

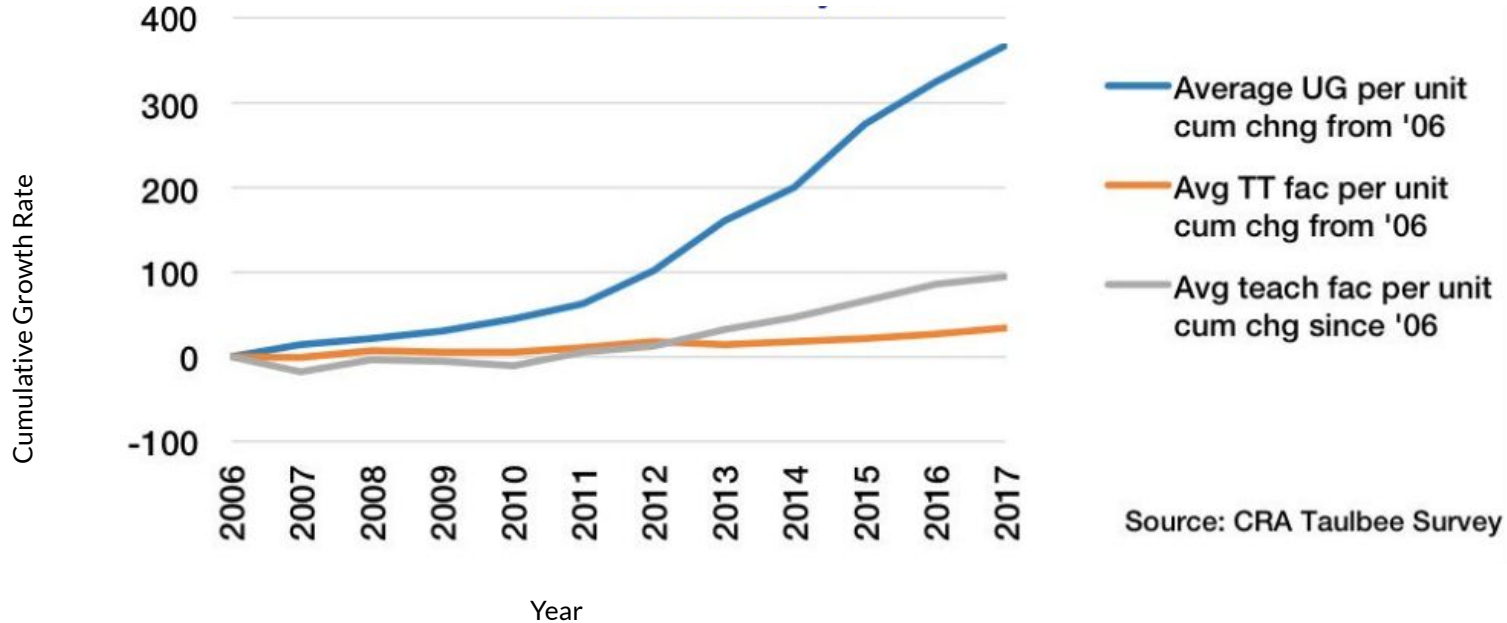
Long Term Effects of Pair Programming

Max O. Smith

May 8th, 2019

Appeared in: IEEE Transactions on Education (2018)

Cumulative Growth Rate for CS Majors and Faculty at PhD Granting Institutions



[CRA '17]



This is "office hours" for a CS class at Cornell. Demand & supply of CS educators here totally out of wack. I assume many schools are facing the same problems with the sudden uptick of interest in the CS major.



Scaling Education

- **Need:** method to scale education.
- Massively Open Online Courses (MOOCs) [Reich '19]:
 - Low completion rates (2-10%).
 - Low return rates (12%).
- Setting has huge influence on pedagogies' success [Dede '05].

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- **Need:** method to scale **CS** education.

Pair Programming

- Software development technique.
- Two engineers & one workstation.
- *Driver* writes code, while *navigator* reviews [Williams '01].
- Alternate roles.

- Students learn from each other.
- Students scale with students.



[Grampa, '18]

Pair Programming in Class

- Higher project scores, but mixed exam results .
 - [Giugliano '16, Mendes '05].
- Higher programming skills for student with lower SAT scores.
 - [Wood '13].
- Higher performance for students with low confidence levels.
 - [Braught '08].
- Positive effect on attitude toward programming.
 - [Umapathy '17].

