Effects of mathematical skills on labour market outcomes and life conditions

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Annual earnings (incl. pension) for college graduates 2012-2016, 5 years after college

Source: cepos, Statistics Denmark.

Rank	Formal label	Education	Income (kr)
1	cand.act.	Insurance mathematics	916.000
2	cand.polyt.	Engineering (wireless comm)	795.000
3	cand.merc.(mat.)	Business economics and mathematics	768.200
4	cand.oecon.	Economics	756.600
5	cand.polyt.	Engineering (business systems)	756.300
6	cand.polit.	Economics	755.200
7	cand.odont.	Dentistry	754.300
8	cand.polyt.	Engineering (supply chain and innovation mgmt)	753.000
9	cand.polyt.	Engineering (pharma-technolgy)	746.300
10	civilingeniør	Information technology	735.400
11	cand.merc.aud.	Auditing	725.600
12	cand.med.	Medicine	718.200
13	cand.polyt.	Engineering (chemistry)	716.100
14	cand.polyt.	Engineering (industrial economics and tech)	715.600
15	cand.polyt.	Engineering (software development)	708.000
16	cand.polyt.	Engineering (robot tech)	703.000
17	cand.scient.	Computer science	701.900
18	cand.polyt.	Engineering (computer tech)	698.500
19	cand.scient.oecon.	Mathematics-economics	695.500
20	cand.merc.(bio)	Business economics and bio entrepreneurship	693.700
21	cand.oecon.agro.	Agricultural economics	691.800
22	cand.polyt.	Engineering (comm tech)	689.600
23	cand.merc.(it)	Business economics and IT	686.700
24	cand.polyt.	Engineering (systems design)	686.400
25	cand.polyt.	Engineering (tech-based business dev)	680.700
26	cand.polyt.	Engineering (maths and computing)	675.100
27	cand.jur.	Law	671.600
28	cand.soc.	Business economics	670.100
29	cand.it.	Software design	667.400
30	cand.merc.	Business economics	666.600
31	cand.san.	Health and information	666.000
32	cand.scient.tech.	Construction management	664.700
33	cand.polyt.	Engineering (AI)	662.700
34	cand.polyt.	Engineering (construction)	662.100
35	cand.polyt.	Engineering (Electro tech)	660.100
36	cand.polyt.	Engineering (mechanics)	658.700
37	cand.it.	Communication and IT	650.600
38	cand.merc.(jur.)	Business economics and law	649.200
39	cand.polyt.	Engineering (physics)	648.600
40	cand.scient.	Statistics	647.900
41	cand.geom.	Land surveyor	642.800
42	cand.polyt.	Engineering (medicine and tech)	641.800
43	cand.pharm.	Pharmacology	641.400
44	cand.lact.	Dairy science	641.000
45	cand.polyt.	Engineering (product development)	640.400
46	cand.scient.tech.	Management and information in construction	637.700
47	cand.polyt.	Engineering (autonomous systems)	637.500
48	cand.polyt.	Engineering (material and process tech)	636.100
49	cand.scient.	Information technology	633.900
50	cand.merc.(pol.)	Business economics and politics	632.600
51	cand.polyt.	Engineering (vision, graphics etc)	631.300
52	cand.polyt.	Engineering (regulation and automation)	631.000
53	cand.scient.	Interdisciplinary science education	630.200
54	cand.polyt.	Engineering (chemistry and bio-chem tech)	628.500
55	cand.it.	Digital innovation and management	628.000
56	cand.polyt.	Engineering (construction tech)	626.700
57	cand.scient.pol.	Political science	625.800
58	cand.it.	IT, communication and organisation	624.500
59	cand.polyt.	Construction management	624.200
60	cand.polyt.	Engineering (transportation and logistics)	622.900

Math skills are scarce skills

- In the production process, input factors in short supply receive a “rent”
- Standard examples
  - access to natural resources
  - location close to a river
  - patent
  - etc.
- Other examples
  - workers with an extraordinary talent or authorization
    - e.g. athletes, artists, surgeons, musicians
  - workers with scarce skills
    - e.g. quantitative or mathematical skills
- Careers requiring math skills pay more due to scarcity of those skills

Math skills are scarce skills

- Paglin & Rufolo (1990) used this to explain the gender wage gap 😐
  - Males and females receive the exact same return to quantitative skills
  - Males more often possess high-level quant skills than females (due to curriculum choice)

