Teaching math and science as a logical system

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Objective

- Multiple indicators by international assessments show that cognitive capability of US students is behind to that of their Asian counterparts (e.g. PISA, TIMSS, Pearson's index of cognitive skills and educational attainment, Lynn's national IQ study…etc.)
- Shortcomings of rote learning, late boomer, poverty, and others arguments
- Why previous reforms didn't work (e.g. Back to basics, No child left behind, New Standards)?
- What can the US learn from Asia?
- Examples of teaching math and science as a mode of logical reasoning

OECD members as of the time of the study are in **boldface**.

Maths			Science			Reading		
1	Shanghai, China	613	1	Shanghai, China	580	1	Shanghai, China	570
2	Singapore	573	2	Hong Kong, China	555	2	Hong Kong, China	545
3	Hong Kong, China	561	3	Singapore	551	3	Singapore	542
4	Taiwan	560	4	**Japan**	547	4	**Japan**	538
5	**South Korea**	554	5	**Finland**	545	5	**South Korea**	536
6	Macau, China	538	6	**Estonia**	541	6	**Finland**	524
7	**Japan**	536	7	**South Korea**	538	7=	Taiwan	523
8	Liechtenstein	535	8	Vietnam	528	7=	**Canada**	523
9	**Switzerland**	531	9	**Poland**	526	7=	**Ireland**	523
10	**Netherlands**	523	10=	Liechtenstein	525	10	**Poland**	518
11	**Estonia**	521	10=	**Canada**	525	11=	Liechtenstein	516
12	**Finland**	519	12	**Germany**	524	11=	**Estonia**	516
13=	**Canada**	518	13	Taiwan	523	13=	**Australia**	512
13=	**Poland**	518	14=	**Netherlands**	522	13=	**New Zealand**	512
15	**Belgium**	515	14=	**Ireland**	522	15	**Netherlands**	511
16	**Germany**	514	16=	Macau, China	521	16=	Macau, China	509
17	Vietnam	511	16=	**Australia**	521	16=	**Switzerland**	509
18	**Austria**	506	18	**New Zealand**	516	16=	**Belgium**	509
19	**Australia**	504	19	**Switzerland**	515	19=	**Germany**	508
20=	**Ireland**	501	20=	**Slovenia**	514	19=	Vietnam	508
20=	**Slovenia**	501	20=	**United Kingdom**	514	21	**France**	505
22=	**Denmark**	500	22	**Czech Republic**	508	22	**Norway**	504
22=	**New Zealand**	500	23	**Austria**	506	23	**United Kingdom**	499
24	**Czech Republic**	499	24	**Belgium**	505	24	**United States**	498
25	**France**	495	25	Latvia	502	25	**Denmark**	496
26	**United Kingdom**	494	26	**France**	499	26	**Czech Republic**	493
27	**Iceland**	493	27	**Denmark**	498	27=	**Austria**	490
28	Latvia	491	28	**United States**	497	27=	**Italy**	490

Math [edit]

Fourth grade [edit]

TIMSS (1995)			TIMSS2003			TIMSS2007			TIMSS2011		
1.	Singapore	625	1.	Singapore	594	1.	Hong Kong	607	1.	Singapore	606
2.	South Korea	611	2.	Hong Kong	575	2.	Singapore	599	2.	South Korea	605
3.	Japan	597	3.	Japan	565	3.	Taiwan	576	3.	Hong Kong	602
4.	Hong Kong	587	4.	Taiwan	564	4.	Japan	568	4.	Taiwan	591
5.	Netherlands	577	5.	Flanders (Belgium)	551	5.	Kazakhstan	549	5.	Japan	585
6.	Czech Republic	567	6.	Netherlands	540	6.	Russia	544	6.	Northern Ireland	562
7.	Austria	559	7.	Latvia	536	7.	England (and Wales)	541	7.	Flanders (Belgium)	549
8.	Slovenia	552	8.	Lithuania	534	8.	Latvia	537	8.	Finland	545
9.	Ireland	550	9.	Russia	532	9.	Netherlands	535	9.	England (and Wales)	542
10.	Hungary	548	10.	England (and Wales)	531	10.	Lithuania	530	10.	Russia	542

- Rote learning vs. problem solving?: These Asian countries/regions had the highest percentages of students reaching the Advanced International Benchmark for science.
- At Grade 4, Singapore and Taiwan had 36 and 19 percent of their students, respectively, achieving at or above the benchmark.
- At Grade 8, Singapore and Taiwan had 32 and 25 percent of their students, respectively, meeting at or exceeding the benchmark.
- The medians: 7 percent at Grade 4 and 3 percent at Grade 8.