Pair Programming in Industry

- Experienced more happiness and confidence in their work.
 - [McDowell '03, McDowell '06].
- Produced higher quality code in less elapsed time.
 - Slightly more programming hours (15%).
 - [Nagappan '03].
- Higher quality code was only present when task complexity was high,
- Lower quality code was produced for simpler tasks [Werner '04].

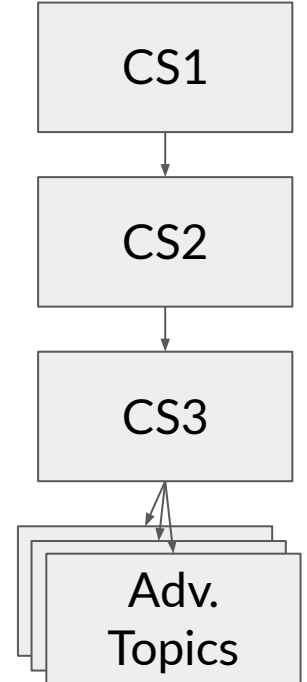
Concerns

- One student does all of the work.
- Students divide and conquer the work.
 - Each student missings different learning opportunities.
- Students become dependent, unable to program without partner.

Question: What are the effects of pair programming?

In the Classroom

- **CS1, CS2, CS3:** intro computer science course sequence.
- **CS1:** introduction to programming.
 - EECS 183, ENGR 101, ENGR 151.
- **CS2:** data-structures and programming paradigms.
 - EECS 280.
- **CS3:** advanced data-structures and algorithms.
 - EECS 281.



Research Questions

“Do partnerships affect students’ future performance?”

- Do students partnerships in CS2 impact long-term student performance in a later CS3 course where they must work alone?
 - Are gender and GPA demographics affected differently?

Research Questions

“Do partnerships affect students’ future performance?”

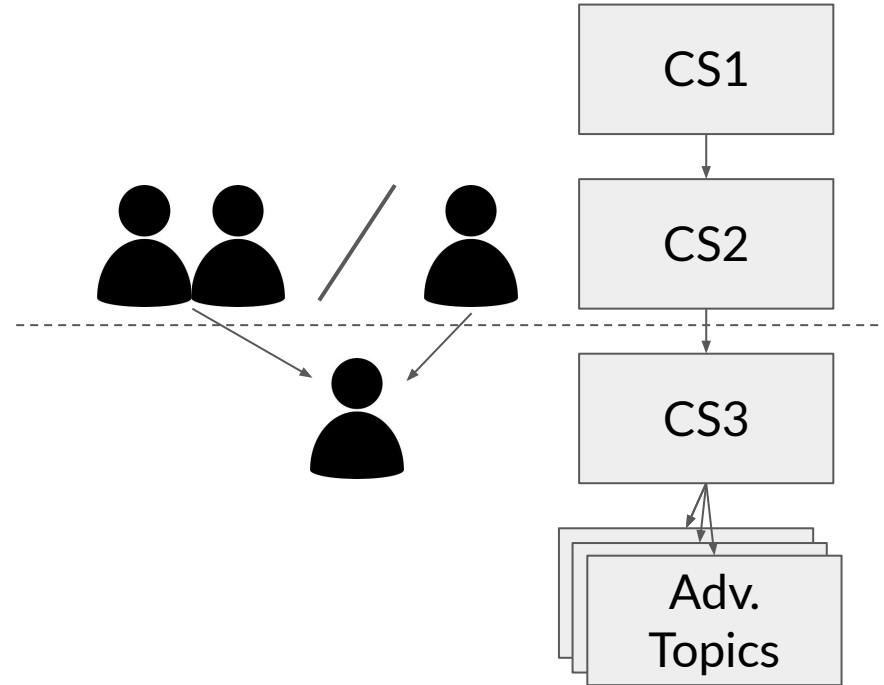
- Do students partnerships in CS2 impact long-term student performance in a later CS3 course where they must work alone?
 - Are gender and GPA demographics affected differently?

“Do partnerships actively hurt students’ current performance?”

- Are previously-observed effects of pair programming robust to a larger sample size?

Methodology

- Observational study of CS2 and CS3 students.
- IRB approved human-subjects research.
- Students given option to partner in CS2.
- Students must work alone in CS3.



Human-Subjects Research

- Preferred experimental design: randomized controlled trial.
 - Randomly assign partnered/alone, and randomly assign partner.
- Literature suggests partnerships are positive.
- Unethical to knowingly put some students at a disadvantage.
- **Trade-off:** accept some selection bias, putting our subjects' well being first.