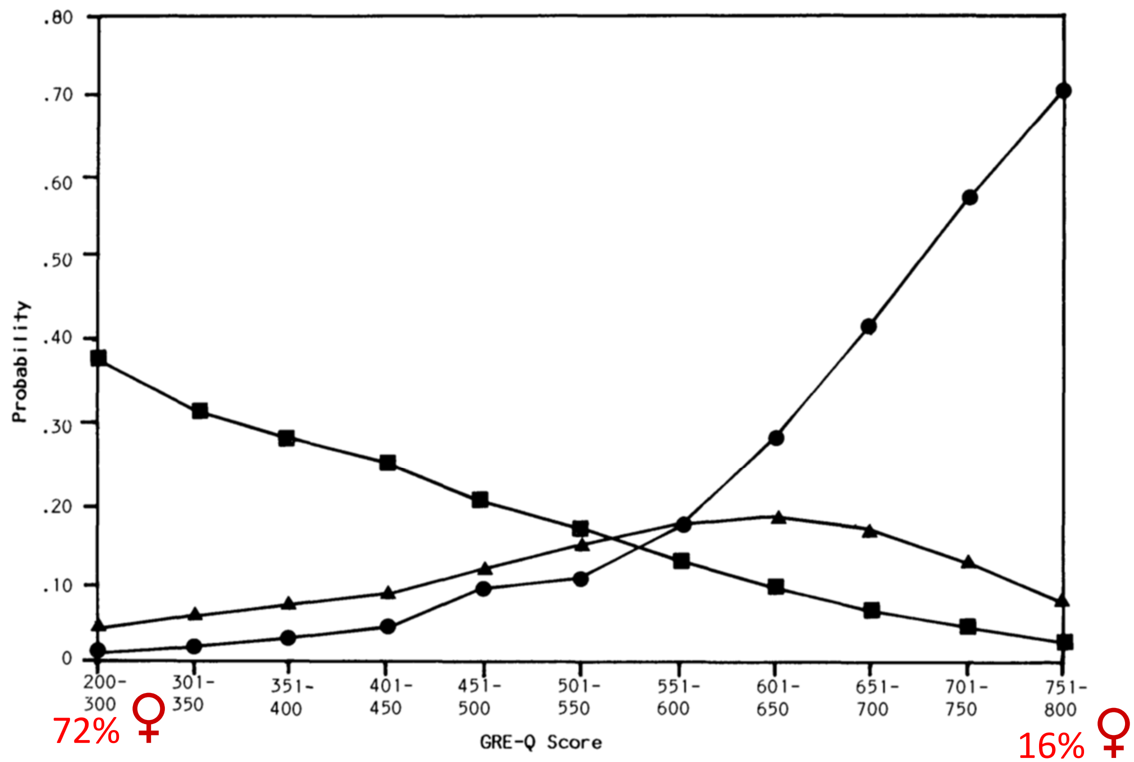

FIG. 2.—Probability of major by GRE-Q. Probabilities in each GRE-Q interval would total 100% if all subject majors were shown. Source.—Derived from Educational Testing Service data, tape of all test takers in academic year 1981–82 (see Goodison 1983). ■ Education and social science (excludes economics); ▲ biological and health sciences; ● engineering, math, and physical sciences.

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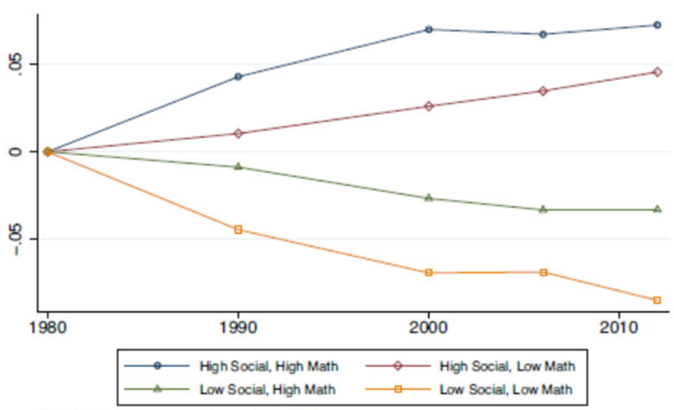
Math skills are scarce skills

- Math and quant skills are no longer enough
  - Higher-order skills needed
    - evaluation, problem-solving, critical thinking, make connections to new ideas, etc. etc.
  - Social skills are needed
    - teamwork, interpersonal skills
- Such skills allow us to trade tasks with each other in a team and exploit our comparative advantages

Math skills are scarce skills

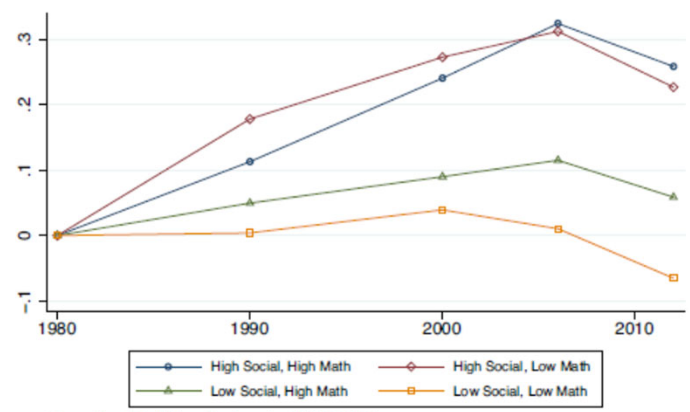
- Deming (2017) studies the combination of math and social tasks
- High employment and wage growth in math-intensive occupations ***if*** combined with social tasks



Occupational Task Intensities based on 1998 O*NET

FIGURE IV

Cumulative Changes in Employment Share by Occupation Task Intensity, 1980–2012



Occupational Task Intensities based on 1998 O*NET

FIGURE V

Cumulative Changes in Real Hourly Wages by Occupation Task Intensity, 1980–2012

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Math skills are scarce skills

- … across the entire distribution

FIGURE A.3

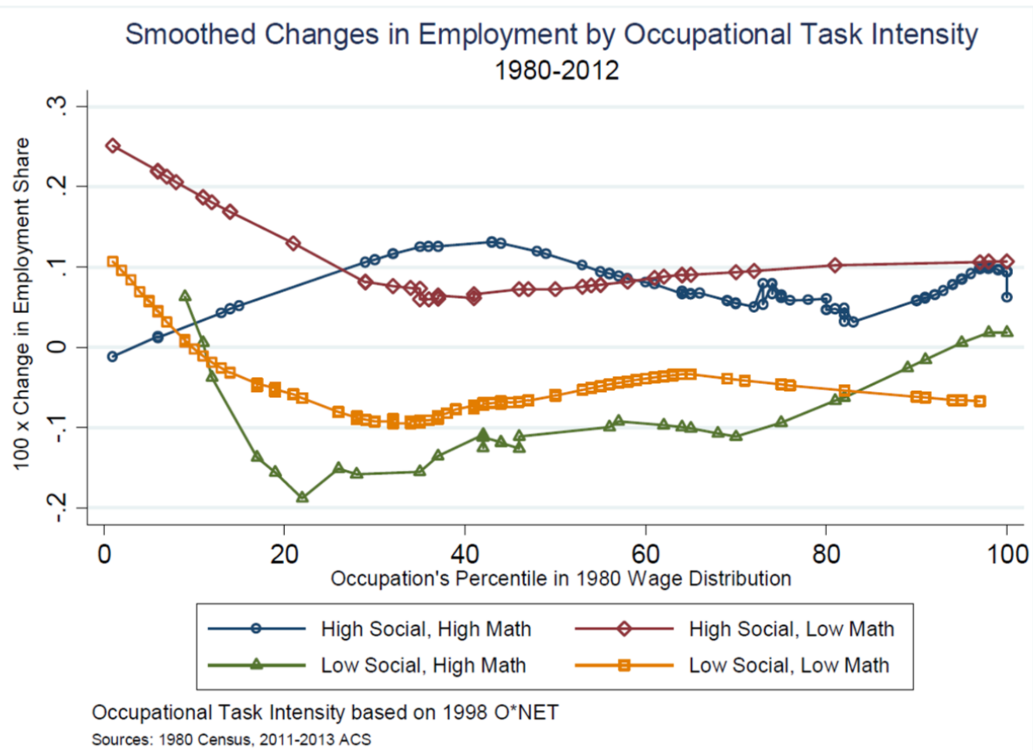
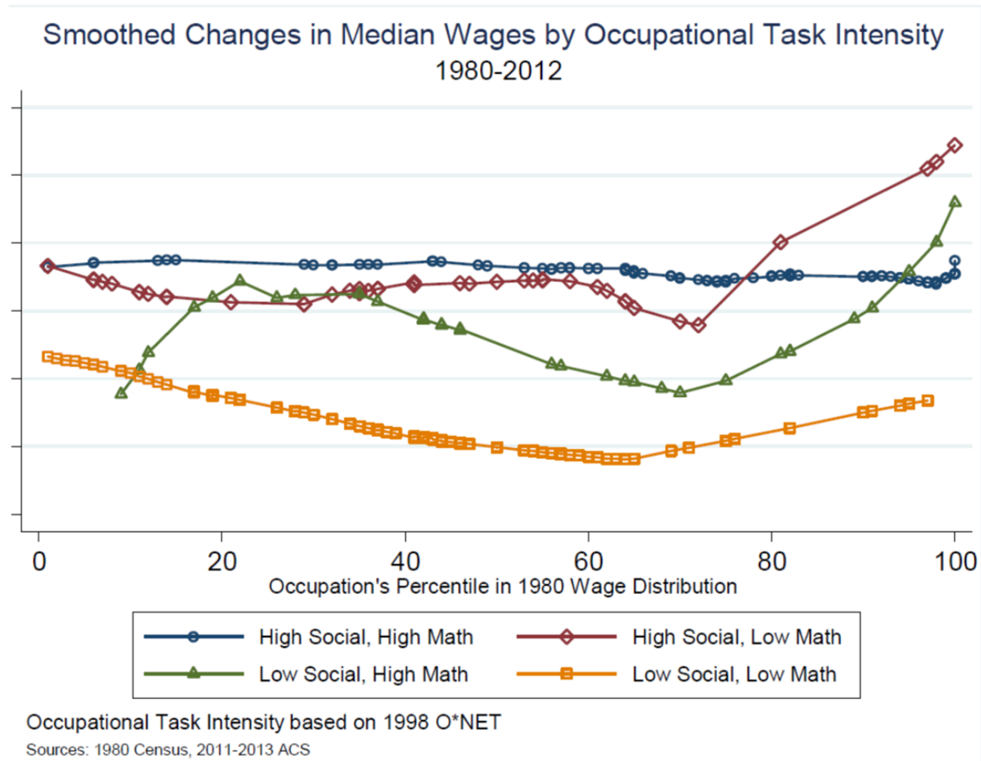