Pearson's study

Index of cognitive skills and educational attainment

Index ranking 2014 | Index heat map | Index ranking 2014 v 2012 | How to use

A to Z	Overall Index rank and score		Cognitive Skills rank and score		Educational Attainment rank and score	
SOUTH KOREA	[Rank 1]	1.30	[Rank 2]	1.35	[Rank 1]	1.19
JAPAN	[Rank 2]	1.03	[Rank 4]	1.20	[Rank 6]	0.70
SINGAPORE	[Rank 3]	0.99	[Rank 1]	1.65	[Rank 33]	-0.33*
HONG KONG-CHINA	[Rank 4]	0.96	[Rank 3]	1.34	[Rank 18]	0.20*
FINLAND	[Rank 5]	0.92	[Rank 5]	0.99	[Rank 4]	0.79
UNITED KINGDOM	[Rank 6]	0.67	[Rank 8]	0.52	[Rank 2]	0.96
CANADA	[Rank 7]	0.60	[Rank 6]	0.77	[Rank 15]	0.25
NETHERLANDS	[Rank 8]	0.58	[Rank 7]	0.57	[Rank 7]	0.58
IRELAND	[Rank 9]	0.51	[Rank 10]	0.49	[Rank 10]	0.55
POLAND	[Rank 10]	0.50	[Rank 16]	0.33	[Rank 3]	0.85
DENMARK	[Rank 11]	0.46	[Rank 17]	0.32	[Rank 5]	0.75
GERMANY	[Rank 12]	0.41	[Rank 12]	0.48	[Rank 14]	0.28
RUSSIA	[Rank 13]	0.40	[Rank 9]	0.50	[Rank 21]	0.19*
UNITED STATES	[Rank 14]	0.39	[Rank 11]	0.49	[Rank 20]	0.19
AUSTRALIA	[Rank 15]	0.38	[Rank 13]	0.43	[Rank 13]	0.29
NEW ZEALAND	[Rank 16]	0.35	[Rank 21]	0.23	[Rank 8]	0.57*

From Intelligence and the Wealth and Poverty of Nations by Richard Lynn

Rank	Country	IQ estimate
1	Hong Kong	107
2	South Korea	106
3 ^	Japan	105
4	Taiwan	104
5	Singapore	103
6 *	Austria	102
6 ^	Germany	102
6 **	Italy	102
6 *	Netherlands	102
10	Sweden	101
10	Switzerland	101
12	Belgium	100
12 **	China	100
12	New Zealand	100
12 **	United Kingdom	100
16	Hungary	99
16	Poland	99
16 **	Spain	99
19	Australia	98
19	Denmark	98
19 *	France	98
19	Mongolia	98
19	Norway	98
19 *	United States	98

Richard Lynn's study

Late boomers? OECD on adults

OECD on US adults

- Thirty-six million American adults have low skills.
- In numeric and technological proficiency, young Americans ages 16 to 24 rank last.
- Learner's proficiency peak at age 30 and then going down.
- Start out with bad education and low skills → persist throughout their entire lives.

USSR is gone!

- Ravitch said, “The Soviet Union launched its Sputnik satellite in 1957. We did not respond by raising our test scores on international assessments… something is wrong with those international assessments, if our allegedly terrible public schools continue to produce the greatest workers, thinkers, leaders, and innovators that created the greatest economy in the world. The Soviet Union is gone, but we are still here!”

Poverty argument

- Martin Caroy and Richard Rothstein (2013): Disadvantaged students are oversampled in the US.
- David Berliner: If we remove the US students from the lowest SES, the US students are the best in PISA.
- What if we do the same in other samples?