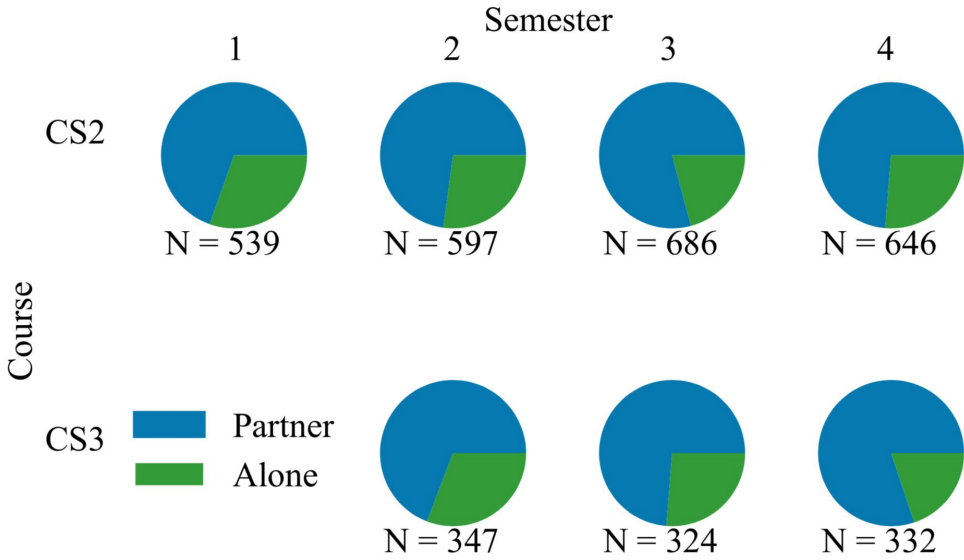
Pair Programming Guidelines

- GOAL: guide students towards good pair programming practices.
- DO:
 - Choose a partner from the current semester of this course.
 - Submit one assignment from your partnership.
 - Collaborate only with your partner.
- DO NOT:
 - Split the work in two.
 - Form a partnership without planning how and when you will work on the project together.
 - Form a partnership late in the project, or if one member has done significant work already.
 - Partner with anyone who is not currently enrolled in the course.
 - Share code or test cases with anyone other than your partner and staff.

Dataset & Statistical Tests

Dataset

- Student records from CS2 and CS3.
- Two academic years (4 semesters).



Data Cleaning

- Removed students who withdrew.
 - Tested impact of partnership on withdrawal in CS3.
 - No significant effect.
- Removed duplicate records.
 - Students who retook the course.
- Remove auditors, incompletes, and students reported for cheating.
 - Different performance incentives.

	CS2	CS3
Before filtering	2,696	1,880
After filtering	2,468	1,003

Independent Variables

- **Partnership in CS2:** if a student had a partner for at least one project in CS2.
- **Gender:** self-reported gender as man or woman.
- **GPA:** student's cumulative GPA on entry to CS2.

Dependent Variables

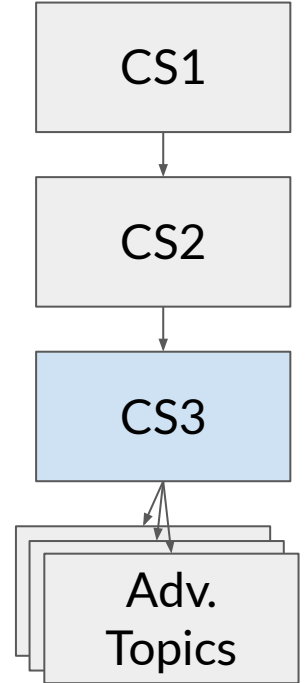
- CS2:
 - Project scores.
 - Exam scores.
- CS3:
 - Project scores.
 - Exam scores.

Statistical Tests

- **Z-score:** number of standard deviations from the mean.
 - Per-assignment, per-semester normalization of scores.
- **ANOVA:** test if there is an interaction between ≥ 1 independent variable(s) on a dependent variable.
 - **AN**alysis **O**f **V**ariance.
 - Between group variance / Within group variance.
- **χ^2 :** tests if there is a significant association between two categorical variables.
- Tests were performed with a 95% confidence interval, and $\alpha=0.05$.

