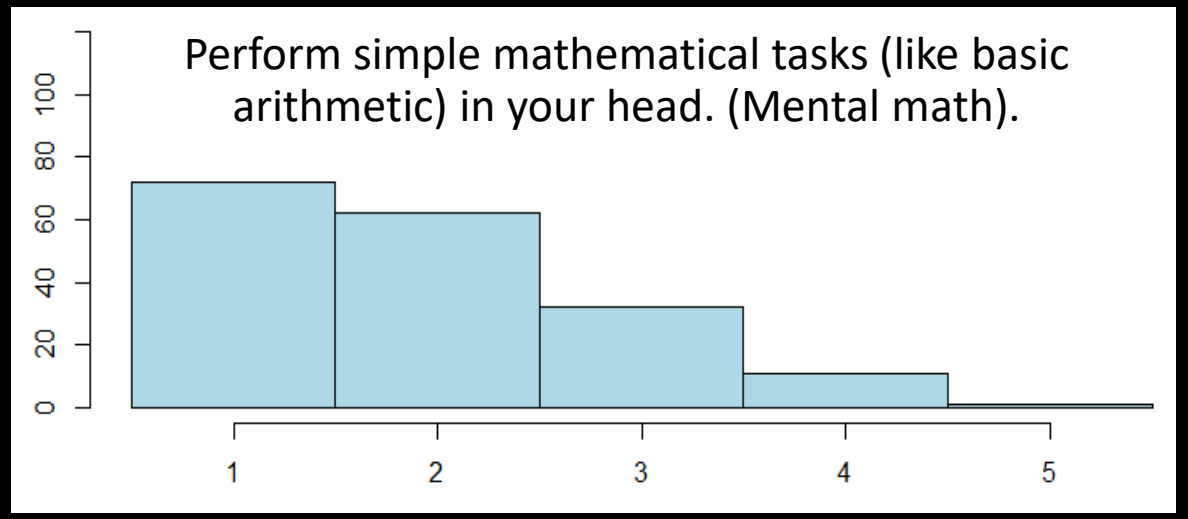
GQPS Research Questions

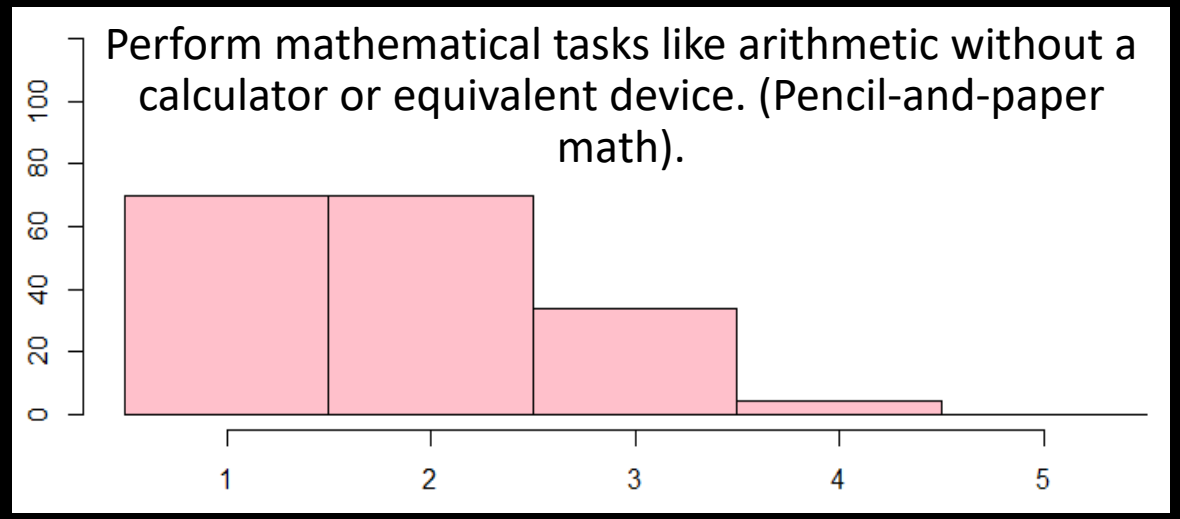
To what extent do early career geologists self-identify as quantitatively literate relative to the demands of their careers?

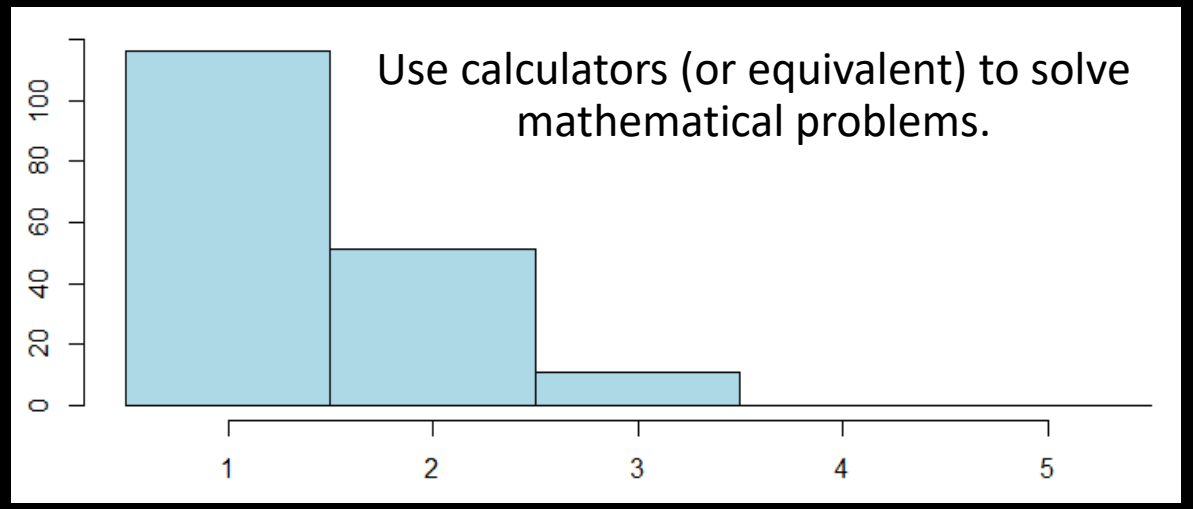
To what extent are early career geologists satisfied with the quantitative preparation they received as undergraduates relative to the demands of their careers?

