Enhancing CS Degree Programs by Reducing Structural Complexity

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Does Structural Complexity Influence Diversity of Students?

Based on: Does Curricular Complexity in Computer Science Influence the Representation of Women CS Graduates?

By Albert Lionelle, McKenna Quam, Carla Brodley, and Catherine Gill

https://dl.acm.org/doi/10.1145/3626252.3630835

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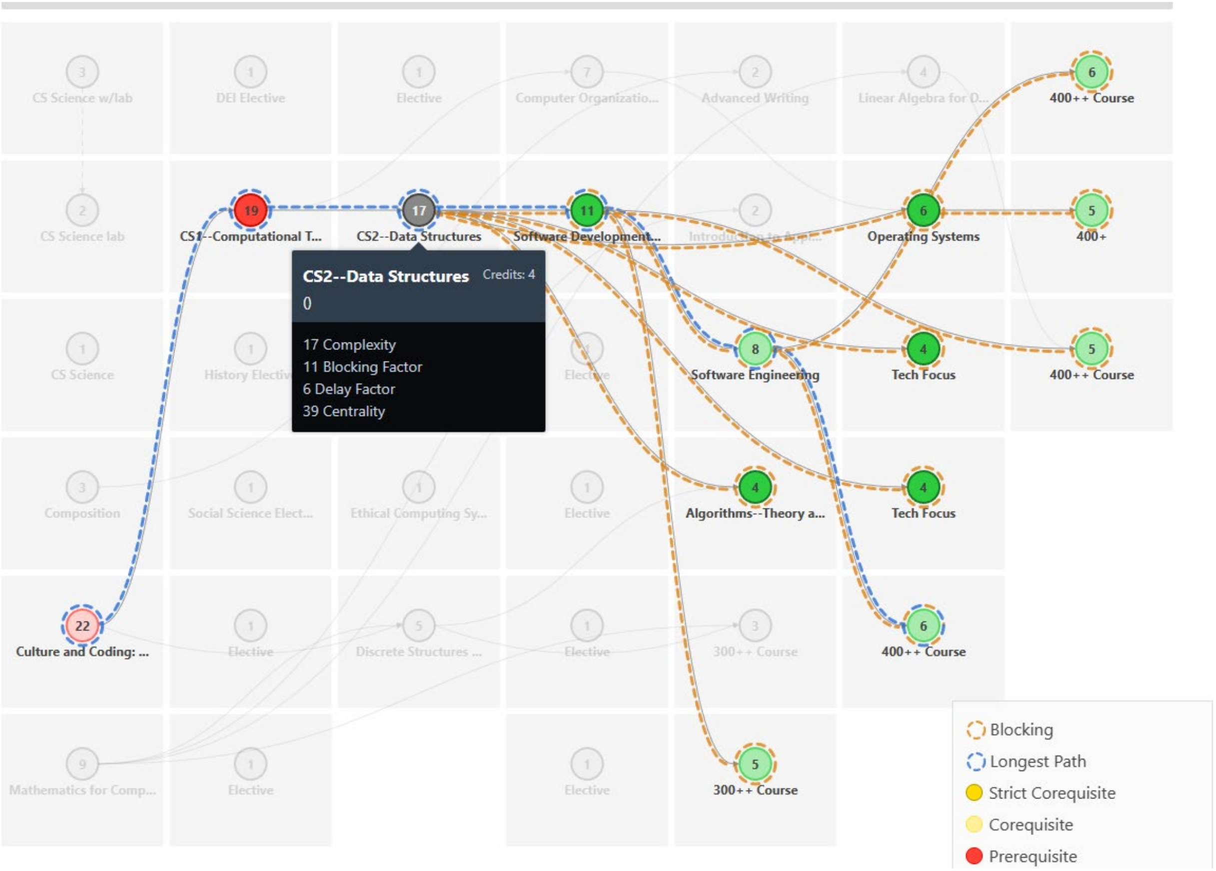
What is Curricular Complexity?