CS3

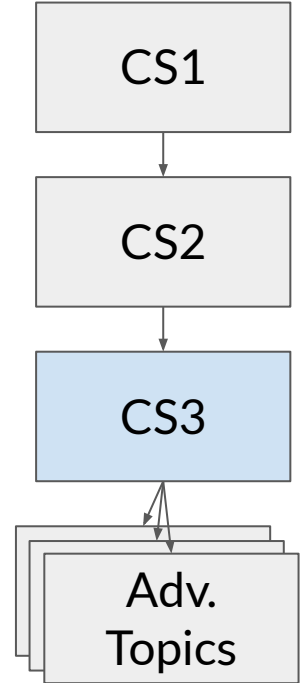
“Do partnerships affect students’ future performance?”



CS3

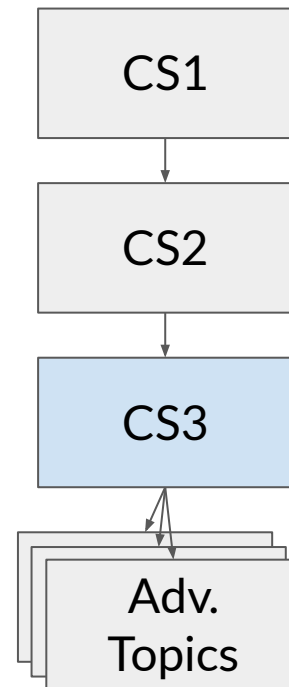
“Do partnerships affect students’ future performance?”

Yes, higher performance on projects.



CS3

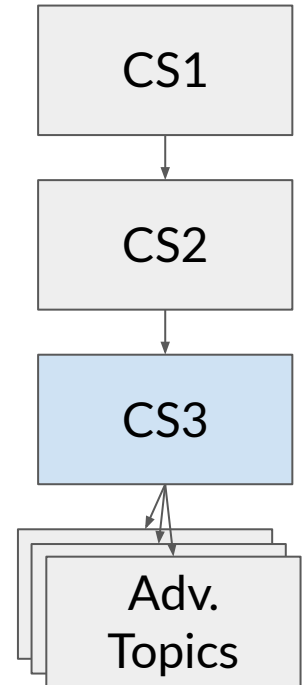
		CS3 Exams		
	df	Mean Sq.	F	P(>F)
Partner (CS2)	1	0.9	1.1	2.9e-01
GPA	1	201.0	245.0	2.6e-49
Partner x GPA	1	0.1	9.9	1.8e-03
Residual	954	0.8		



CS3

- **Independent variables**
- Interactions shown as “**x**” of variables.

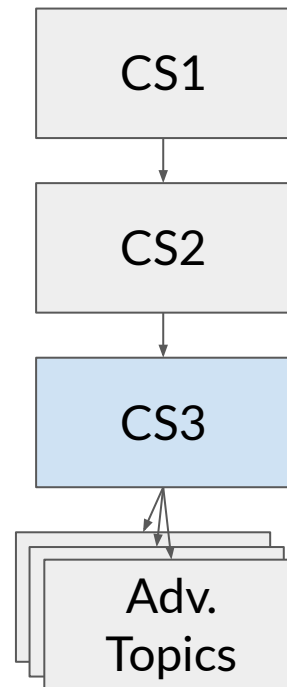
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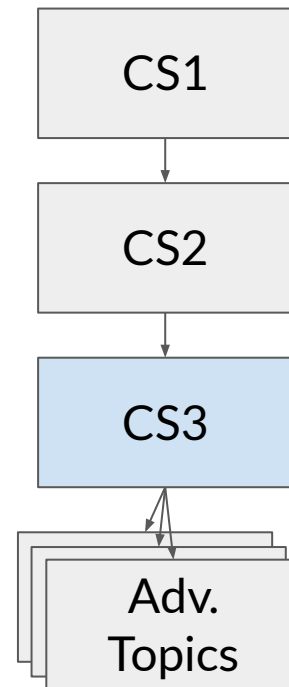
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Residual	954	0.8			0.8		



CS3

- **Dependent variables:** variable being tested.
- Shown in first row.

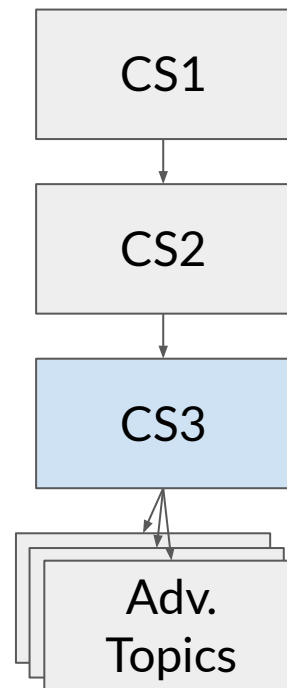
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CS3

- **df**: degrees of freedom.
- **Mean Sq**: mean sum of square deviations.
- **F**: ratio of variation between groups to variance within groups.
- **P(>F)**: probability of obtaining an effect at least as extreme as the sample.