TABLE 2A

Share of PISA 2009 sample in each social class group, by country

Social class group	Canada	Finland	Korea	France	Germany	U.K.	U.S.
Group 1 (Lowest)	9%	6%	5%	15%	12%	14%	20%
Group 2	13	11	9	17	13	16	18
Group 3	31	34	31	31	29	29	28
Group 4	21	23	23	18	19	18	16
Group 5	17	20	22	13	16	15	12
Group 6 (Highest)	9	6	9	7	10	8	6

Source: Authors' analysis of OECD Program for International Student Assessment (PISA) 2009 database for each country

Overall average scale scores, mathematics, for U.S. and six comparison countries, PISA 2009 (with standardization for average social class distribution in top-scoring countries)

	TOP SCORING				SIMILAR POST-INDUSTRIAL				U.S.	U.S. VERSUS:	
	Canada	Finland	Korea	Average*	France	Germany	U.K.	Average*		Top-scoring average	Similar post-industrial average
National average math score (from Table 1)	527	541	546	538	497	513	492	501	487	-50	-13
National average math score, standardized for top-scoring country average social class distribution	531	541	543	538	513	522	504	513	504	-34	-9
Difference between social class standardized math scores and actual average reading scores	4	0	-3	0	17	10	11	13	17		

* Simple (unweighted) average of three countries

Current reform

- NATIONAL ACADEMY OF SCIENCES
- NATIONAL ACADEMY OF ENGINEERING
- INSTITUTE OF MEDICINE
- NATIONAL RESEARCH COUNCIL

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

ISBN
978-0-309-21742-2

320 pages
8 1/4 x 10
PAPERBACK (2012)

Committee on Conceptual Framework for the New K-12 Science Education Standards; National Research Council

Goals of the new framework

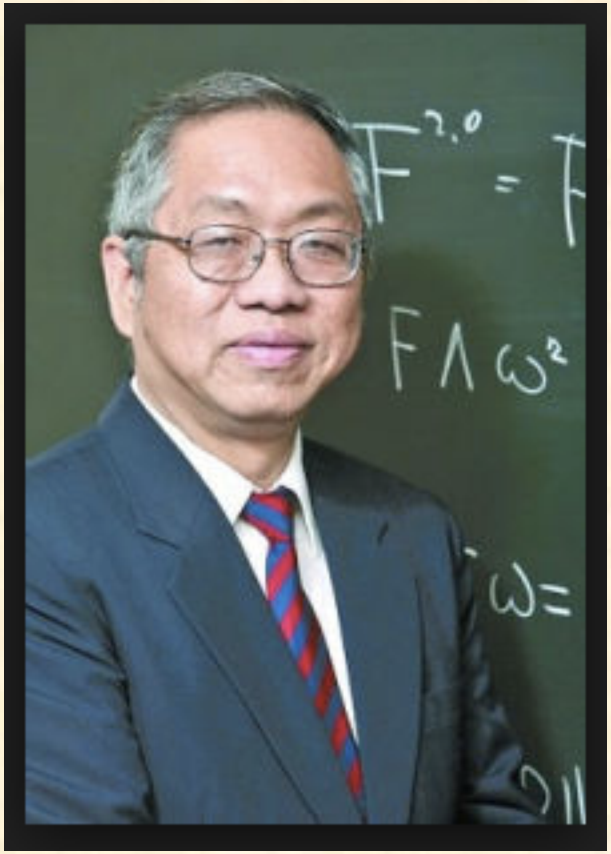
- by the end of 12th grade, all students have some appreciation of the beauty and wonder of science
- possess sufficient knowledge of science and engineering to engage in public discussions on related issues
- are careful consumers of scientific and technological information related to their everyday lives
- are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology.

Numerous previous proposals and reforms

- 1980s: Back to the basic
- American Association for the Advancement of Science (AAAS) (1993): Science for All Americans and Benchmarks for Science Literacy
- NRC (1996): National Science Education Standards
- No Child Left behind (2002)
- AAAS: Project 2061
- National Science Teachers Association (2009): Anchors project
- But does it help to write more reports?

Shing-Tung Yau 邱成桐

- Chinese (Hong Kong) American Mathematician
- Versed in Chinese literature and history
- To be proficient in math and science, the learner must learn humanity
- Humanity gives us passion
- A scientist needs passion



Passion

- To build passion the learner need to see the value.
- You won't love a person or a subject matter if you don't see it valuable.
- We can look outside math and science (literature, humanity) to build passion.
- But how about within math and science?