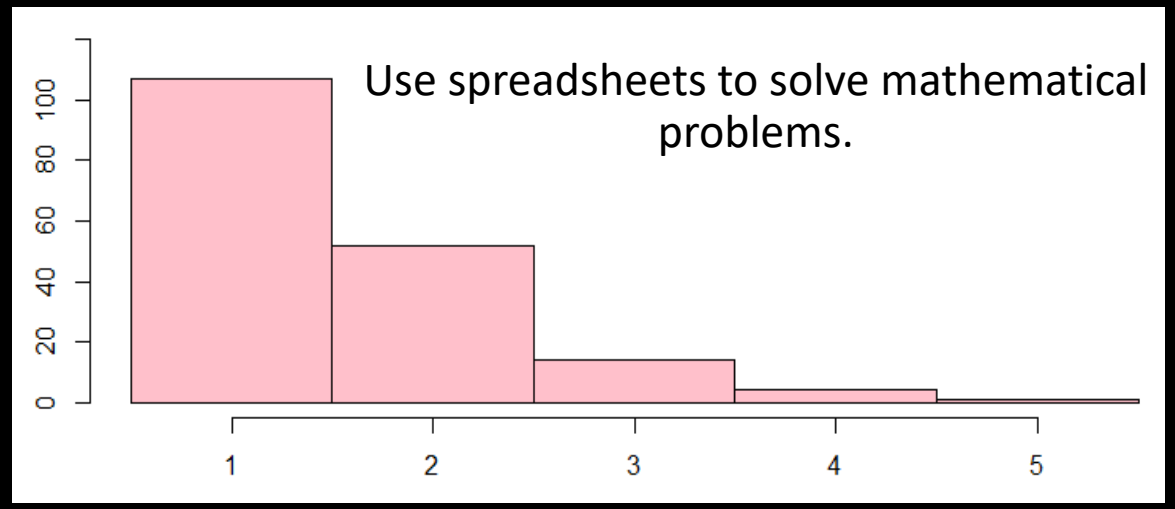
Please rate how confident you are in your ability to:

Frequency



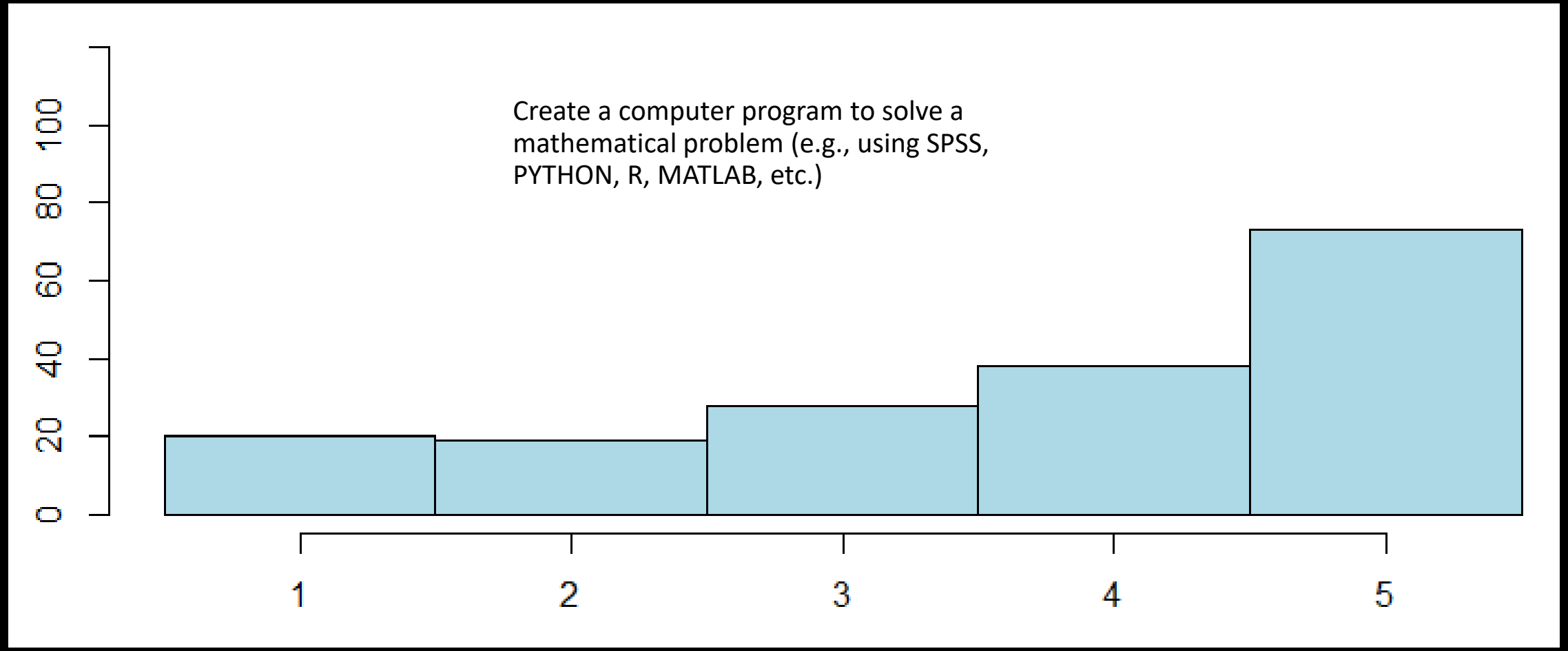






Confidence: Higher ← Lower

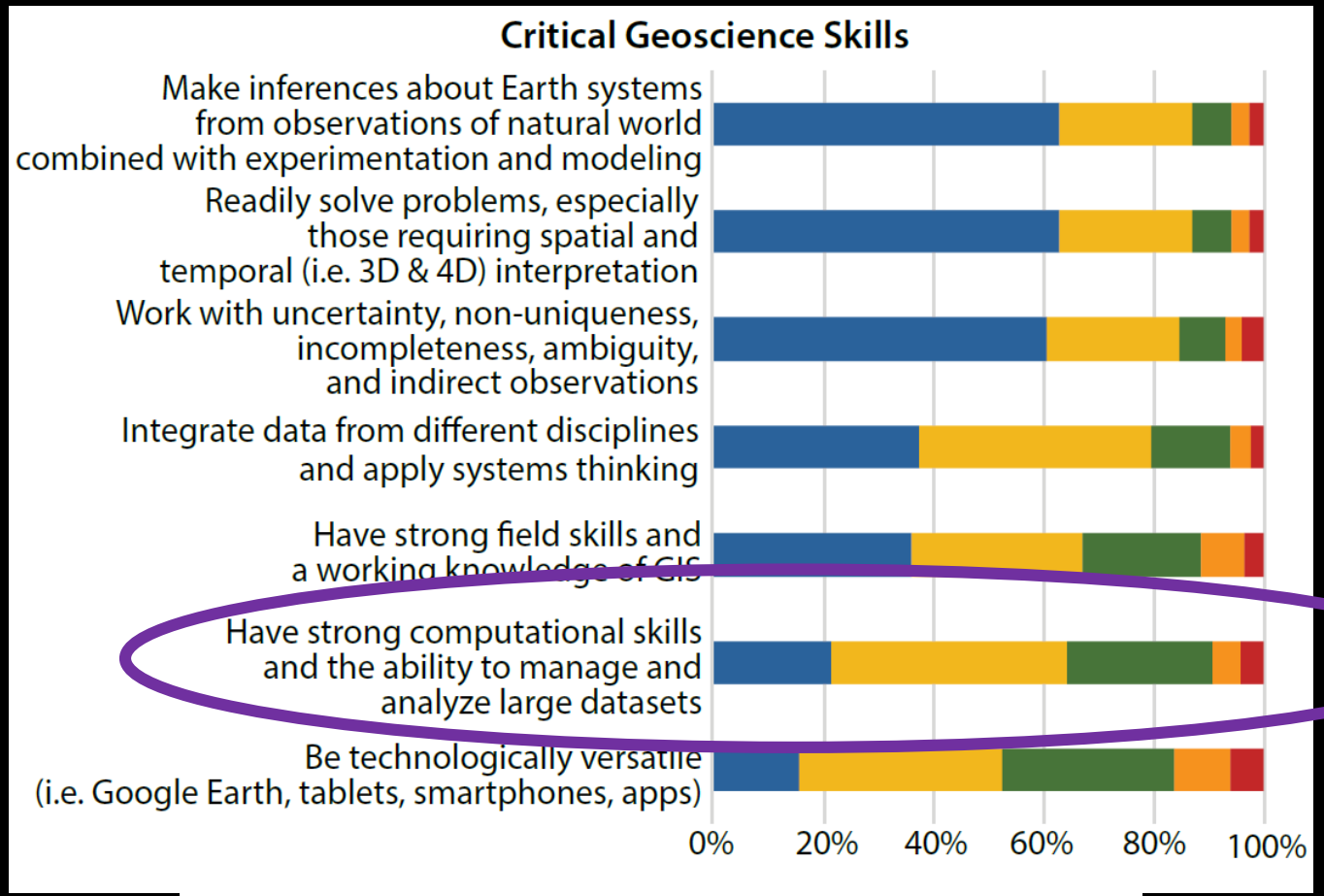
Please rate how confident you are in your ability to:



Confidence: Higher ← Lower

Remember This?

From Mosher (2015)



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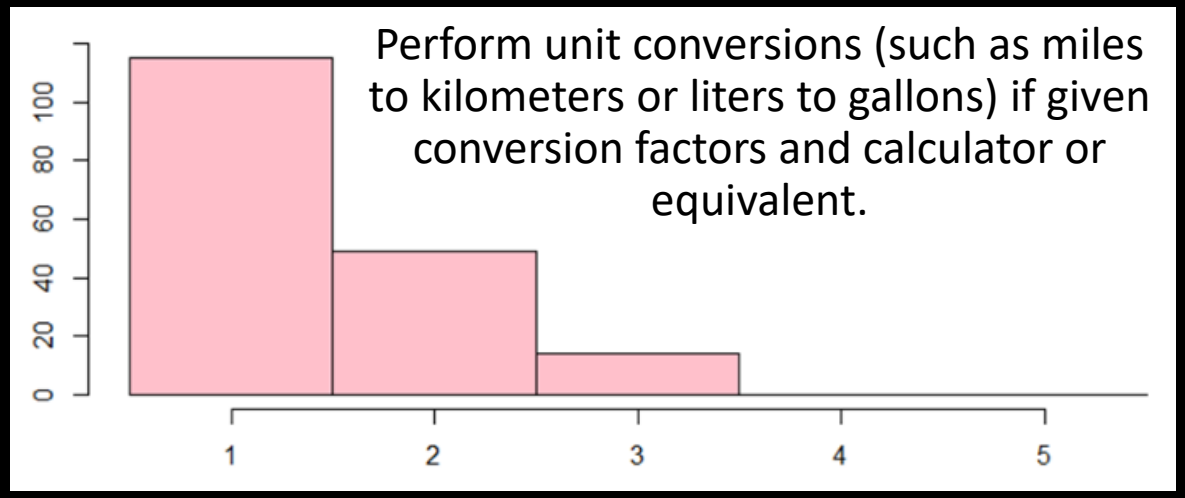