FIGURE A.4



Do high school students acquire advanced math skills?

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Only few Danish high school students do:

Ordinary academic track, STX (N=27865)	
English A, Social science A	30%
Biology A, Chemistry B	15%
Math A, Social science A	14%
Math A, Physics B, Chemistry B	9%
Bio-tech A, **Math A**, Physics B	8%
Any course package w/Math A	**36%**

Business tracks, HHX (N=9615)	
Marketing A, Bus. economics A	42%
Marketing A, Int. economics A	29%
Marketing A, Innovation B	11%
Int. econ. A, Bus. econ. A	8%
Math A, Bus. economics A	7%
Any course package w/Math A	**8%**

Technical tracks, HTX (N=5008)	
Physics A, **Math A**	19%
Bio-tech A, **Math A**	19%
Tech A, Design B	14%
Math A, Programming B	10%
Comm./IT A, Programming B	8%
Any course package w/Math A	**61%**

- 32% of the high school cohort 2019/20 chose a course package with Math A
- **Policy option: introduce a new (attractive) course package with Math A?**

How to improve math skills in high school?

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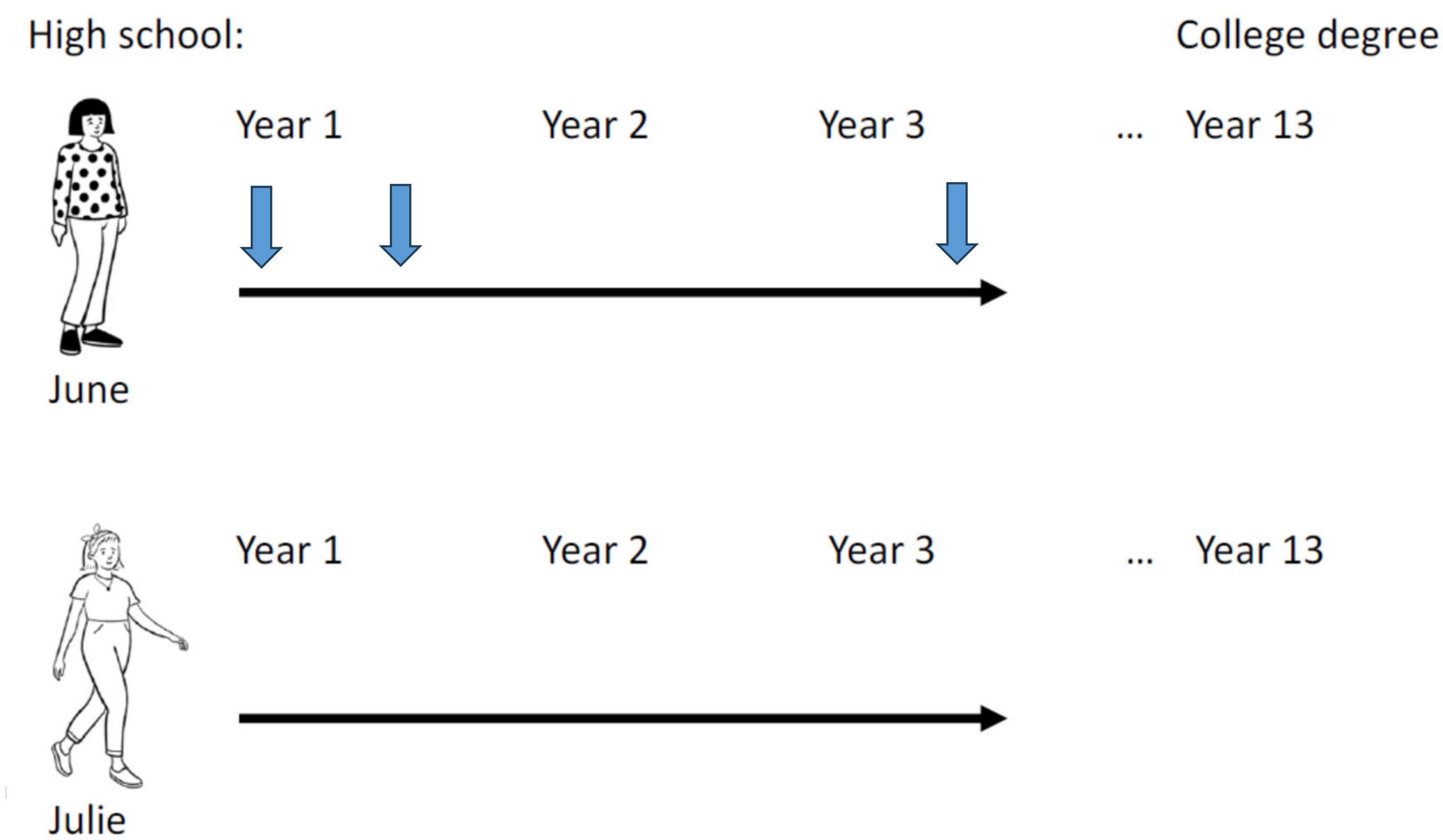
Causal inference from policy variation