Interviews in Asia

- By interviewing students, teachers, parents, and professors in several top-performing countries/regions in TIMSS and PISA in June and July 2014, the authors found that learners in these countries/regions, contrary to the popular belief, were not motivated by career prospects.

	High school students/graduates	Parents	High school teachers	Professors
Taiwan	5	5	21	2
Hong Kong & Macau	7	4	2	3

US has the incentives

- The US has the world's largest high tech economy that provides financial incentives for learning and science.
- The US also has the world's strongest basic (theoretical) research infrastructure supported by NSF that provides the environment for studying subatomic particles, cosmology…etc.

However…

- In 2003, of the 21.6 million scientists and engineers in the US, 16% (3,352,000) were immigrants (Kannankutty & Burrelli, 2007).
- In the same year, foreign-born doctorate holders represented approximately 50% of the workforce in engineering and computer science, and 37% and 43% of the workers in the physical sciences and mathematics, respectively (National Science Board, 2010).

Graduate degrees

- National Science Foundation reported that in 2006 foreign students earned about 36.2% of the doctoral degrees in the sciences and about 63.6% of the doctoral degrees in engineering. At the postdoctoral level, 56% in engineering are foreign doctorate holders, 50% in mathematics, and 42% in physical sciences (Salzman & Lowell, 2008).

National Foundation for American Policy: 2010 figures

Full-time Graduate Students and the Percent of International Students by Field (2010)

Field	Percent of International Students	Number of Full-time Graduate Students – International Students	Number of Full-time Graduate Students – U.S. Students
Electrical Engineering	70.3%	21,073	8,904
Computer Science	63.2%	20,710	12,072
Industrial Engineering	60.4%	5,057	3,314
Economics	55.4%	7,587	6,117
Chemical Engineering	53.4%	4,012	3,504
Materials Engineering	52.1%	2,660	2,891
Mechanical Engineering	50.2%	8,352	8,273
Mathematics & Statistics	44.5%	7,840	9,766
Physics	43.7%	5,716	7,369
Civil Engineering	43.7%	6,202	7,989
Other Engineering	42.1%	7,279	9,992
Chemistry	40.3%	8,059	11,952

Source: National Science Foundation, Survey of Graduate Students and Postdoctorate, webcaspar.nsf.gov. U.S. students include lawful permanent residents.

Nobel prizes

- Between 1950 and 2005, 27 of the 87 American Nobel Prize winners were born outside the US (Vilcek & Cronstein, 2006).
- Counting from 1990, about half of the US Nobel laureates in the scientific and technical disciplines were foreign-born.

Incentives are much weaker…

- Both Hong Kong and Macau are service-oriented economies, and therefore finding a job directly related to math and science is difficult.
- HK economic composition by sector (2008):
  - Manufacturing: 2.3%
  - Finance: 25%
  - Services: 34.7%
  - Others: 11.6%

Incentives are much weaker…

- Although Taiwan has a flourishing high tech industry, engineer is by no means a high-paying job.
- The infrastructure of basic research in Taiwan is significantly weaker than that in the US and Europe
- There is no basic research at all in Hong Kong and Macau.

In spite of, not because of

- In spite of the absence of a direct career path to the fields related to math and science, these societies treasure the intrinsic values of math and science.
- Many stakeholders express that learning math and science could enhance one's logical reasoning, and this mode of reasoning can be well-applied to all other domains.

What is behind science?

- Based on this finding the research team suggests that the value/logical system of math and science should be taught side by side with the factual contents.
- A new pedagogy is under development with the aim of guiding the learners to embrace the logics behind math and science as an all-encompassing tool in life.

Example 1:
Logarithm transformation

- Many US high school students cannot see the purpose of learning abstract math that seems to be very remote from reality.
- After the exam, they hit a "delete" button.