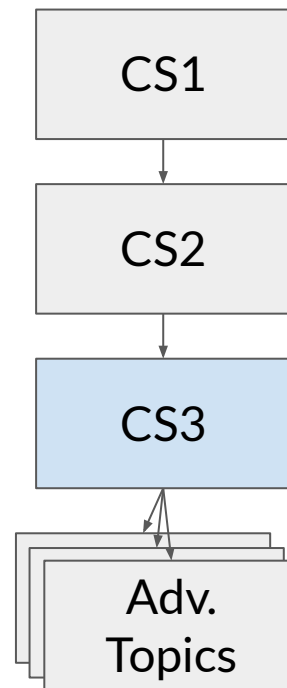
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CS3

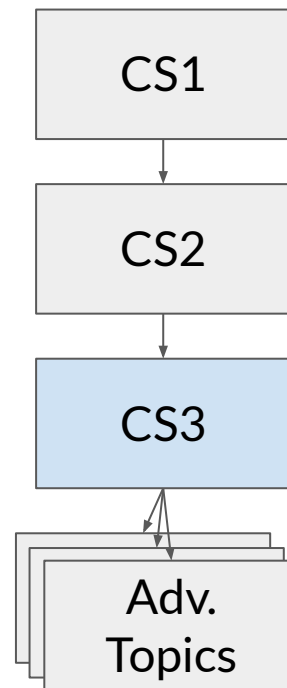
- Partnership main effect on CS3 project scores.
- Partnership and GPA interaction on CS3 exam scores.

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Residual	954	0.8			0.8		



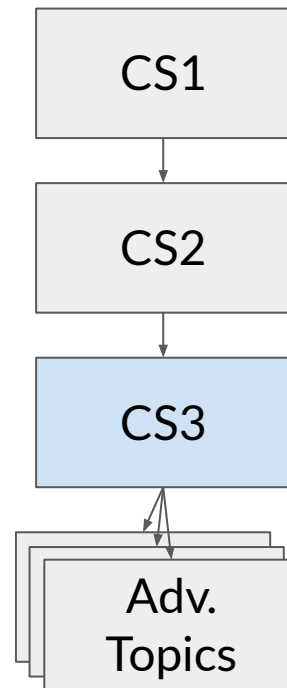
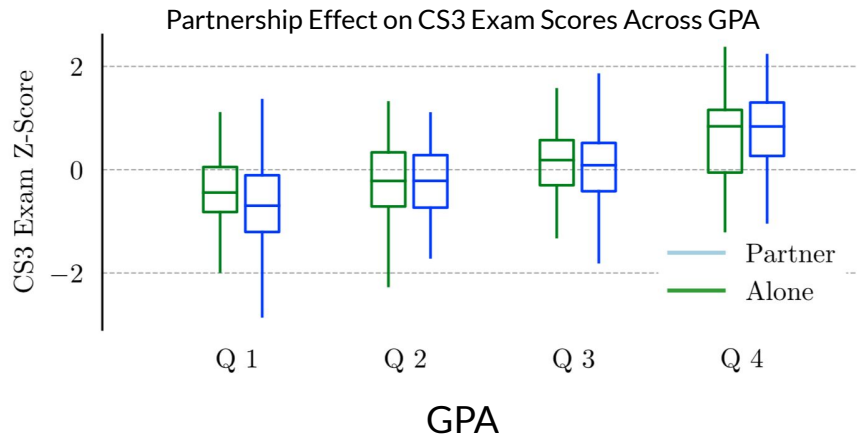
CS3

- Partnered students, controlled for GPA, had a 0.14 higher project Z-score.
 - ~2.1% higher final grade.