- Random experiments
  - Large-scale policy experiments are rare
- Quasi-experiments
  - Plausibly exogenous policy variation affecting a fraction of the population
- Four examples
  1. New course package (Joensen & Nielsen, 2016)
     - unanticipated introduction after school start (instrumental variables strategy)
  2. Semi-external assessment of math (Burgess et al. 2021)
     - random draw of exam course in high school (random assignment)
  3. Double-dose algebra (Nomi et al. 2021, Cortes et al. 2015)
     - students below a test score cutoff assigned to support course (regression discontinuity design)
  4. Growth mindset intervention (Bettinger et al. 2018, Rege et al. 2021)
     - randomized controlled trial

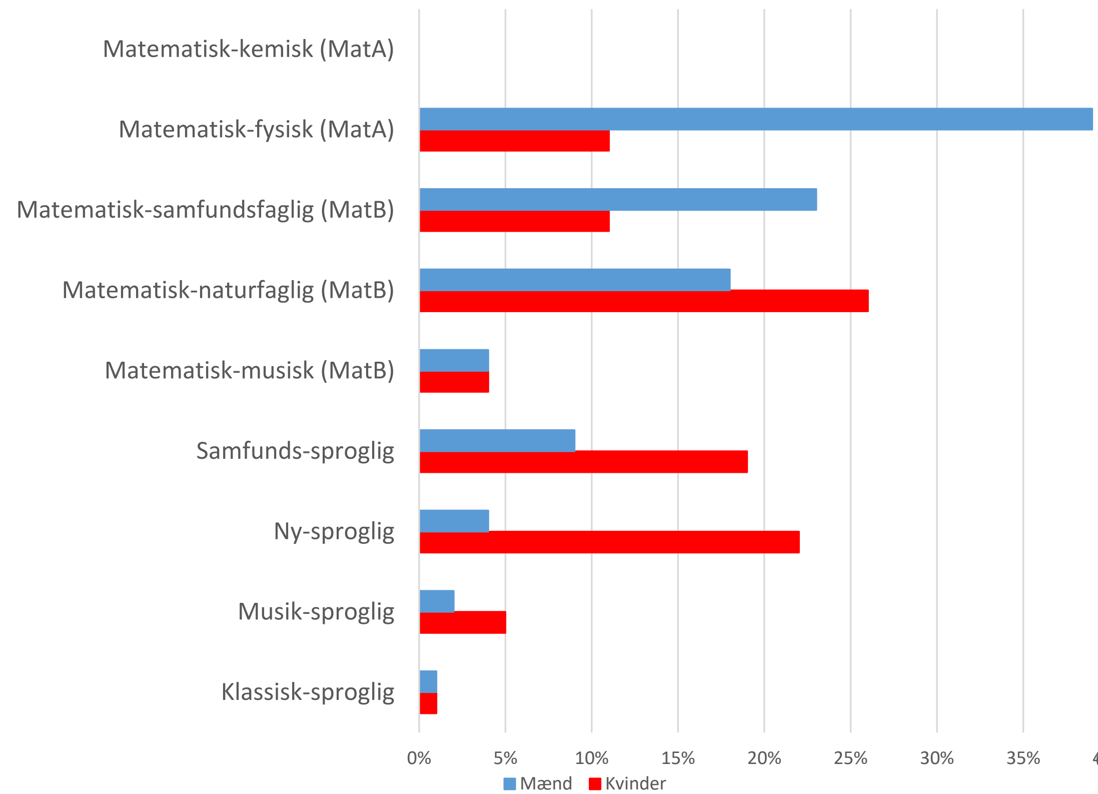
Causal inference from policy variation

- June is treated
- Julie is control
- Exposed to as-good-as-random policy variation

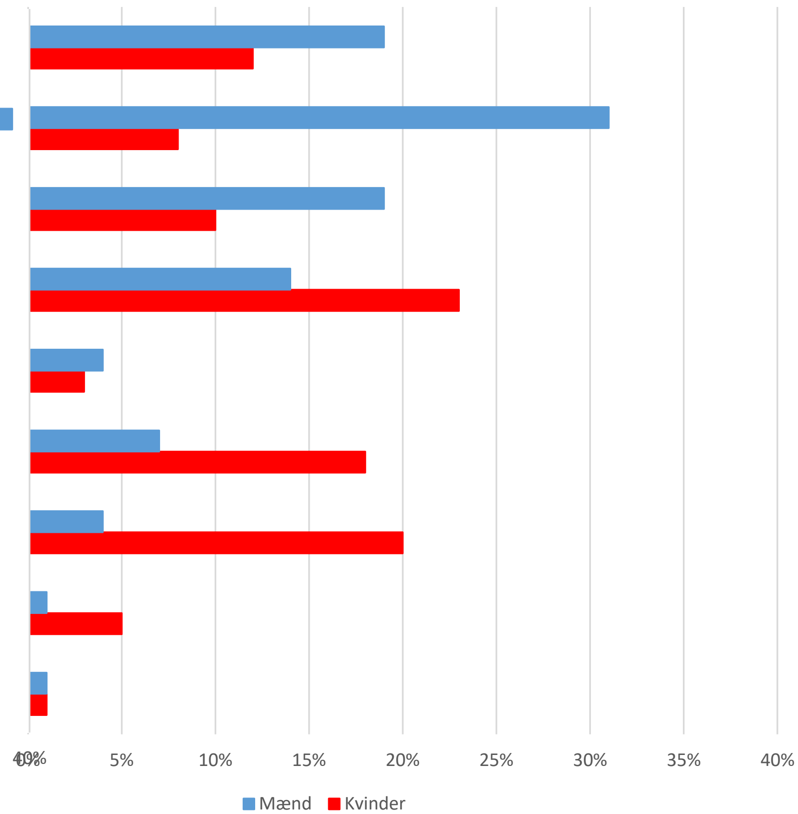


New course package

Course package STX w/o pilot, 1987-1990



Course package STX w/pilot, 1987-1990



♀ 11% → 20%

♂ 39% → 50%

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Who changed their course package?