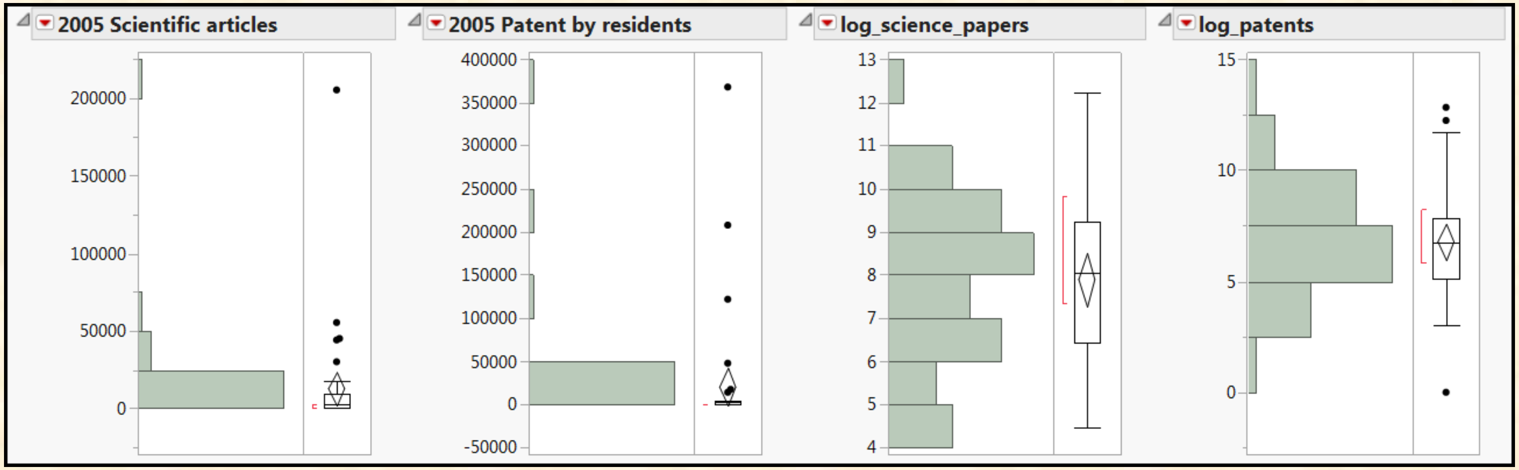
Logarithm	Exponent Form	Number	
0	10^{0}	1	($\log_{10} 0 = 1$)
0.08720	$10^{0.08720}$	1.222	($\log_{10} 1.222 = 0.087$)
0.39076	$10^{0.39076}$	2.459	($\log_{10} 2.459 = 0.39076$)
0.69644	$10^{0.69644}$	4.971	($\log_{10} 4.971 = 0.69644$)
1	10^{1}	10	($\log_{10} 10 = 1$)

Logic behind transformation

- Scaling is human-made. This is not an inherent property of an object.
- The logic of log transformation is: transformation → rescaling → emergence of hidden patterns.
- This logic can be well applied to many other forms of problem-solving.
- You can unveil the hidden patterns of this world (passion)!