- Curriculums have an innate structure
  - Prerequisites, course requirements
- Curricular Complexity – the complexity of that *structure*
  - Not to be confused with course complexity
- Four measurements to compare curricular structure
    - Developed by Gregory L. Heileman and Ahmad Slim
  - Complexity
  - Centrality
  - Delay Factor
  - Blocking Factor

Curricular Analytics



- Blocking Factor
  - Number of courses that require course. 11 in example
- Delay Factor
  - Measures sequential ordering (max) that it is a member. 6 in the example
- Centrality
  - Sum of delay factors “how many course chains include this course”.
- Complexity
  - Combination of Blocking + Delay
- Curricular Complexity
  - Sum of all course complexities. 175 in example

https://curricularanalytics.org/

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Why does this matter?

- Curricular Structure
  - Influences students directly
    - How long until graduation, ordering, etc
  - Measure to compare “best practices” in curricular design
- Heileman et al. found[1]
  - Higher ranked Engineering and CS programs had lower curricular complexity
- Meaning
  - The structure of the curriculum was less complex
  - Making it easier to
    - Take courses in different orders
    - Transfer into the program later
    - Less assumptions about previous knowledge going into courses (hopefully)

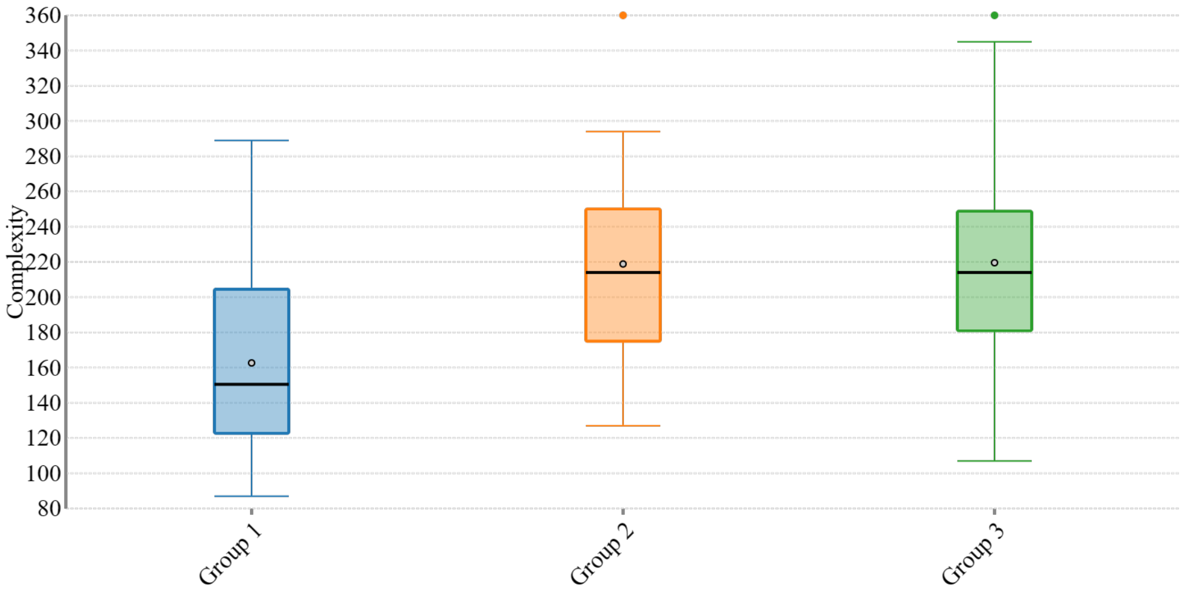
[1] https://doi.org/10.18260/1-2--32677

Degree Complexity Related to % Women

- Sampled 60 programs (20 each group)
- Built 60 degree maps
- By public facing websites
- Assumed calculus ready, no AP credits, bias towards reduced prerequisites, and 'quickest path' to graduation