- Counterfactual course packages
  - Math A + Physics A (+ Chemistry B) -> Math A + Chemistry A (+ Physics B)
  - Math B + Social science A /Natural science A -> Math A + Chemistry A
- Females
  - Chemistry less male-stereotypical
  - Gender composition more equal
  - Class environment less competitive
    - Females less willing to enter mixed-sex competition
    - Females often perform worse in mixed-sex competition

Effect of Advanced Math on earnings across the ability distribution

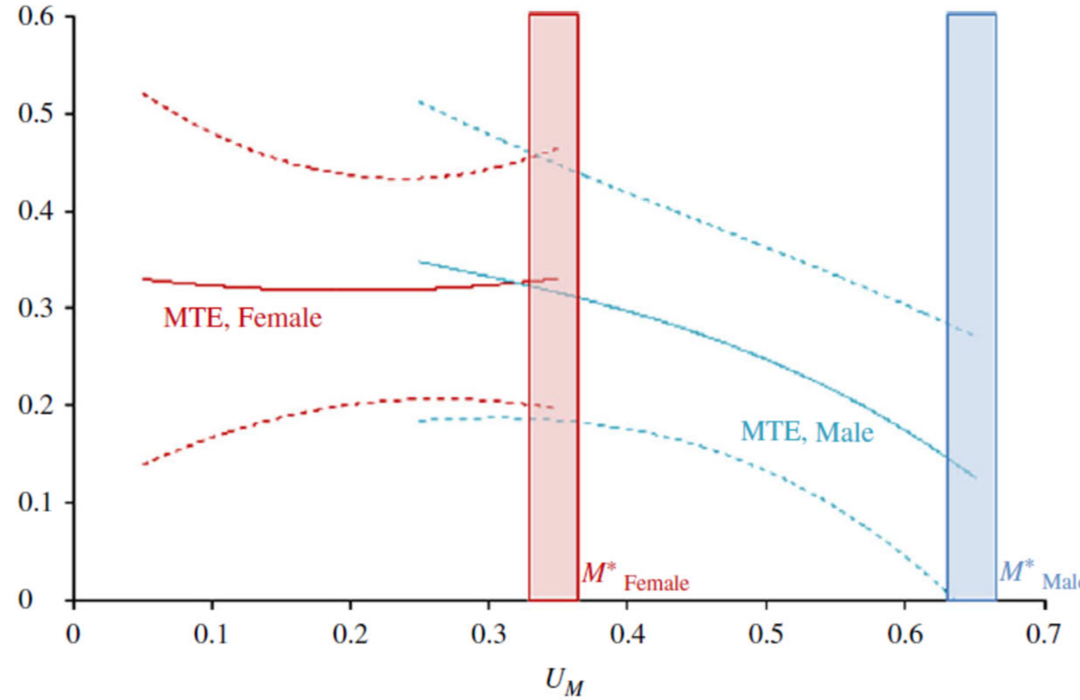

Fig. 3. *Marginal Treatment Effects (MTEs) of Mathematics on Earnings, Marginal Students*

Source: Joensen & Nielsen (2016), Mathematics and Gender: Heterogeneity in Causes and Consequences. *Economic Journal* 126: 1129-63.

Semi-external assessment in math

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Semi-external assessment in math (SEAM)

- Not surprising that
  - coursework and instruction time affect skills
- More surprising that
  - assessment, test-taking and exams affect skills
- However, it may affect human capital and <u>belief formation</u>

- Burgess et al. (2022) exploit policy variation
  - Students are randomly assigned to have an oral exam with an external examiner present in a subset of courses
- June and Julie both attended Math A and Danish classes
  - June is randomly allocated to an oral exam in Math A, but not Danish
  - Julie is randomly allocated to an oral exam in Danish, but not Math A
- Mechanisms:
  - If SEAM affects GPA => access to more college programs
  - If SEAM affects beliefs about math skills => choice of college degrees requiring or demanding math skills

Effect of semi-external assessment in math (SEAM) on short- and long-term outcomes

Table 3
Regression results: the effect of SEAM on subsequent education.

	Overall			Math degrees	
	GPA (1)	Enroll (2)	Graduate (3)	Req. (4)	Dem. (5)
Female	0.204***	0.009	0.049***	−0.049***	−0.005
	(0.018)	(0.006)	(0.007)	(0.006)	(0.004)
SEAM	−0.026**	−0.003	−0.007	−0.005	−0.002
	(0.012)	(0.004)	(0.005)	(0.004)	(0.003)
SEAM X Female	0.030*	0.010**	0.015**	0.012**	0.007*
	(0.017)	(0.005)	(0.007)	(0.006)	(0.004)
SEAM+SEAM X Female	0.004	0.006	0.008	0.007	0.005
P-val	0.768	0.092	0.120	0.049	0.040
MDV Female	8.593	0.906	0.842	0.089	0.040
MDV Male	8.432	0.905	0.800	0.165	0.057
Observations	48,165	48,165	48,165	48,165	48,165

ENCES

Source: Burgess et al. (2022), The importance of external assessments: High school math and gender gaps in STEM degrees. *Economics of Education Review* 88: 102267.

Semi-external assessment in math (SEAM)

- If female students in programs with Math A are randomly drawn for SEAM, they are more likely to
  - enroll in and graduate from college (borderline significant)
  - chose programs requiring Math A (e.g. engineering, math, physics) or programs demanding Math A (programs where average written math exam grade>90p)
- Mechanisms:
  - Mechanical effect through GPA (no)
  - Human capital effect through studying for the oral exam (maybe)
  - Second opinion affects belief about own math ability (yes)
  - Effects driven by girls with high SES or high math abilities (yes)