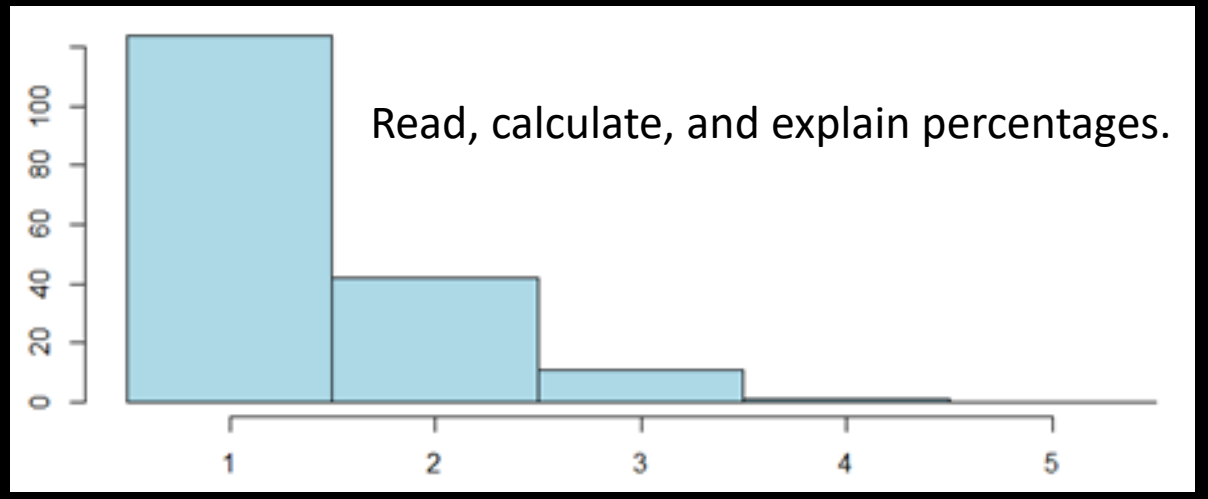

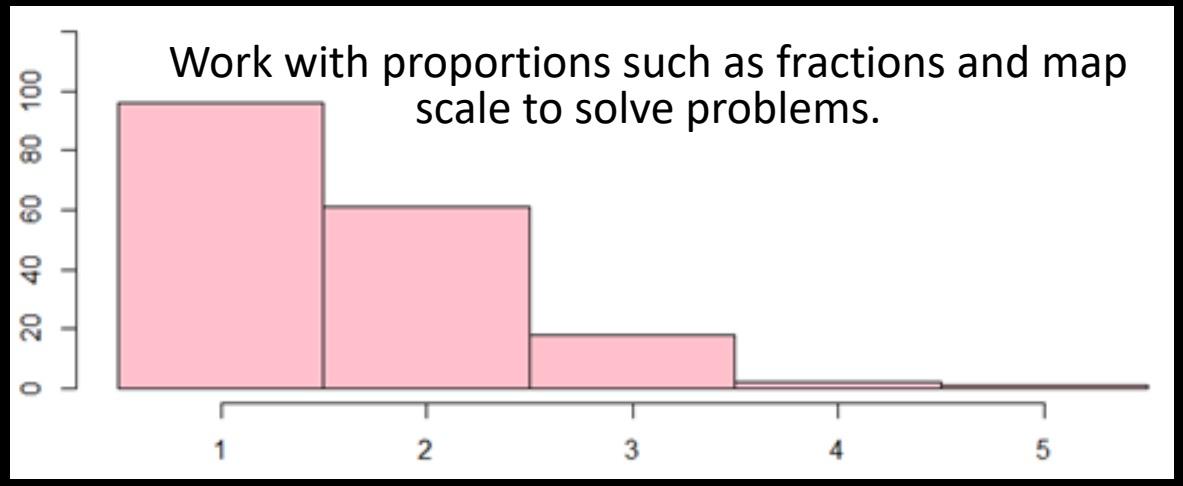

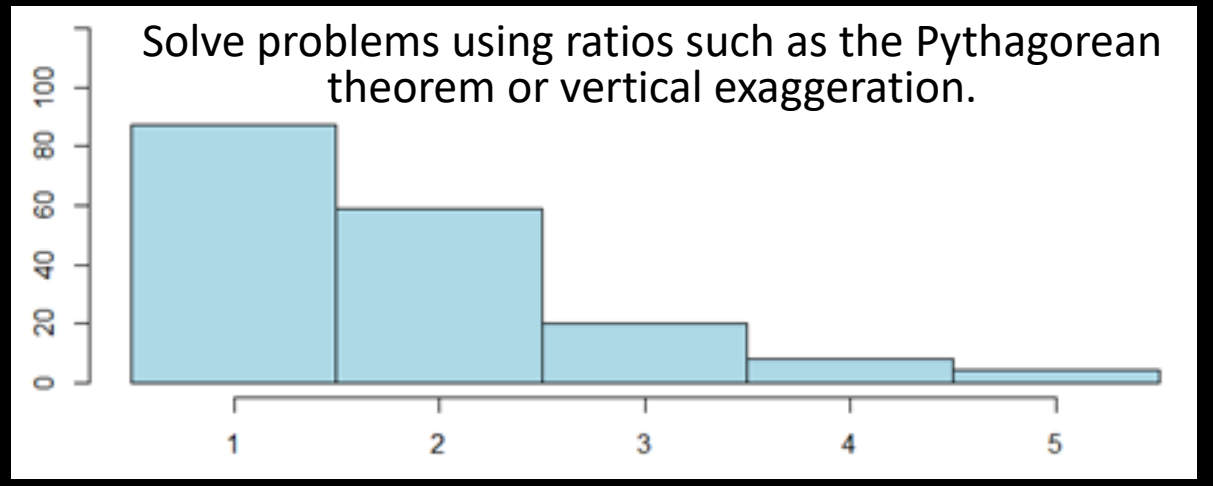

Confidence: Higher ⟵ Lower

Please rate how confident you are in your ability to:

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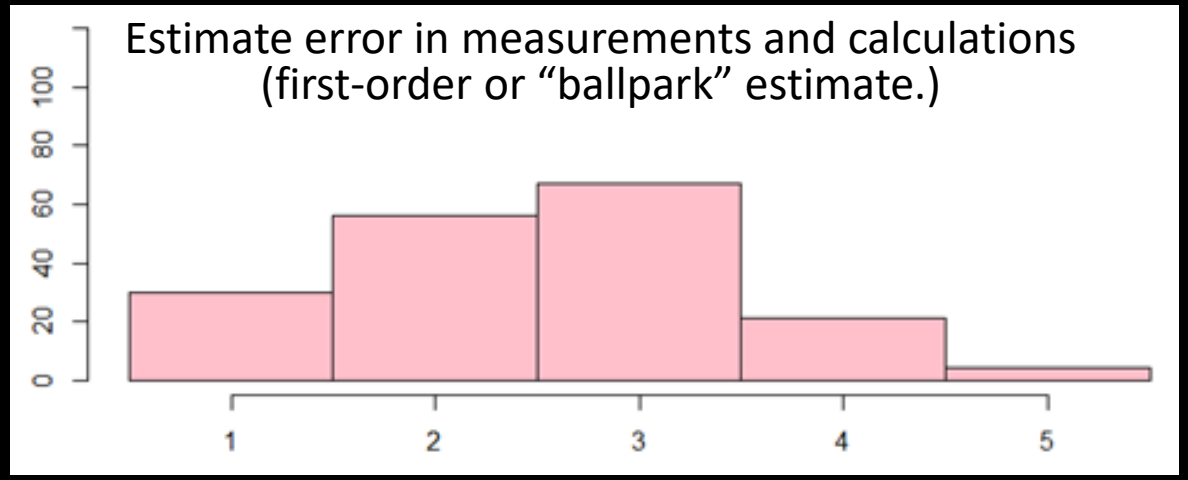