	% women	Mean Complexity	Median longest delay factor
Group 1	n > 20%	162.7 ± 12.8	5
Group 2	20% >= n > 15%	218.9 ± 13.1	6
Group 3	n < 15%	219.6 ± 14.4	6

p = 0.003



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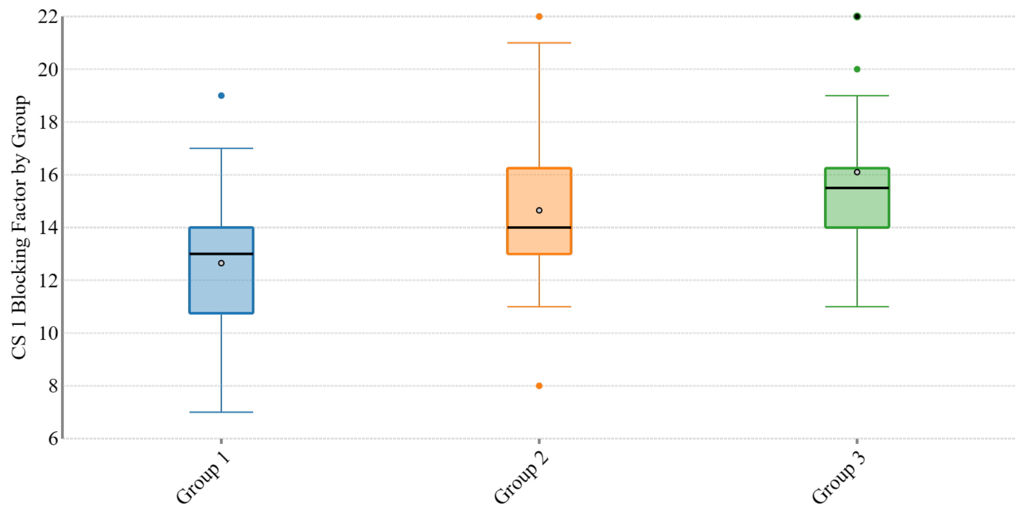
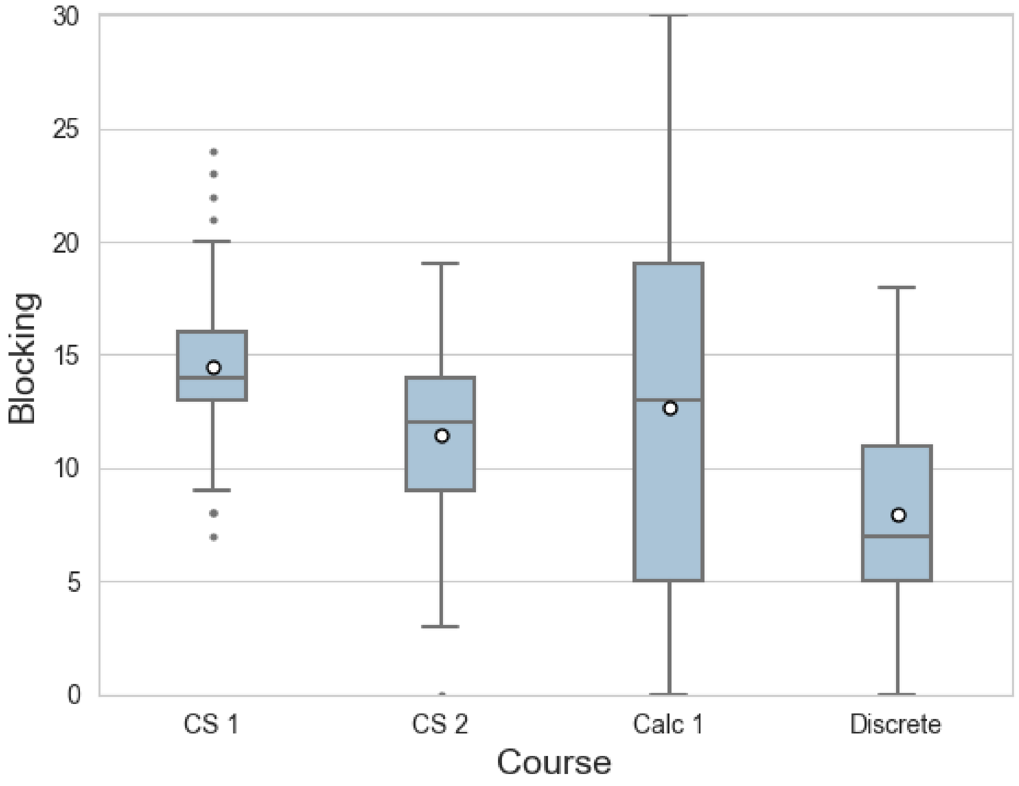
Blocking Overall

- Blocking prevents progress
- Across all 60 schools
  - CS 1 should be blocking (mostly)
  - Calculus I, no consensus!