Double-dose algebra

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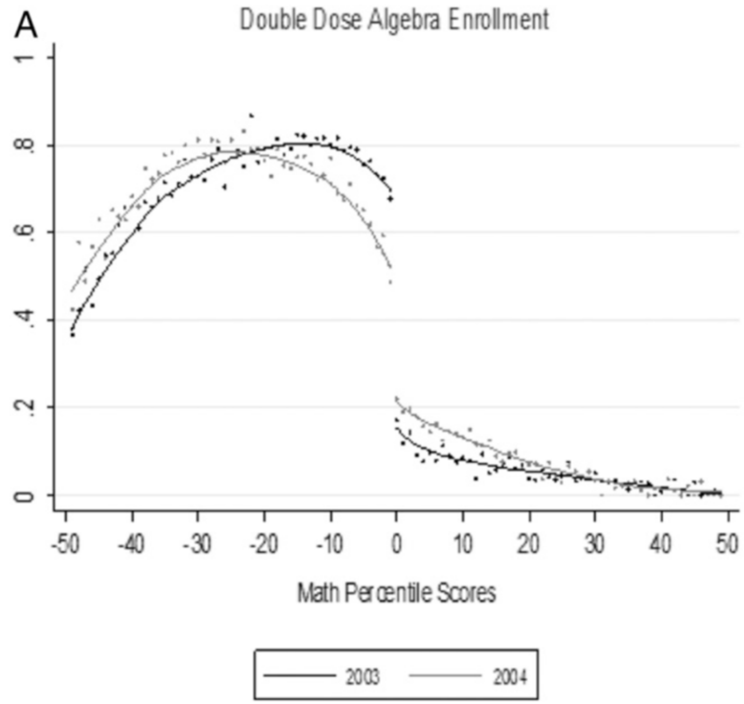
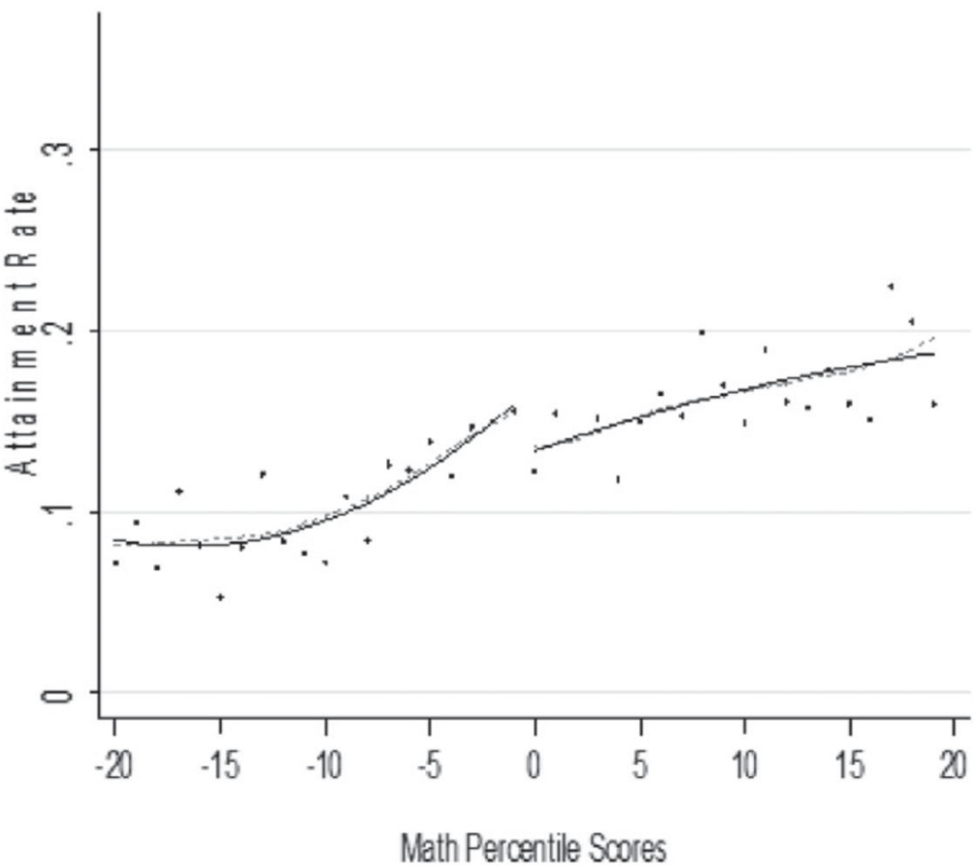
Double-dose algebra

- RQ: Does additional algebra support improve education outcomes?
- From 2003, students in need in Chicago Public Schools received double-dose algebra: regular + support algebra
- Offered to students whose 8th grade math scores were below the national median



A Degree Attainment: Any Degree
(9th-grade cohort in 2003)



B Degree Attainment: Any Degree
(9th-grade cohort in 2004)