CS3

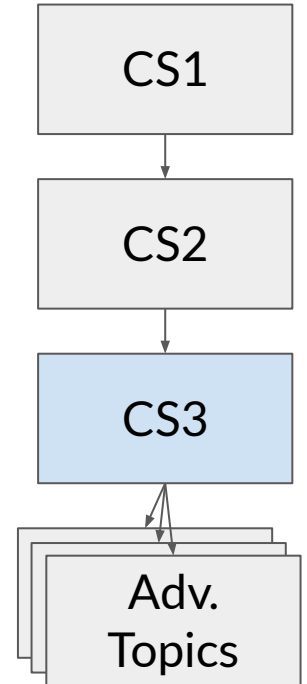
- Partnered students, controlled for GPA, had a 0.14 higher project Z-score.
 - ~2.1% higher final grade.
- Students in the lowest GPA quartile experienced lower exam scores (-0.26 Z-score).



CS3 Gender

- Gender discrepancy on exams.

	df	CS3 Exams			CS3 Projects		
		Mean Sq.	F	P(>F)	Mean Sq.	F	P(>F)
Partner (CS2)	1	0.9057	1.1e+0	2.9e-01	6.99	8.5	3.6e-03
Gender	1	17.9640	2.3e+1	2.4e-06	2.21	2.7	1.0e-01
GPA	1	208.0989	2.6e+2	4.7e-52	126.78	154.0	7.0e-33
Partner x GPA	1	7.6064	9.5e+0	2.1e-03	1.97	2.4	1.2e-01
Partner x Gender	1	0.1332	1.7e-1	6.8e-01	1.59	1.9	1.7e-01
Gender x GPA	1	0.4645	5.8e-1	4.5e-01	1.92	2.3	1.3e-01
Par x GPA x Gend	1	0.0001	1.0e-4	9.9e-01	0.45	0.6	4.6e-01
Residual	950	0.7973			782.06		

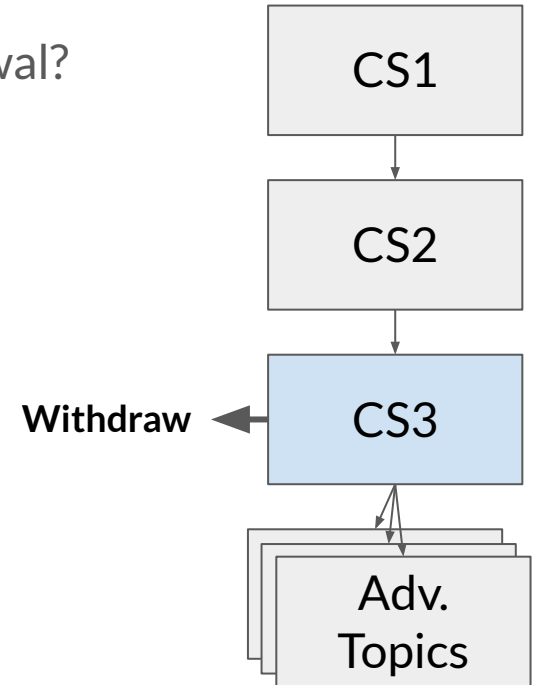


CS3 Withdrawal Rate

- 72 students completed CS2 and withdrew from CS3.
- Is there a relationship between partnership in withdrawal?

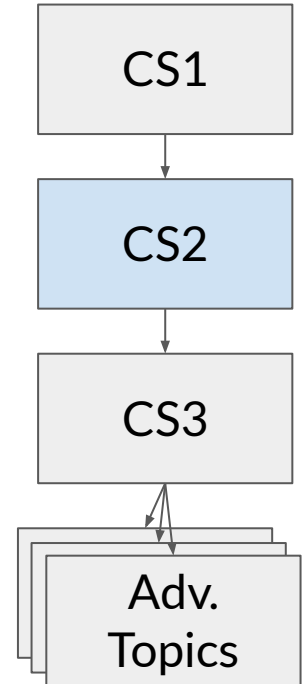
	Partner in CS2	Alone in CS2
Withdrew CS3	57	19
Completed CS3	747	273

- $\chi^2(1, 1096) = 0.0405$
- $p = 0.8405$



CS2

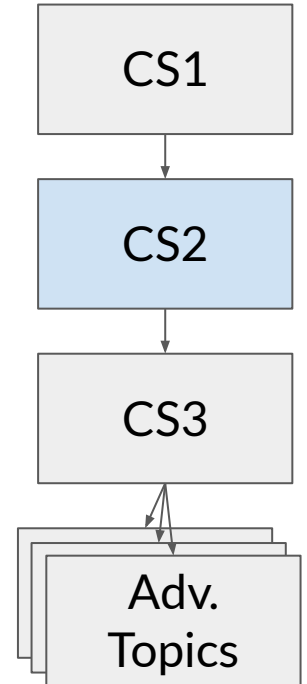
“Do partnerships *actively* hurt students’ performance?”