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More on math requirements

Based on “An Analysis of the Math Requirements of 199 CS BS/BA Degrees at 158 U.S. Universities”

By Carla E. Brodley, McKenna Quam, and Mark Weiss

https://cacm.acm.org/research/an-analysis-of-the-math-requirements-of-199-cs-bs-ba-degrees-at-158-u-s-universities/

Math’s Roll in Computer Science

All U.S. CS programs with 150+ graduates with publicly available degree plans

199 degrees at 158 universities

- 80% Bachelor’s of Science, 20% Bachelor’s of Arts
- 100 in Engineering, 99 not
- 83 ABET-accredited
- 55 MSIs, 47 AAU, 4 online
- 60% of all CS graduates in the U.S.

Results

Course	# of Degrees	% of Degrees
Calculus 1	191	96.0%
Calculus 2	152	76.4%
Discrete	198	99.5%
Probability/Statistics	140	70.4%
Linear Algebra	116	58.3%
Calculus 3	43	21.6%

Additional Findings

- High inclusion of Discrete, no consensus on placement in the program.
  - 117 requires it for Algorithms and 73 data structures, but shows up across 29 different classes at substantially lower rates
- Calculus 1
  - 73 require for Discreet
  - 33 require for CS 1!
  - All assume calc ready
- Calculus 2
  - 108 have it, but not tied to any other computing course (pre/post req)

Forming Best Practices

Best Practices Observed

- Critically Evaluate Prerequisites and Assumptions
- Minimize Delay on Transfer Students
- Eliminate choke points preventing progress
- Offer flexibility around when calculus must be completed
- Small core, with flexible options after core
- How you communicate degree plans matter

Critically Evaluate Prerequisites

- Look at prerequisites
  - Is it really needed or is a proxy for something else
    - Proxy for “mathematical maturity”
    - Proxy for advising paths
- Don’t block progress unless majority of content is needed
  - Especially true for mathematics courses
    - Don’t let other departments determine who is in your major
  - Ensure there is time to discover CS
    - Ensure time to graduate after discovery
- Question college assumptions – example COE
  - Rethink common engineering core for first year
  - Does CS benefit from engineering core or just hurting discovery?

Minimize Delay on Transfer Students

- The number of transfer students
  - Increase every year
  - Primary concern: time to graduation
- Use curricular maps to look at time to graduation
- Reduce if transfer students have “added” complexity
  - Extremely common!
- Minimize barriers on transferring into the program
  - Also true for AP credits or partial transfers!

Flexibility

- Programs with greater representation had
  - More options for students at various points
  - Smaller core requirements
    - 26% - group 1 compared to 33% group 3
  - Group 1 is characterized by minimal prerequisite
    - Often 300/3000 lvl upper division only required Data Structures
  - Don’t assume calc-ready

Choke Points and Calculus

- Choke points
  - Very evident in a curricular map
  - Programs with greater diversity often had ‘pathways’
    - Allows progression to prevent frustration of a choke point
- Calculus 1 – if placed early becomes a choke point
  - Yet, there is NO consensus between programs
  - Suggestion:
    - Only require it *as needed* for a course
    - Delay when it is needed
      - Allows time for pre-calc requirements
    - CS2023: ACM/IEEE-CS/AAAI Computer Science Curricula

Communication Matters

- Students do use websites
- We found:
  - Some programs made it very difficult to find information
    - Requirements often listed across multiple pages (university, college, degree)
    - Often contradicting information
    - Sometimes prereqs listed, sometimes not
  - Nearly everyone had a single “calc ready” suggested plan
- Suggestion:
  - Have a clean page that lists / links to courses, prereqs and plans.
  - Have multiple degree plans
    - Calc ready
    - No mathematical background
    - Transfer student plans (internal and external transfers)
  - These present to the students that everyone belongs

Additional Reading: Top Ten List for Making a Great “Major Requirements” Web Page
McKenna Quam

Does a fluid degree structure keep quality?
Case study: Colorado State University

Does Reducing Curricular Complexity Impact Student Success in Computer Science?

