SYSTEMS ENGINEERING RESEARCH CENTER

PURDUE AERONAUTICS & ASTRONAUTICS

RT-206: Data science approaches to prevent failures in systems engineering

Sponsor: DASD(SE)

By

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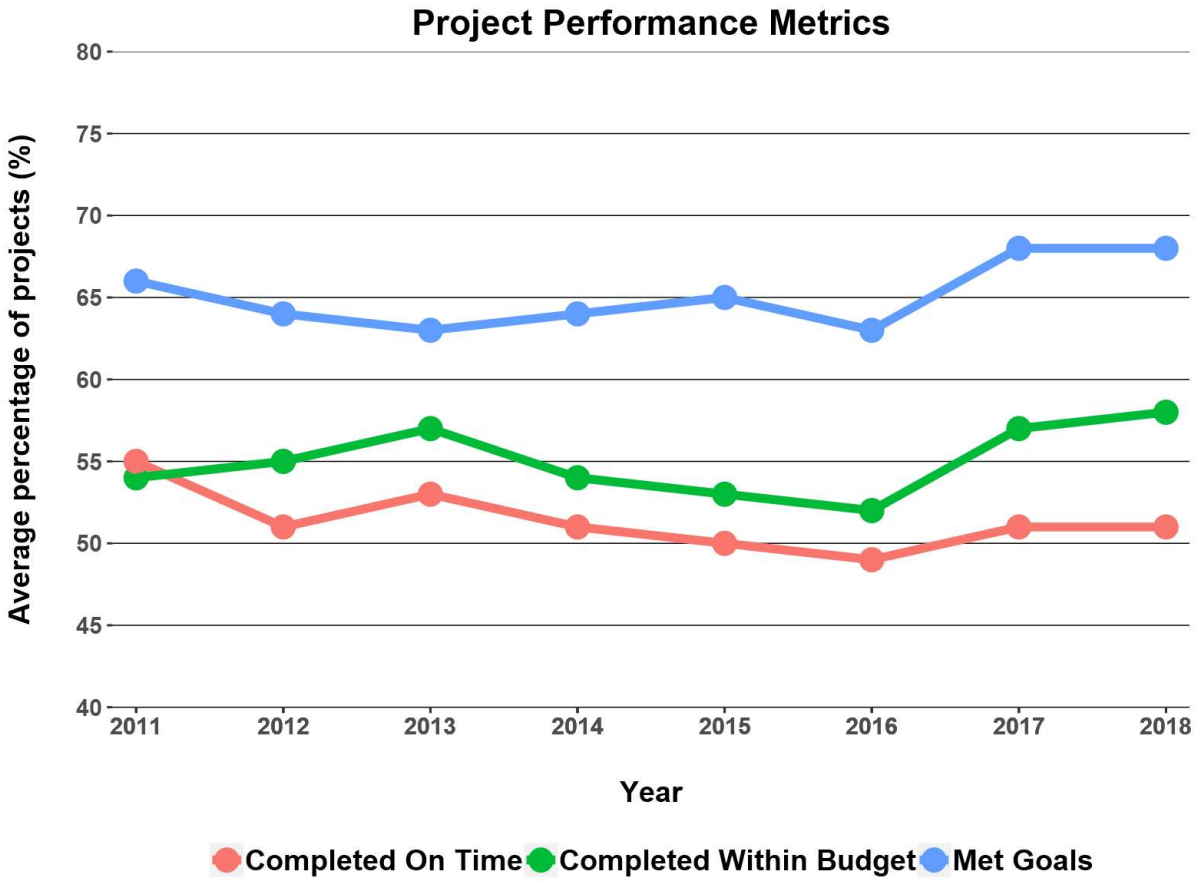
10 YEARS of SERC

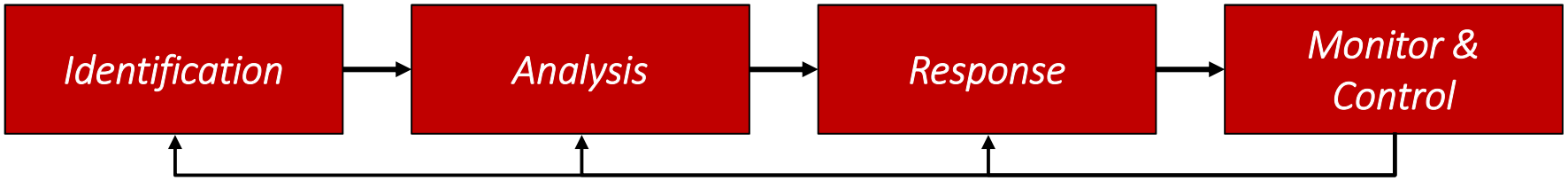
Project failures occur despite systems engineering best practices