CS2

“Do partnerships *actively* hurt students’ performance?”

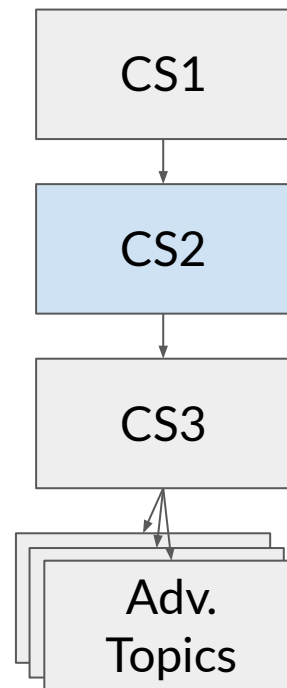
Mixed. Hurts performance on exam, but helps on projects. **Net positive.**



CS2

- Partnership main effect on exams and projects.
- Interaction between partnership and GPA on projects.

	df	CS2 Exams			CS2 Projects		
		Mean Sq.	F	P(>F)	Mean Sq.	F	P(>F)
Partner (CS2)	1	13.3227	22.5	2.3e-006	6.9022	83.9	1.1e-019
GPA	1	506.12	853.0	2.9-160	56.06283	681.5	3.8e-132
Partner x GPA	1	1.15	1.9	1.6e-001	8.9185	108.4	7.5e-025
Residual	2352	0.5933			0.0823		



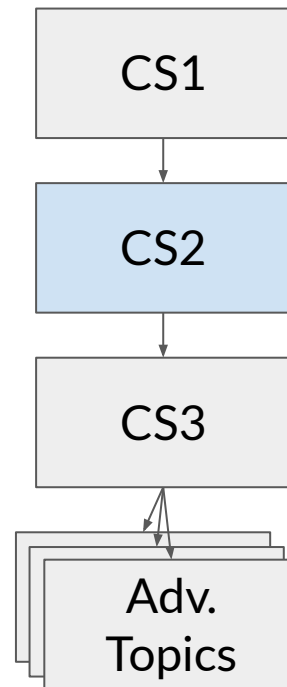
CS2

Partnership had a main effect on project and exam scores.

- Partnerships had **0.21 higher project Z-score**.
- Partnerships had a **0.12 lower exam Z-score**.
- Net **1.2% higher course grade**.

Interaction between partnership and GPA on projects.

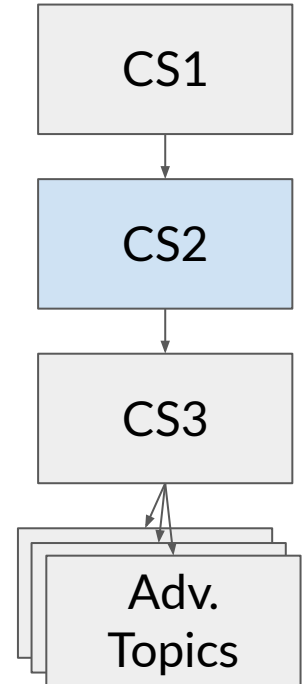
- Bottom GPA quartile had the largest difference.
- 2-3% higher course grade for partnerships.



CS2 Gender

- Gender discrepancy on exams, and interaction with partnership.

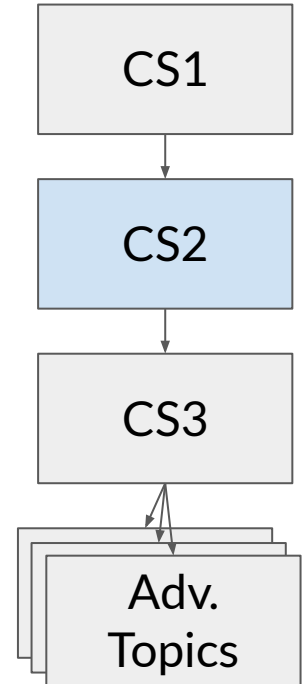
		CS2 Exams			CS2 Projects		
	df	Mean Sq.	F	P(>F)	Mean Sq.	F	P(>F)
Partner	1	13.32	23.0	1.8e-006	6.90	83.9	1.1e-019
Gender	1	20.81	35.9	2.4e-009	0.10	1.2	2.7e-001
GPA	1	515.22	888.2	8.2e-166	55.89	679.3	9.4e-132
Partner x GPA	1	1.25	2.2	1.4e-001	8.96	108.9	5.8e-025
Partner x Gender	1	2.57	4.4	3.5e-002	0.08	0.9	3.4e-001
Gender x GPA	1	0.81	1.4	2.4e-001	0.02	0.2	6.4e-001
Par. x GPA x Gend	1	0.12	0.2	6.5e-001	0.25	3.1	7.9e-002
Residual	2348	0.58					



CS2 Gender

Interaction between partnership and gender on exam scores.