Sumukhi Ganesan, Albert Lionelle, Catherine Gill, and Carla Brodley

SIGCSE 2025, to appear. prepublication copy:
https://github.com/NeuCurricularAnalytics/papers

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Curricular Revamp

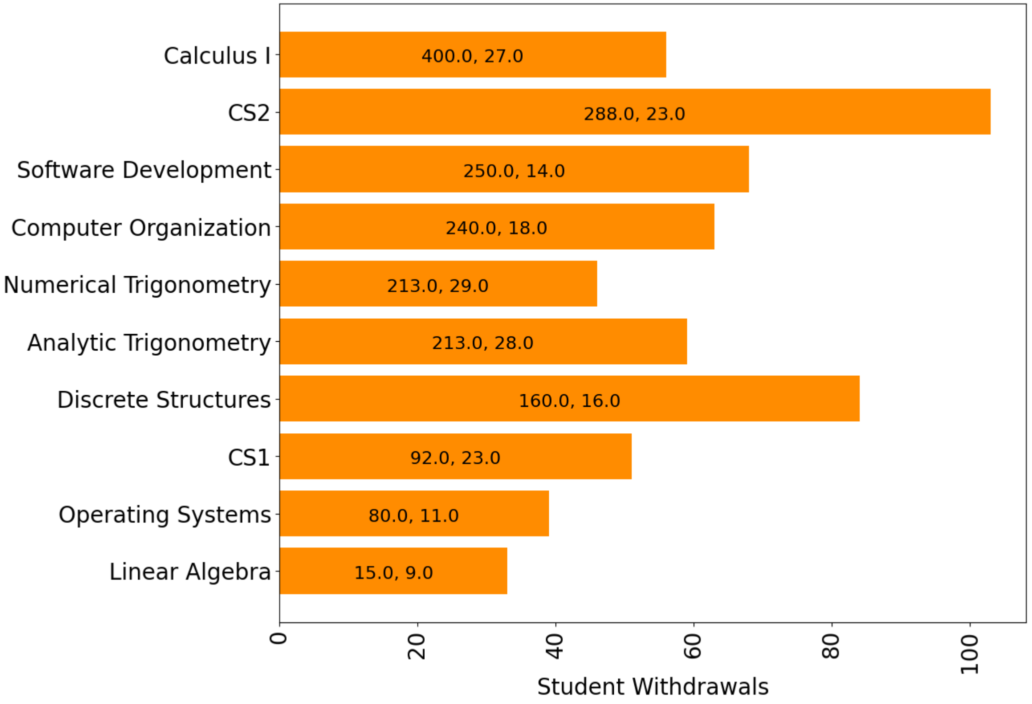
- For 20 years, only minor updates
- Discovered multiple ‘hidden’ prerequisites that
  - Drove away students
  - Made minoring in CS impossible
  - Created a very rigid structure and students were not graduating in 4 years
- Revamped curriculum in three phases
  1. Revamped prerequisites for individual courses
  2. Addressed overall degree program
  3. (in progress) Systematically updating weak points and barriers

     -- Arguably this should always be in progress

Old Curriculum Issues

- Math major barrier
  - 45% of CS majors NOT calc-ready
  - 55% of seeking CS NOT calc ready
  - Most students dropped while in math, often never taking CS
- Minor in CS 40 credits!
  - Should be 21-24 credits
  - 40 due to hidden pre-reqs
- Transfer Students
  - 3.5 years minimum
  - Created financial barrier both internal and external transfers
- Most students 4.5 or 5 years to graduate
- Overall – department was seeing minimum growth
  - And negative growth in URMs

Terminal Course(s)
The last course a student took before leaving program. Often math.



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Phase 1: Reduce Prerequisites

- Systematically
    - Approached faculty teaching courses – in small groups
    - Asked what were the *minimum* prerequisites needed
        - Focused on needed content, not “nice to have” content
        - Faculty had *many* misconceptions on what was taught where!
            - Focused on content itself, then curriculum expert pointed out which courses that content actually showed up in (especially in lower division courses)
- Redesigned Prerequisites to go from
    - “Interconnected” core of every 2xx and 3xx course to
    - Required core with three “pillars”
        - **Systems** (CS 1 → Computer Org → Upper Division Operating Systems)
        - **Software Engineering** (CS 1 → CS 2 → CS 3 → Upper Division SE)
        - **Algorithms and ML** (CS 1 → Discreet Structures → Upper Division Algorithms)
            - Calculus I, Linear Algebra, Statistics are part of this pillar
        - Data Structures technically in SE, but also acts as central course for most upper division courses

Phase 1: Reduce Prerequisites cont.