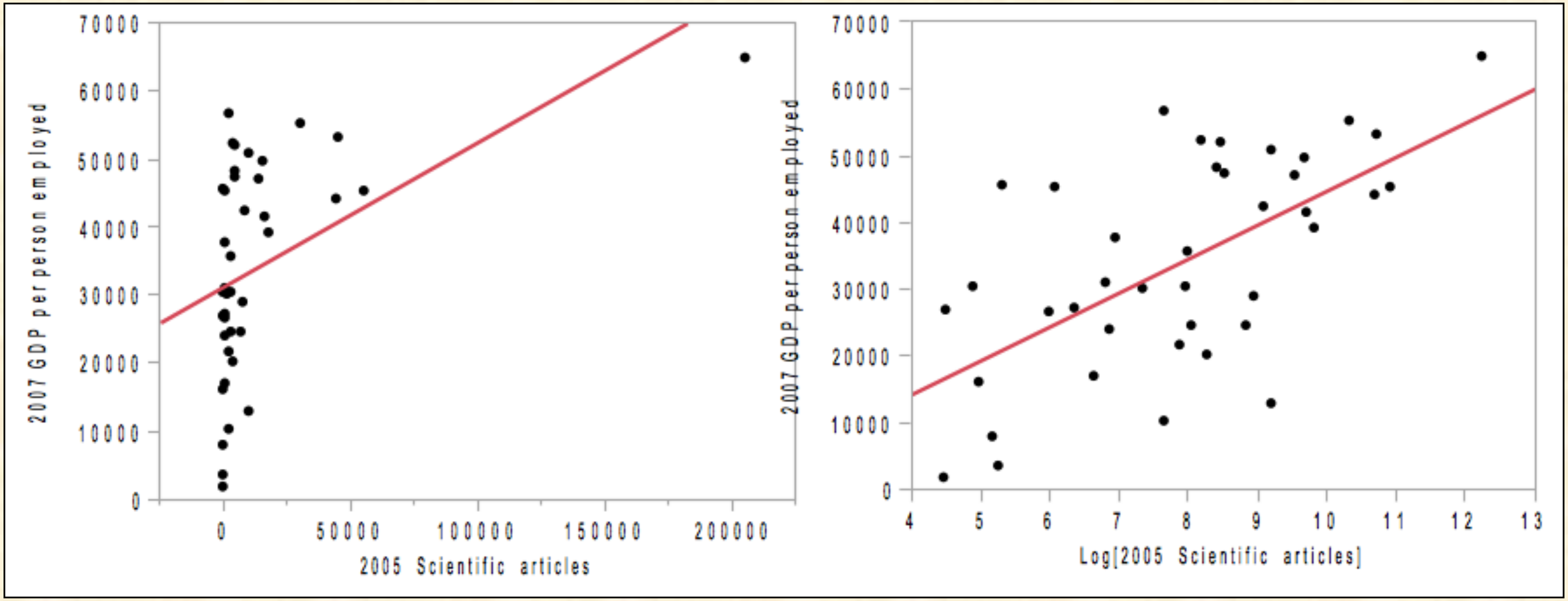
Hidden pattern

- The distributions of publication of scientific studies and patents are skewed. A few countries (e.g. US, Japan) have the most.
- Log transformation can normalize them.