- Women working alone averaged 0.32 higher exam Z-score than partnered women.
- Men working alone averaged a 0.14 higher exam Z-score than partnered men.



Limitations

- Students opt-in to partnerships.
- Students choose who they partner with.
- No data on student compliance with pair programming guidelines.

Summary

“Do partnerships affect students’ future performance?”

- **Yes, higher performance on projects.**

“Do partnerships actively hurt students’ current performance?”

- Mixed. Hurts performance on exam, but helps on projects. **Net positive.**

Collaborators: Andrew Giugliano, Andrew DeOrio.

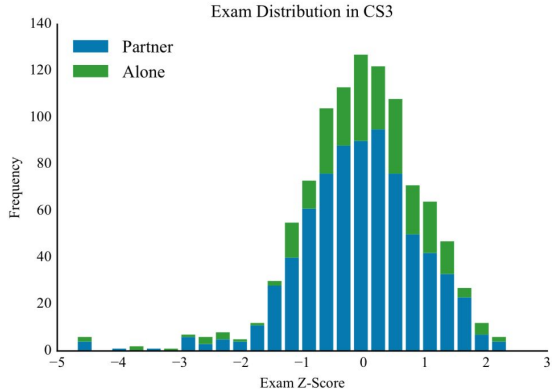
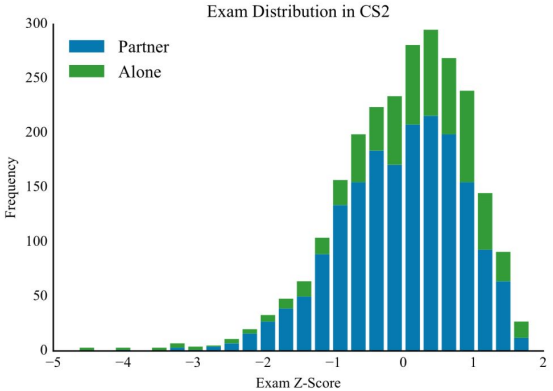
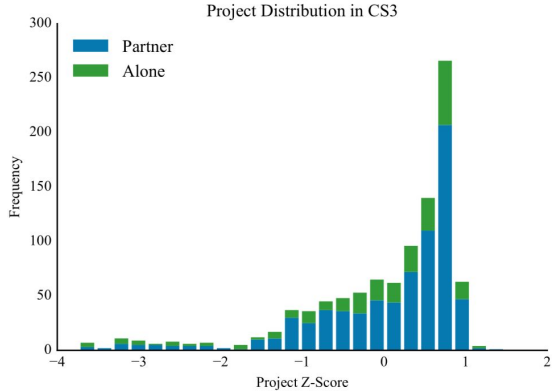
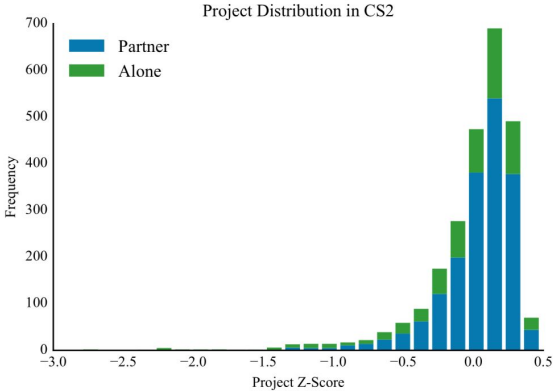
Questions?

Dataset

- Gender breakdown of CS3 students, by CS2 partnership.

	Men	Women	Total
Partner (CS2)	593	152	745
Alone (CS2)	212	46	258
Total	805	198	1003

Dataset



Time between CS2 and CS3

- Decrease gap between courses was associated with increase CS3 performance.

	df	CS3 Exams		CS3 Projects	
		F	P(>F)	F	P(>F)
Time	1	2.38	9.33e-02	8.97	1.39e-04
GPA	1	252.10	1.66e-50	148.26	8.66e-32
Time x GPA	1	7.73	4.67e-04	4.41	1.24e-02