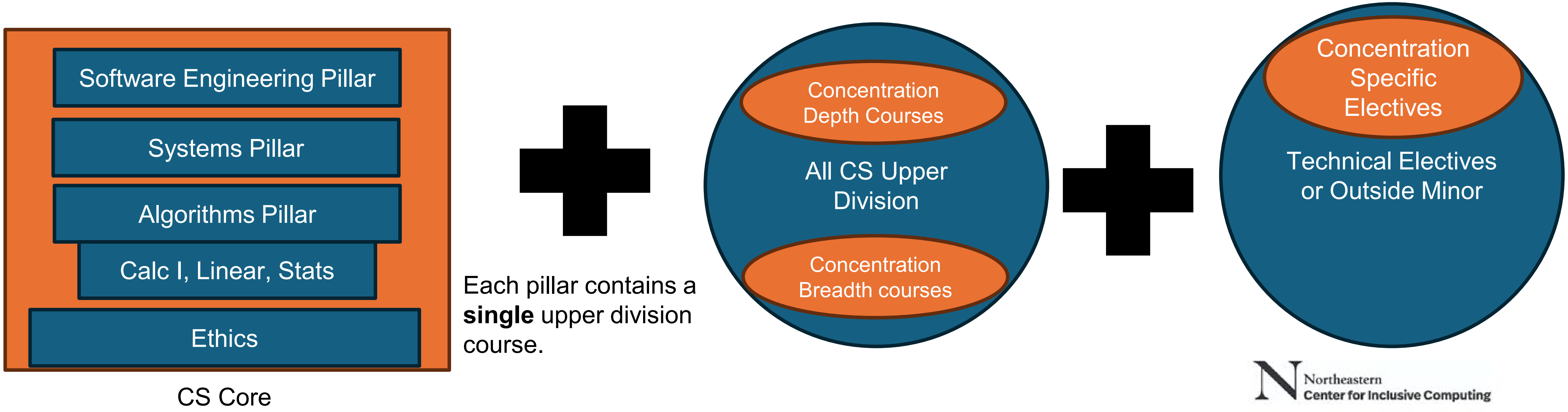
- CS majors required to take the full core
  - But we removed pre-req inter-connections among three pillars
  - Allows student progress in one pillar even if struggling in a topic in another pillar
  - Allowed ‘minors’ to be a single pillar.
- **Requirement: Keep course outcomes the <u>same</u>**
  - Put measures in place to compare performance between semesters (such as exam timing, content, etc)
- Was in place for a year before degree redesign
  - Used the year to measure outcomes and student performance
    - Students performed equally well

Phase 2: Degree Redesign

- Added more CS courses overall (13 courses → 15-18 courses)
  - Added CS 0 (optional) – As gen-ed and for majors new to coding
  - Added Ethics in CS – Also a gen-ed option
  - Added additional upper division CS electives
- Moved Calculus II as optional/part of tech elective picklist
- Reduced natural sciences (3 courses → 2 courses)
- Added Concentrations
  - All fall back into the ‘general’ concentration
  - General concentration had room for CS+x programs

Concentration Design

- Core Requirement
- CS Upper Division
  - Specific to concentration – general concentration contains all of them
  - Most concentrations have two sub lists to pick from to ensure specific courses but with flexibility
  - Prerequisites kept to a minimum / only what is exactly needed.
- Technical Electives
  - Specific for concentration or general picklist of all of them
  - For general: could also be a minor in another field
- Concentrations added – specific to primary research areas in the department
  - General, AI/ML, Cybersecurity, Education, Human Centered Computing, Software Engineering, Systems