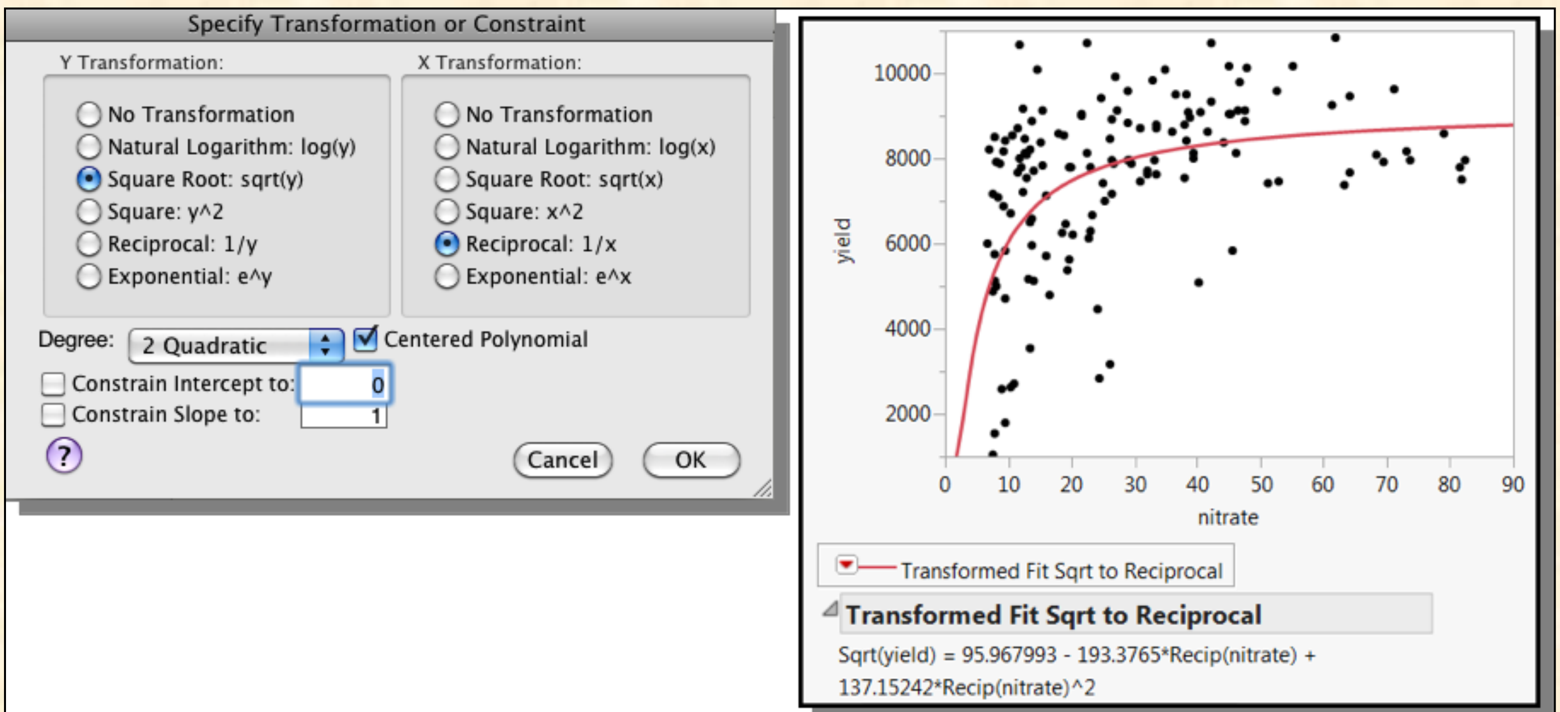
Before and after transformation

- It makes more senses!



Other transformations

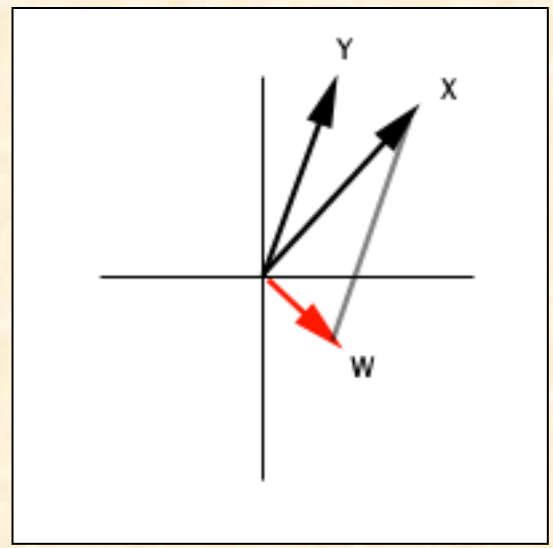
- The logic of transformation can be well-applied to other scenarios.



Example 2: Matrix algebra and vector geometry

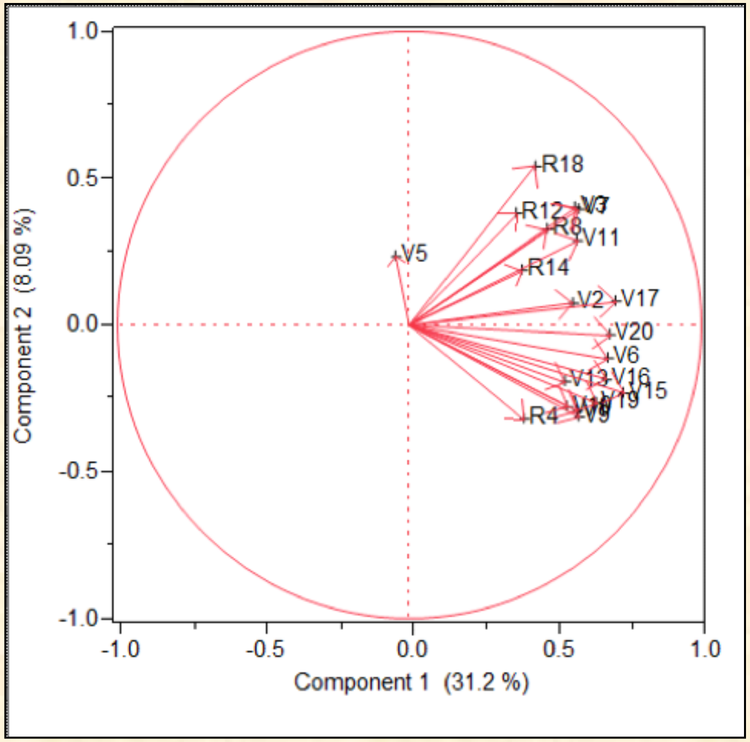
- "Why do we learn these?"