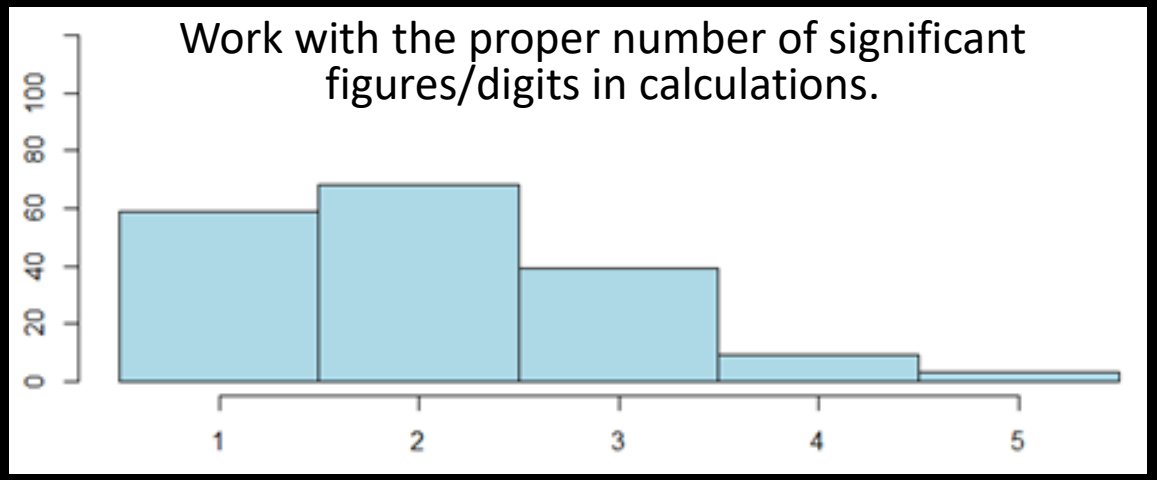

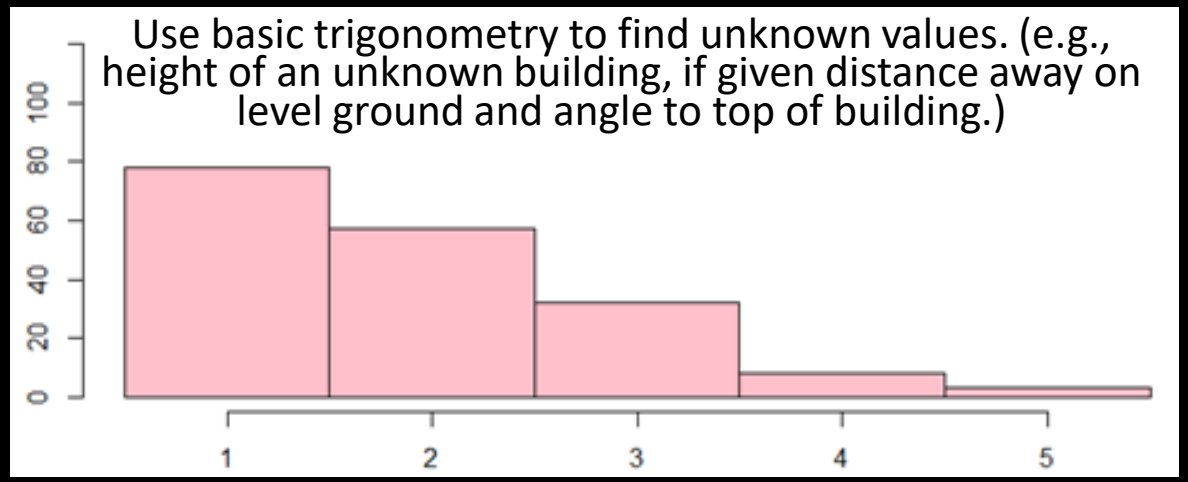

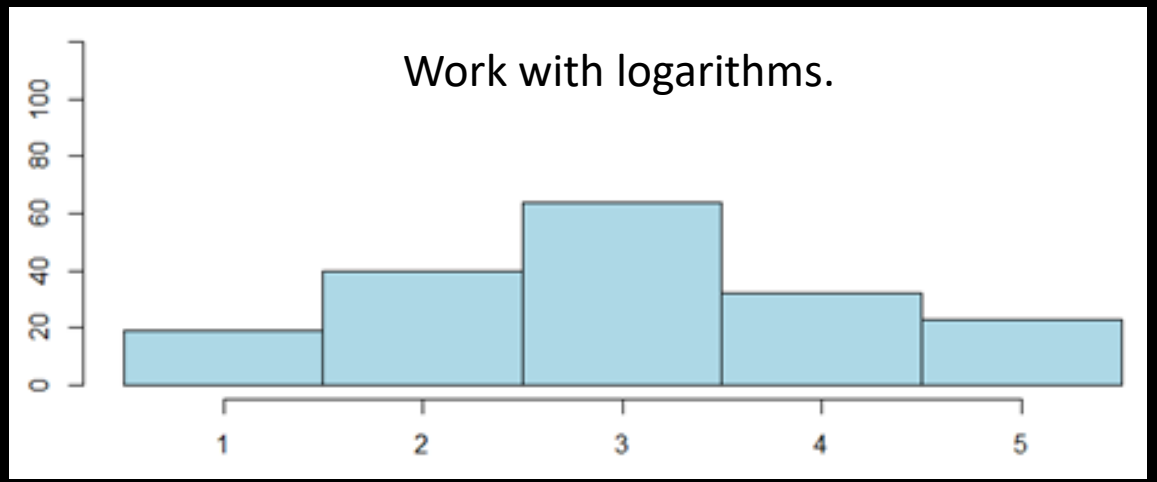

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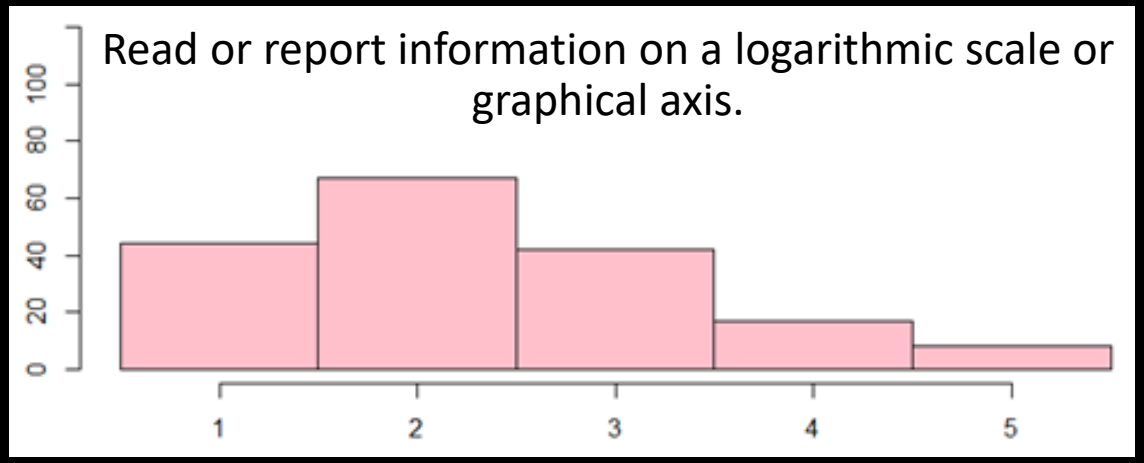
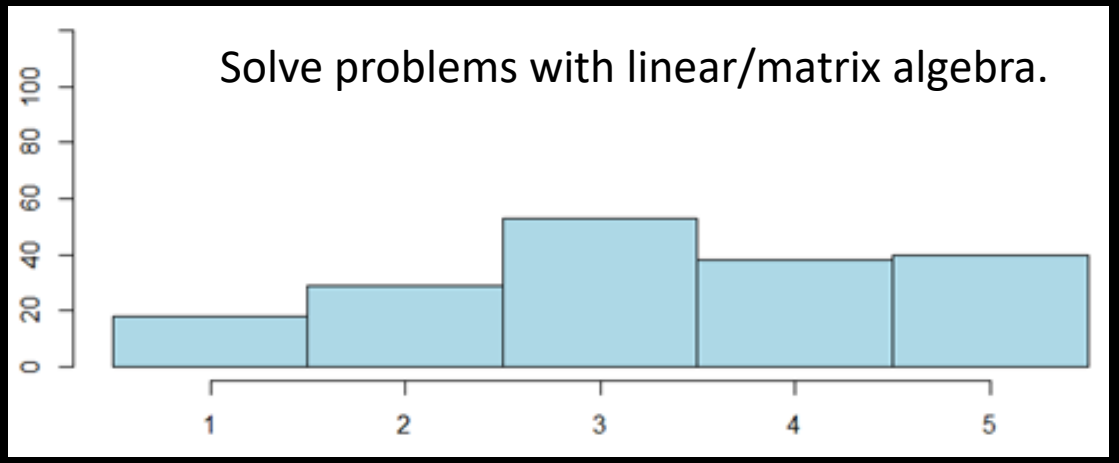
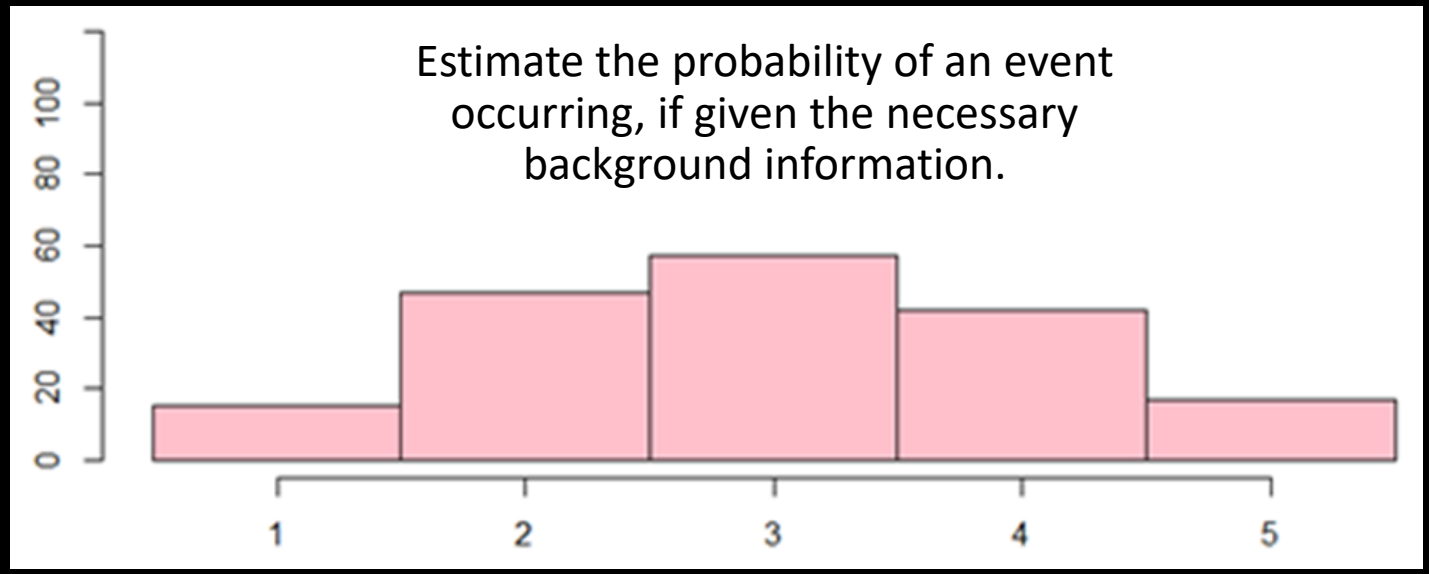
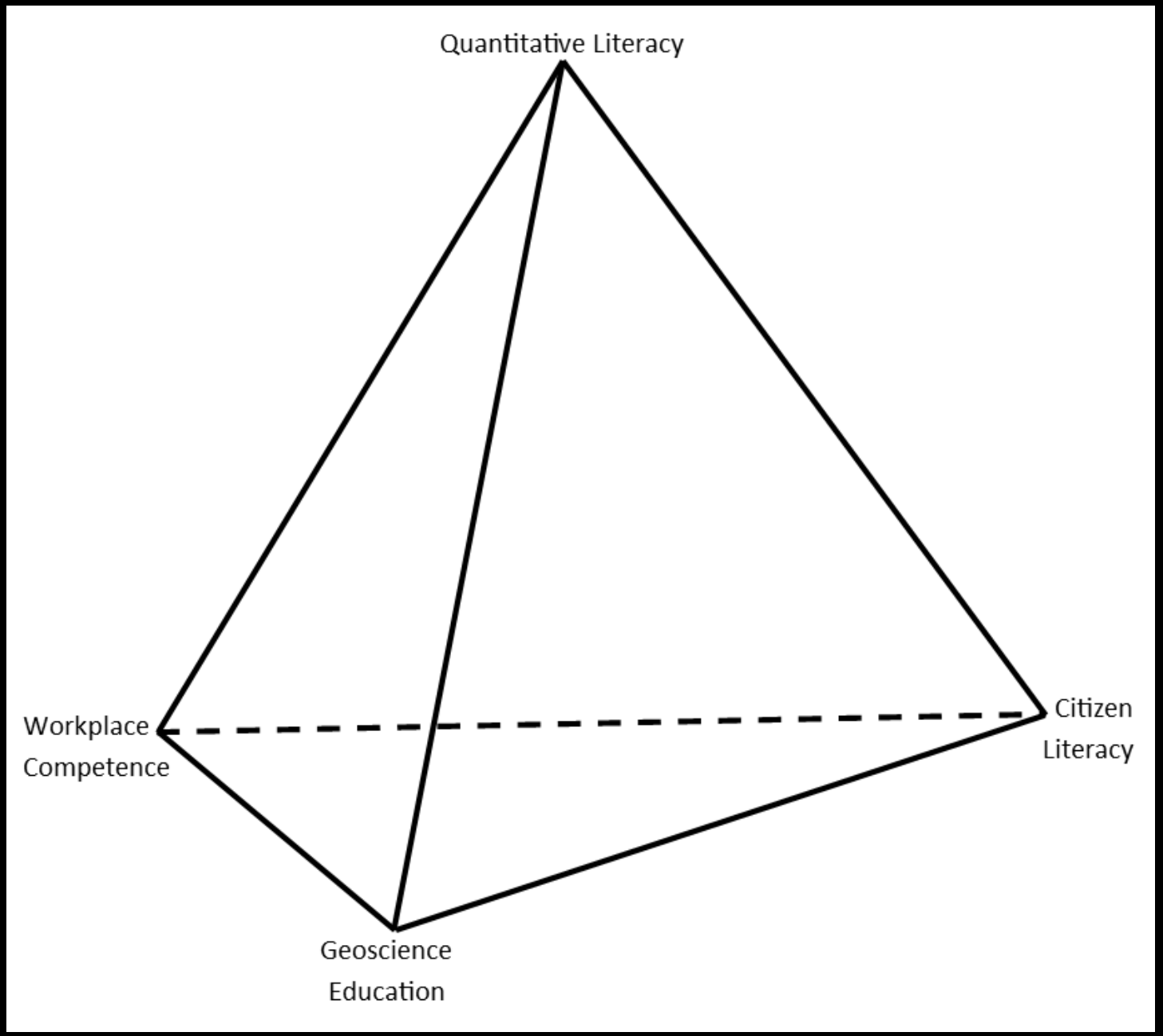






Confidence: Higher ⟵ Lower

Skill	Q	Yes	No	% Yes	% Yes	Yes	No	Q
Mental math	7.1	166	12	93%	97%	173	5	8.1
Pencil-and-paper math	7.2	153	25	86%	88%	156	22	8.2
Calculator math	7.3	164	14	92%	90%	161	17	8.3
Spreadsheet math	7.4	165	13	93%	69%	122	56	8.4
Programming for math	7.5	59	119	33%	10%	17	161	8.5
Unit conversions	7.6	164	14	92%	91%	162	16	8.6
Fractions	7.7	150	28	84%	87%	155	23	8.7
Proportions	7.8	136	42	76%	80%	142	36	8.8
Averages	7.9	171	7	96%	89%	158	20	8.9
Ratios	7.10	148	30	83%	74%	131	47	8.10
Estimating error	7.11	105	73	59%	19%	34	144	8.11
Significant digits	7.12	116	62	65%	17%	30	148	8.12
Trigonometry	7.13	96	82	54%	37%	66	112	8.13
Logarithms	7.14	61	117	34%	7%	12	166	8.14
Logarithmic scales/axes	7.15	95	83	53%	7%	13	165	8.15
Matrix algebra	7.16	32	146	18%	4%	8	170	8.16
Estimating probability	7.17	71	107	40%	35%	63	115	8.17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Workplace Competence
Citizen Literacy
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Skill	Q	Yes	No	% Yes	% Yes	Yes	No	Q
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Ratios	7.10	148	30	83%	74%	131	47	8.10