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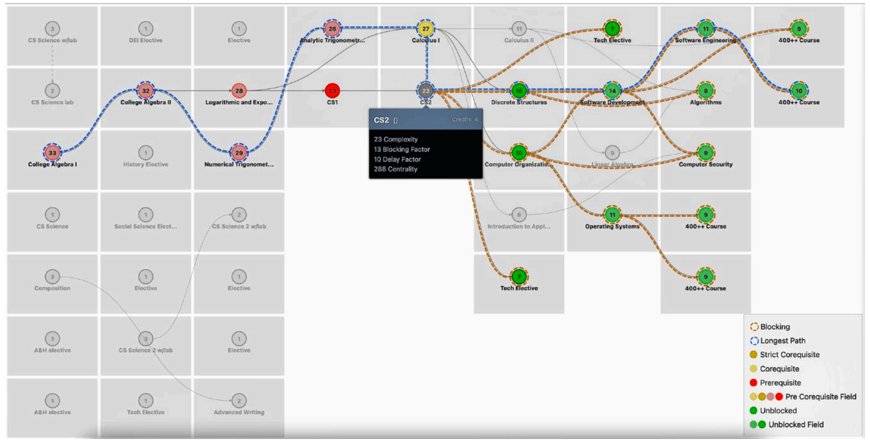
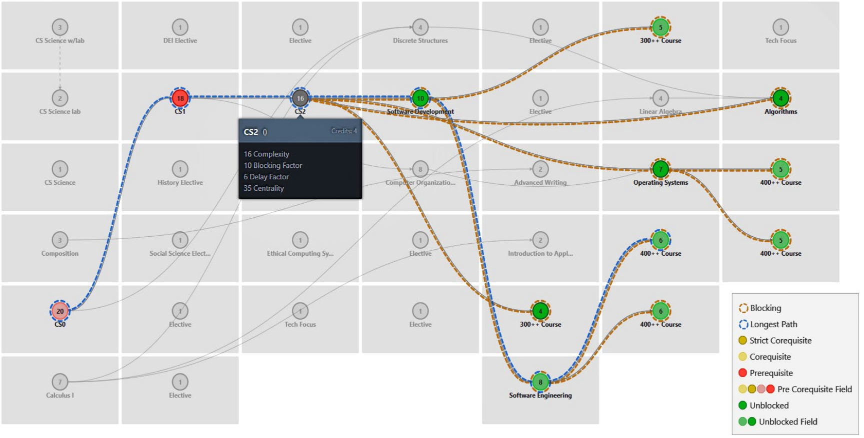
Did it work? (As of Spring 23)

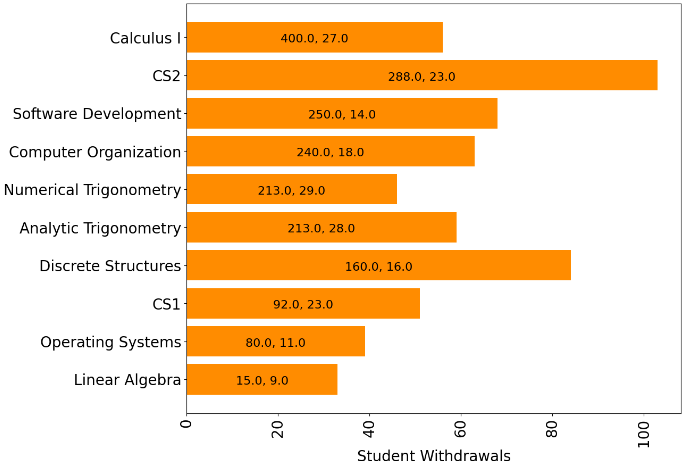


415 Complexity, multiple blocking courses

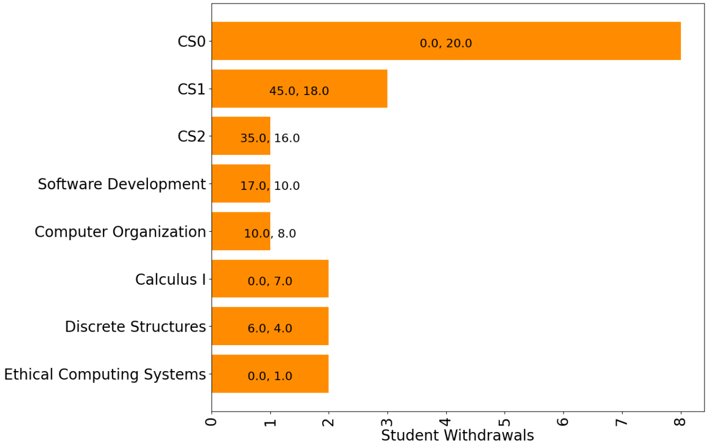
60% reduction!