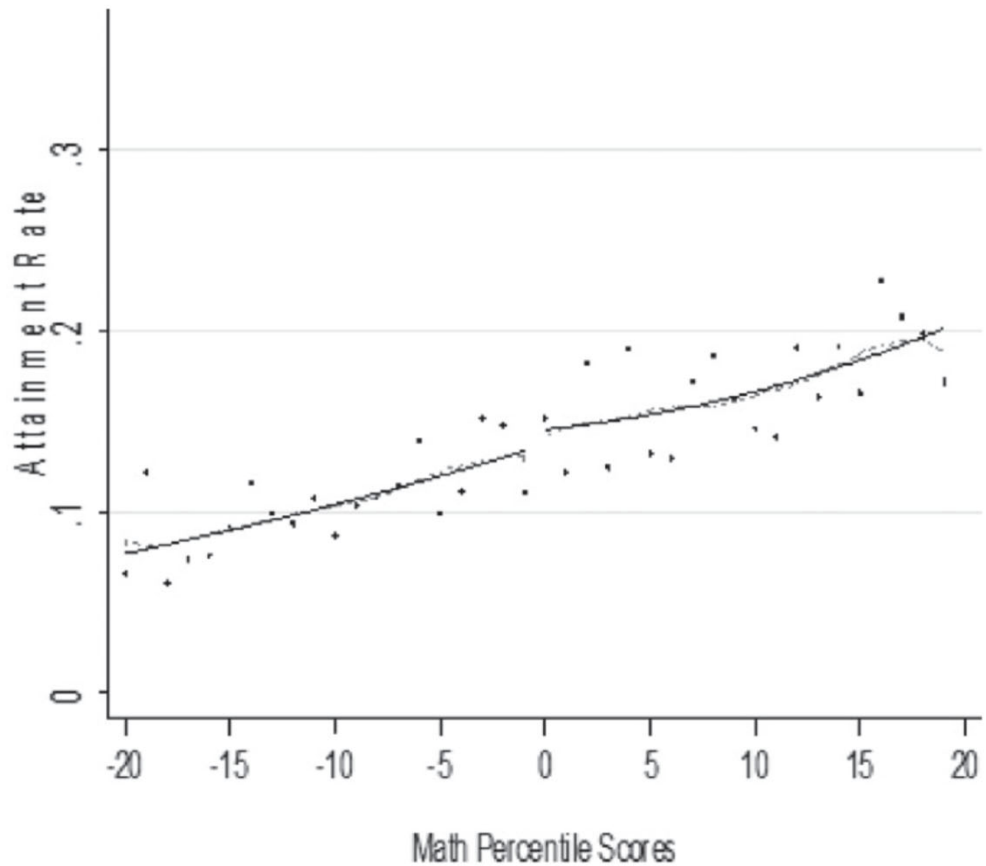


Table 1. The average impact of being assigned to double-dose algebra

Outcomes	2003 Estimate	2003 SE	2004 Estimate	2004 SE
Total semesters				
Control mean	9.082***	0.220	9.496***	0.371
Treatment effects: all students	0.468***	0.138	−0.055	0.147
20% bandwidth	0.427**	0.201	0.043	0.224
10% bandwidth	0.540**	0.258	−0.156	0.261
Any degree/certificate				
Control mean	0.146***	0.018	0.141***	0.028
Treatment effects: all students	0.034**	0.014	0.017	0.013
20% bandwidth	0.031*	0.017	0.001	0.017
10% bandwidth	0.032	0.021	−0.010	0.020
4-y degree				
Control mean	0.070***	0.013	0.084***	0.023
Treatment effects: all students	0.033***	0.012	0.007	0.009
20% bandwidth	0.025*	0.013	−0.021	0.012
10% bandwidth	0.026*	0.015	−0.023	0.015
No. of students				
All students	19,800		20,491	
20% bandwidth	10,286		10,418	
10% bandwidth	5,368		5,408	
No. of schools	62		66	

***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

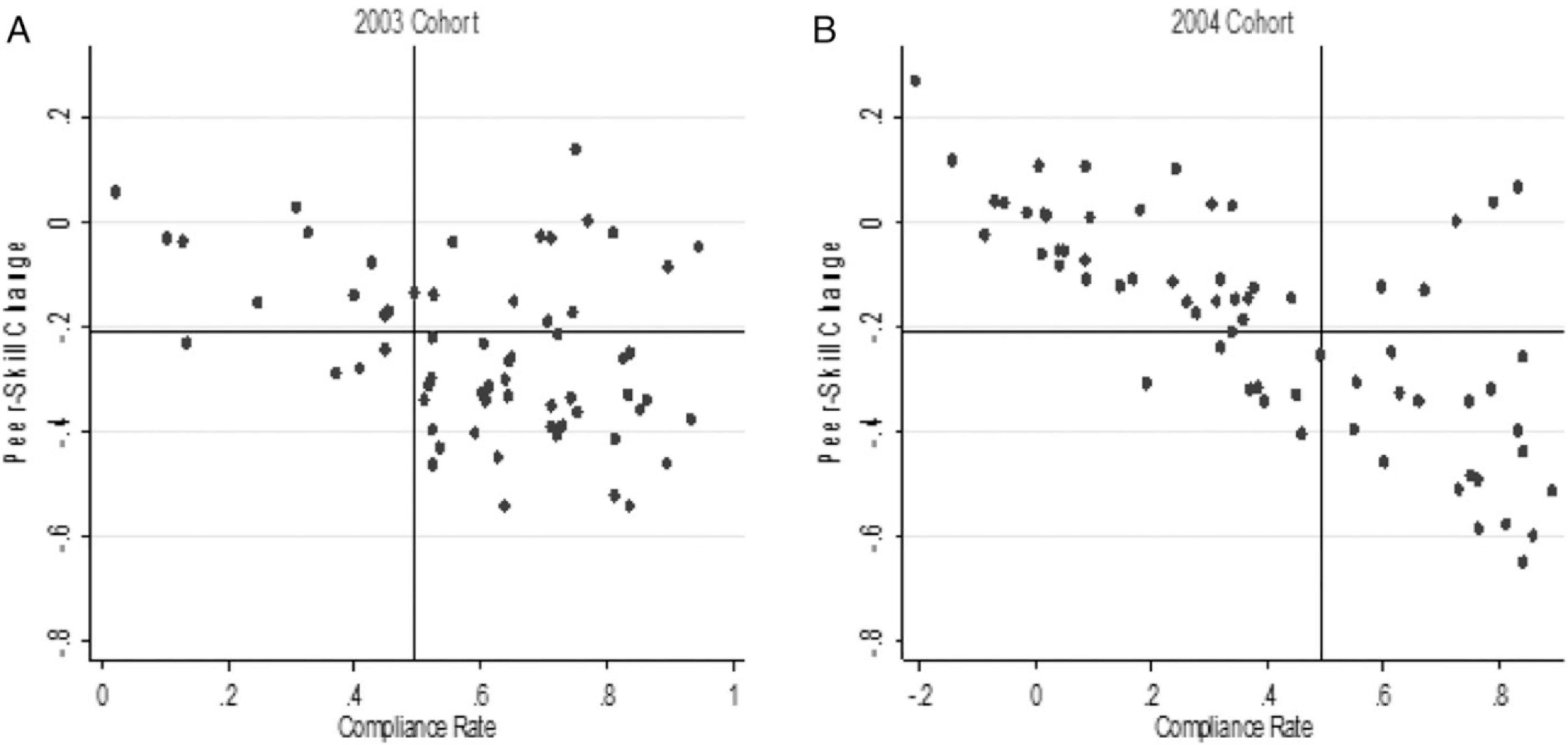


Fig. 6. School-average impact of scoring below the cut point on taking double-dose (horizontal axis) classroom-peer skill (vertical axis). (*A*) 2003 cohort. (*B*) 2004 cohort.

Table 3. ITT impacts by peer skills: Schools with above-average course compliance in 2003

Outcomes	Small declines (13 schools, 2,090 students)		Large declines (35 schools, 5,922 students)	
	Estimate	SE	Estimate	SE
2003				
Total semesters	0.877*	0.489	0.190	0.247
Any degree/certificate	0.090**	0.040	0.014	0.020
4-y degree	0.060**	0.030	0.017	0.017
	(5 schools, 273 students)		(19 schools, 2,765 students)	
	Estimate	SE	Estimate	SE
2004				
Total semesters	2.456	1.531	0.255	0.419
Any degree/certificate	0.092	0.125	0.026	0.034
4-y degree	0.160	0.100	0.008	0.026

$^{**}P < 0.05$, $^{*}P < 0.1$. Note: This analysis uses 20th percentile bandwidth because the parametric model using all students is sensitive to outliners. The result using the 10th percentile is similar. Also, the analysis by pooling the two cohorts produced similar results.