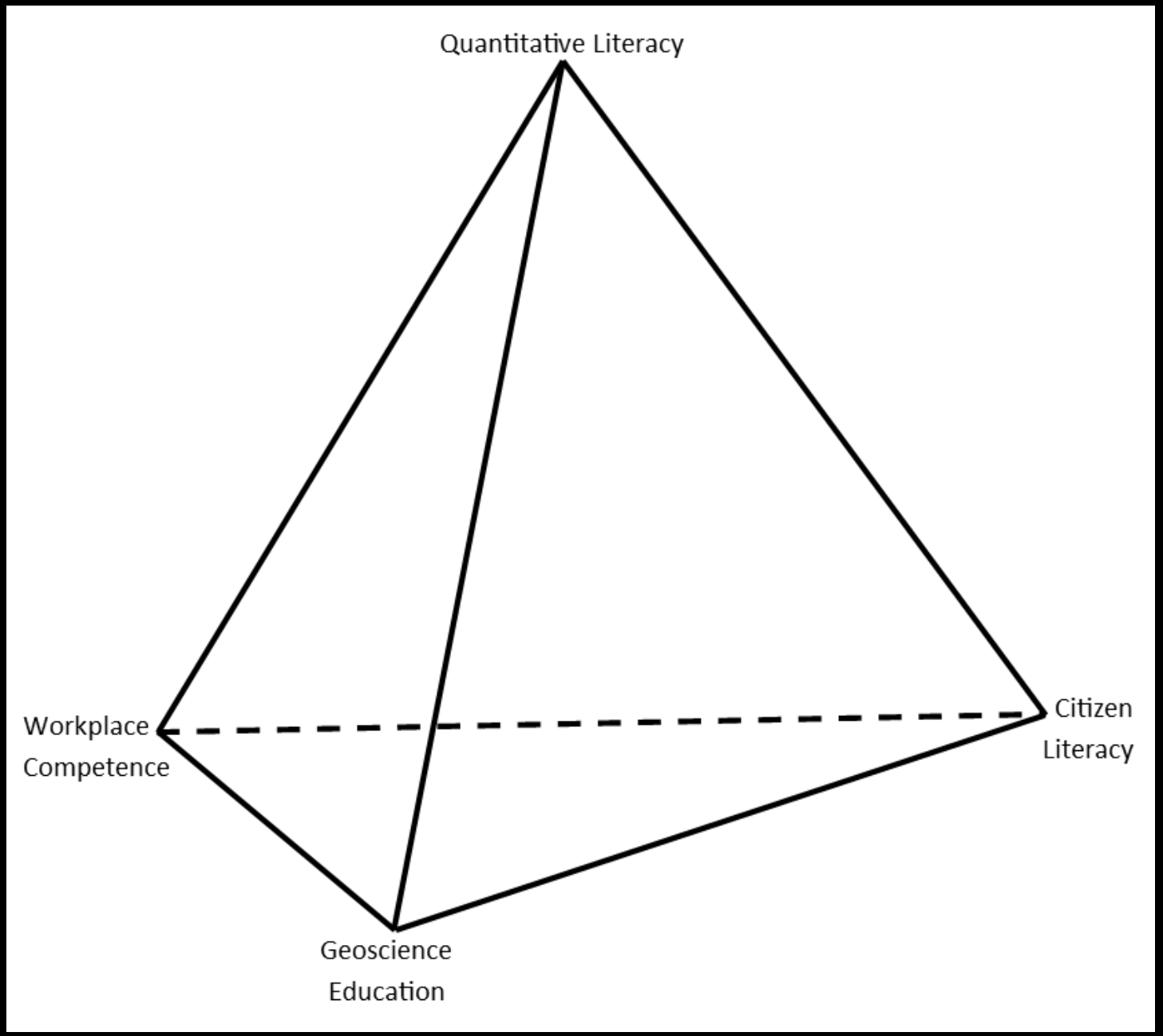
	Total		"Yes" only	
Question/Topic	Median	Skew	Median	Skew
Mental Math	2	0.8	2	0.7
Pencil/paper Math	2	0.6	2	0.7
Calculator Math	1	1.2	1	1.3
Spreadsheet Math	1	1.6	1	1.4
Programming Math	4	-0.7	2	0.6

	Total		"Yes" only	
Question/Topic	Median	Skew	Median	Skew
Unit Conversions	1	1.2	1	1.3
Percentages	1	1.6	1	1.5
Proportions	1	1.3	1	0.9
Ratios	2	1.3	1	1.4
Estimating Error	3	0.2	2	0.5
Sig Figs	2	0.7	2	0.6
Basic Trigonometry	2	1.0	1	1.7
Logarithms	3	0.1	2	0.6
Read/Report using Log Scales	2	0.7	2	1.1
Linear/Matrix Algebra	3	-0.2	2	0.3
Estimate Probability	3	0.1	2	0.3

Are these early career geologists “citizen literate”?

Yes

Skill	Q	Yes	No	% Yes	% Yes	Yes	No	Q
Mental math	7.1	166	12	93%	97%	173	5	8.1
Pencil-and-paper math	7.2	153	25	86%	88%	156	22	8.2
Calculator math	7.3	164	14	92%	90%	161	17	8.3
Spreadsheet math	7.4	165	13	93%	69%	122	56	8.4
Programming for math	7.5	59	119	33%	10%	17	161	8.5
Unit conversions	7.6	164	14	92%	91%	162	16	8.6
Fractions	7.7	150	28	84%	87%	155	23	8.7
Proportions	7.8	136	42	76%	80%	142	36	8.8
Averages	7.9	171	7	96%	89%	158	20	8.9
Ratios	7.10	148	30	83%	74%	131	47	8.10
Estimating error	7.11	105	73	59%	19%	34	144	8.11
Significant digits	7.12	116	62	65%	17%	30	148	8.12
Trigonometry	7.13	96	82	54%	37%	66	112	8.13
Logarithms	7.14	61	117	34%	7%	12	166	8.14
Logarithmic scales/axes	7.15	95	83	53%	7%	13	165	8.15
Matrix algebra	7.16	32	146	18%	4%	8	170	8.16
Estimating probability	7.17	71	107	40%	35%	63	115	8.17


Quantitative Literacy
Workplace Competence
Citizen Literacy
Geoscience Education

	Total		"Yes" only	
Question/Topic	Median	Skew	Median	Skew
Mental Math	2	0.8	2	0.7
Pencil/paper Math	2	0.6	2	0.7
Calculator Math	1	1.2	1	1.3
Spreadsheet Math	1	1.6	1	1.4
Programming Math	4	-0.7	2	0.6

	Total		"Yes" only	
Question/Topic	Median	Skew	Median	Skew
Unit Conversions	1	1.2	1	1.3
Percentages	1	1.6	1	1.5
Proportions	1	1.3	1	0.9
Ratios	2	1.3	1	1.4
Estimating Error	3	0.2	2	0.5
Sig Figs	2	0.7	2	0.6
Basic Trigonometry	2	1.0	1	1.7
Logarithms	3	0.1	2	0.6
Read/Report using Log Scales	2	0.7	2	1.1
Linear/Matrix Algebra	3	-0.2	2	0.3
Estimate Probability	3	0.1	2	0.3