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix}.$$



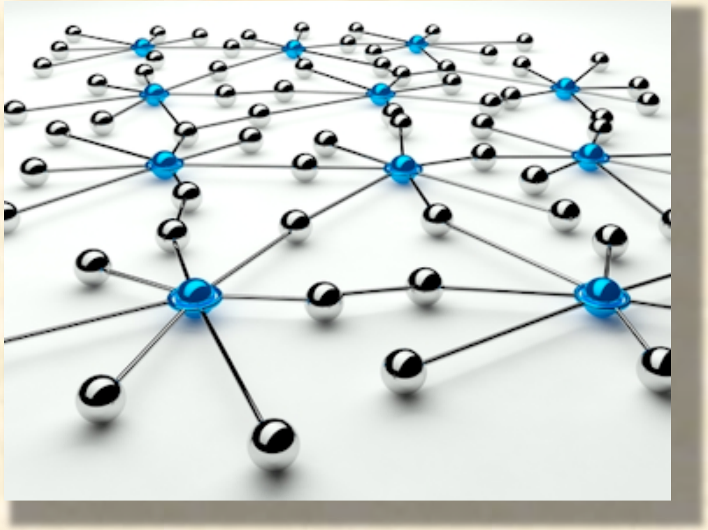
Logic behind…

- When we conceptualize data as matrices and translate algebraic equations into vector graphs, we can find out relationships between objects and phenomena.
- This logic can be well-applied to many scenarios.



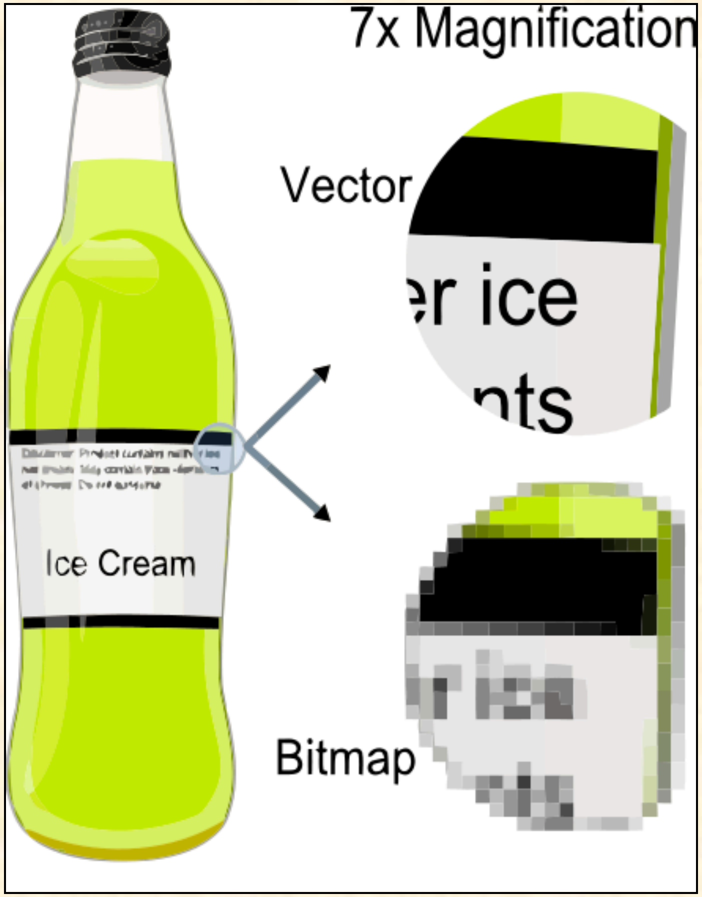
Distance Vector Protocol

- The Distance Vector Protocol is used for a network router to determine which path is the best way to transmit data.
- The router must know two things: Distance (how far is the destination from the source?) and Vector (To what direction should the data travel?)



Computer graphics

- In vector-based graphics, the image is defined by the relationships among vectors instead of the composition of pixels.
- For example, to construct a shape, the software stores the information like "Start from point A, draw a straight line at 45 degrees, stop at 10 units, draw another line at 35 degrees..." In short, the scalars and vectors of vector-based graphics define the characteristics of an image.
- More efficient and sharper image!



Expanding the logical reasoning

- Transformation and rescaling: don't accept anything as the default, transformation (changing representation) can unveil hidden patterns of the problem under study.
- Translate data into matrices, convert matrices into vectors: examine relationships to see the "big picture" instead of looking at the detail.

Question?

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