Double-dose algebra

- Positive effect on math scores and college attainment
  - for median-skilled students assigned to regular classrooms
- No effect
  - for median-skilled students assigned to low-skilled peer group
  - for low-skilled students (post-/pre double-dose policy comparison)

Sources: Nomi et al. (2021) Effects of double-dose algebra on college persistence and degree attainment, PNAS 118(27) and Cortes et al. (2015) Intensive Math Instruction and Educational Attainment Long- Run Impacts of Double- Dose Algebra, Journal of Human Resources 50(1)

Growth mindset

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Growth mindset

- RQ: Does instilling a growth mindset in student increase challenge-seeking and choice of advanced math?
- High school students
  - Norway (N=6451)
  - U.S. (N=14,472)
- Intervention content
  - Sticky metaphor "the brain is like a muscle"
  - Source credibility (e.g. scientific articles or quotes from prof of psych)
  - Descriptive social norms (e.g. read a speech by Michele Obama on how hard work makes you smarter)
  - Self-persuasion or "saying is believing" exercises (e.g. help a struggling 9th grade student handle challenges)

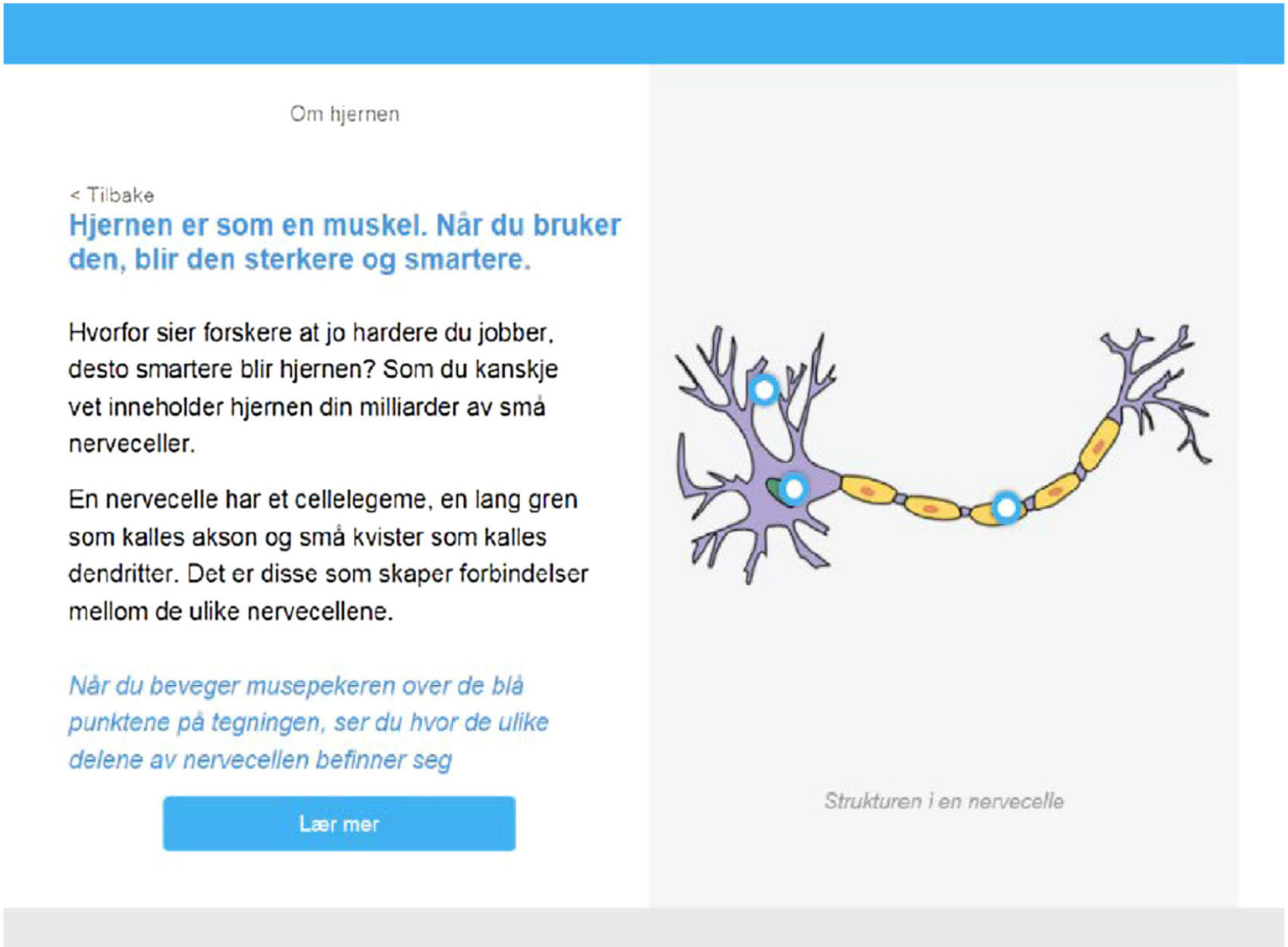

Fig. 2. Screen Shot from Computer Program.

Growth mindset

- Timeline, 1-4 weeks:
  - T=1: baseline + 1st section of treatment/control
  - T=2: 2nd section + outcome
- Measures:
  - Mindset (scale 1 to 6):
    - "You have a certain amount of intelligence, and you really can't do much to change it,"
    - "Your intelligence is something about you that you can't change very much,"
    - "Being a 'math person' or not is something that you really can't change. Some people are good at math and other people aren't."
  - Challenge seeking
    - Choose hypothetical hard ("possibly learn something new") vs. easy ("get most problems right") math homework
  - Advanced math course choice
    - Norway: advanced/theoretical vs. non-advanced/applied math course
    - U.S.: Algebra II/Trigonometry vs. Algebra I/Geometry
- Results:
  - reduced fixed mindset
  - increased challenge seeking behavior (across sub-groups)
  - increased advanced math course taking (motivation) and course passing (performance)

Source: Rege et al. (2021) How Can We Inspire Nations of Learners? An Investigation of Growth Mindset and Challenge-Seeking in Two Countries. *American Psychologist*.

Wrap up

Wrap up

- New course package
  - Think about **gender** and **margin**
- Semi-external assessment in math
  - Think about **gender**
- Double-dose algebra
  - Think about **context** and **margin**
- Growth mindset interventions
  - Promising across **context**