164 Complexity, minimal blocking courses



Terminal Courses – Mainly Math



Terminal Courses – CS 0

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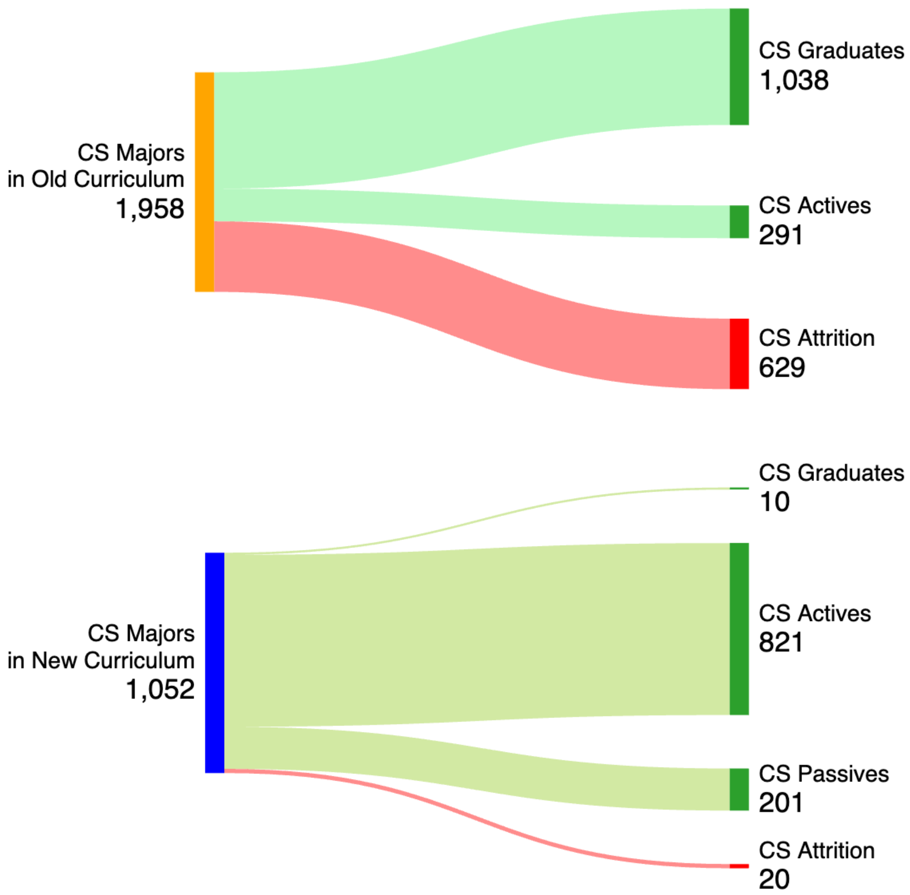
Did retention/attraction increase?

- Program retention increased!
  - 67% Old degree
  - 98% New degree
- Undeclared seeking CS
  - Increased attraction!
  - 47% converted in old degree
  - 69% converted in new degree
- Overall numbers increasing
  - Fall 2015, 725,   12% women (88)
  - Fall 2023, 1078, 19% women (209)
- Students still reporting similar job placements



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Summary/Recommendations

- A systematic review and reduction of prerequisites
  - <u>Does not reduce quality of degree content</u>
  - Gives students flexibility
  - Is attractive to students
  - Math still valuable, but is no longer an entry point
- Faculty
  - Still able to teach their preferred courses
  - Students still select courses
  - Tend to see more students in courses as program grows
- These changes are the start (Phase 3 ongoing)
  - Often snowball effects happen – meaning faculty get excited to make updates
  - Due to flexibility and picklists, possible to have A/B courses and measure differences
    - Picklists outside of minimal core allow for more dynamic changes to keep up with industry

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