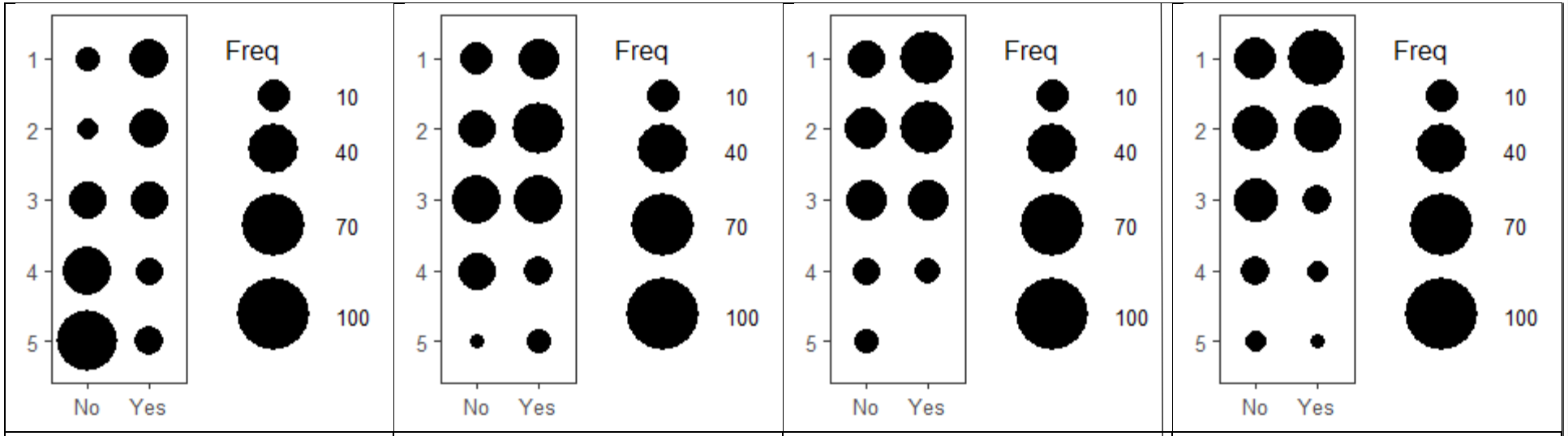
Skill	Q	Yes	No	% Yes	% Yes	Yes	No	Q
Programming for math	7.5	59	119	33%	10%	17	161	8.5
Estimating error	7.11	105	73	59%	19%	34	144	8.11
Significant digits	7.12	116	62	65%	17%	30	148	8.12
Trigonometry	7.13	96	82	54%	37%	66	112	8.13
Logarithms	7.14	61	117	34%	7%	12	166	8.14
Logarithmic scales/axes	7.15	95	83	53%	7%	13	165	8.15
Matrix algebra	7.16	32	146	18%	4%	8	170	8.16
Estimating probability	7.17	71	107	40%	35%	63	115	8.18

	Yes-only Values	
Skill	Median	Skewness
Programming Math	2	0.62
Estimating Error	2	0.52
Sig Figs	2	0.65
Basic Trigonometry	1	1.68
Logarithms	2	0.61
Read/Report using Log Scales	2	1.15
Linear/Matrix Algebra	2	0.34
Estimate Probability	2	0.29

Confidence

High

Low



Programming Math (3.5 vs. 7.5)	Estimate error (5.1 vs. 7.11)	Significant figures (5.2 vs. 7.12)	Basic trigonometry (5.3 vs. 7.13)

Logarithms (6.1 vs. 7.14)	Log Scales (6.2 vs. 7.15)	Linear/Matrix Algebra (6.3 vs. 7.16)	Estimate probability (6.4 vs. 7.17)

Are these early career geologists quantitatively literate relative to the demands of their careers?

Yes…

But there’s room to improve.

Correlations

Likert-style Question (Ordinal or Rank-Order Data)

I could tie a bow tie as well as Dr. Raker.

- Extremely confident
- Very confident
- Moderately confident
- Slightly confident
- Not at all confident

- All confidence and satisfaction Qs in this form.
- No actual numbers.
- Uneven intervals.
- Full Likert scale = series where you add scores for composite range. Not established here (yet).

Spearman Correlations for Math Supports

			Spearman's Rho				
Q/Topic	Median	Q#	3-1	3-2	3-3	3-4	3-5
Mental Math	2	3-1	X				
Pencil/paper math	2	3-2	0.59	X			
Calculator math	1	3-3	0.47	0.64	X		
Spreadsheet math	1	3-4	0.33	0.45	0.57	X	
Programming math	4	3-5	0.13	0.20	0.25	0.28	X

Spearman Correlations for Math Skills

			Spearman's Rho										
Q/Topic	Median	Q#	4-1	4-2	4-3	4-4	5-1	5-2	5-3	6-1	6-2	6-3	6-4
Unit Conversions	1	4-1	X										
Percentages	1	4-2	0.56	X									
Proportions	1	4-3	0.45	0.63	X								
Ratios	2	4-4	0.56	0.58	0.72	X							
Estimating Error	3	5-1	0.26	0.33	0.46	0.42	X						
Sig Figs	2	5-2	0.23	0.28	0.34	0.34	0.45	X					
Basic Trigonometry	2	5-3	0.43	0.39	0.51	0.61	0.37	0.30	X				
Logarithms	3	6-1	0.36	0.43	0.54	0.60	0.46	0.34	0.51	X			
Read/Report using Log Scales	2	6-2	0.31	0.41	0.47	0.52	0.43	0.33	0.44	0.70	X		
Linear/Matrix Algebra	3	6-3	0.20	0.20	0.28	0.34	0.32	0.25	0.23	0.44	0.29	X	
Estimate Probability	3	6-4	0.06	0.19	0.30	0.34	0.46	0.28	0.28	0.49	0.45	0.48	X

Spearman Correlations for Satisfaction

			Spearman's Rho					
Q/Topic	Median	Q#	9-1	9-2	9-3	10-1	10-2	10-3
Quant PS Skills - Dpmt - Satisf.	2	9-1	X					
Quant Com Skills - Dpmt - Satisf.	2	9-2	0.58	X				
Computer Skills -Dpmt - Satisf.	3	9-3	0.46	0.48	X			
Quant PS Skills - Uni - Satisf.	2	10-1	0.36	0.22	0.17	X		
Quant Com Skills - Uni - Satisf.	2	10-2	0.43	0.48	0.24	0.58	X	
Computer Skills - Uni - Satisf.	3	10-3	0.24	0.27	0.50	0.43	0.38	X

This means what?

- High to medium correlations show questions are closely related in topic.

- Correlations below 0.8 (all) show items are *not* collinear (do not ask the same question).

Overall Takeaways

- ECGs quantitatively literate at citizen level.
- ECGs functionally quantitatively literate as professional scientists (relative to the demands of their jobs). There's room for improvement.
  - Those not using higher-than-citizen QL skills had much lower confidence in those skills, especially computers.
- ECGs satisfied with UG prep in quantitative problem solving and quantitative communication.
- EC Geologists' satisfaction with computers is unclear.

So What?

- QL is contextual – it's on geoscience departments to teach it if we want students to have it.
- Professional science skills and competencies in QL realm we should be teaching (especially):
  - Error
  - Significant figures
  - Logarithms and log scales
  - Probability
  - **Computer programming to solve problems**
- Now we can start defining what skills might make up QL for STEM.

Next Steps

- Clean up the GQPS
- Widen to broader Geoscience
- Develop to formal instrument/scale
- Identify and locate ECP

XKCD https://xkcd.com/1403/