Project delays, cost overruns, quality concerns, …

Data obtained from Project Management Institute (PMI): Pulse of the Profession 2018

Consider a traditional project management process



Project Metric	Risk Identification	Response
Schedule	Rocket system fails to clear pre-flight test	Have more frequent tests to ensure systems are ready
Budget	Component breaks	Keep replacement in storage
Operational Performance	Half the engineering design team quits	Optimize human resources in the company
Technical Performance	Satellite deployed at wrong altitude	On-board system for orbit correction

Open-ended process, based on intuition and experience

Why aren't these methods helping (as much as we hope)?

Several possible reasons…

- Reliance on extensive data creation, collection, and tracking
  - —E.g. Cumbersome risk identification during project pressure
- Different organization ≡ Different risk response/tolerance
  - —Rapid turnaround culture vs. slower-paced approach
- Do ***not*** provide guidance on how or where to address risk
  - —Poor requirements engineering, but metrics like budget will not capture this issue or help to address it

Our core ideas:

- Risk assessment based on the “real reasons” for systems engineering failures
- Augment existing data with Wisdom of the Crowd (WoC) indicators, to uncover problems and likely “real reason” causes
- Adaptable process by using machine learning that can be trained at a particular organization and learn how to make predictions

A Crowd-Based Risk Assessment

Fast & Easy

Collect data in a way that is not cumbersome, via an online crowd-signal app

Adaptable

Use data science and machine learning to make the approach adaptable to the organization

"Hard-to-game"

Questions that do not have obvious answers, but capture human behavior

Track Frequently

We could ask the employees about the projects frequently, collecting risk information continuously

Based on the "real reasons" of failure

Previous research has identified 21 "real reasons" that projects fail (e.g. poor requirements engineering)

Multiple Sources

Include a variety of signals from factors that impact project performance

The engineering team responds weekly via an app

Track Frequently

During the past week:

	Never	Rarely	Sometimes	Very often	Always
How often did you feel frustrated by your team members' or by your team's performance?	○	○	○	○	○
How often did you come up with or agree to a new idea for your project?	○	○	○	○	○
How often did you skip, delay, or cancel a task/activity/obligation you were required to do/attend?	○	○	○	○	○
How often did you find yourself being the center of the attention of your team?	○	○	○	○	○
How often did your team members share details about their life with you?	○	○	○	○	○

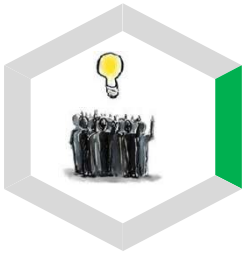
Management provides project metrics weekly via the same app

Track Frequently

What is currently true about the project spending, compared to what you initially planned?

	Project spending	Roughly, by what percentage is this project under/over budget? (If on budget leave blank)
		%
Team 1	▾	
Team 2	▾	
Team 3	▾	
Team 4	▾	
Team 5	▾	

Most systems engineering failures result from rather prosaic reasons:



Based on the "real reasons" of failure

Lost tacit knowledge when employee(s) departed	Subjected to insufficient testing	Created deficient requirements
Failed to provide resources	Violated regulations	Failed to inspect
Used inadequate justification	Violated procedures	Subjected to inadequate reviews
Failed to form a contingency plan	Managed risk poorly	Kept poor records
Failed to consider systems factor	Created deficient procedures	Failed to supervise
Lacked experience	Enforced deficient regulations	Did not allow aspect to stabilize
Failed to consider human factor	Did not learn from failure	Failed to maintain

Diane Sorenson and Karen Marais, "Patterns of Causation in Accidents and Other Systems Engineering Failures," IEEE Systems Conference, April 2016, IEEE, Orlando, FL.

Start from literature to identify factors that may affect project output

Multiple Sources

LITERATURE

6 areas of risk literature:

- Psychology
- Social Sciences
- Human Factors
- Project Management
- Systems Engineering
- WoC Research

CROWD SIGNALS

8 categories of signals:

- Team performance
- Critical success factors
- Cognitive biases
- Individual personality
- Wisdom-of-the-Crowd
- Safety Archetypes
- Indirect factors
- Risk perception

Instead of asking “Are you proactive today?”

We ask:

“Hard-to-game”

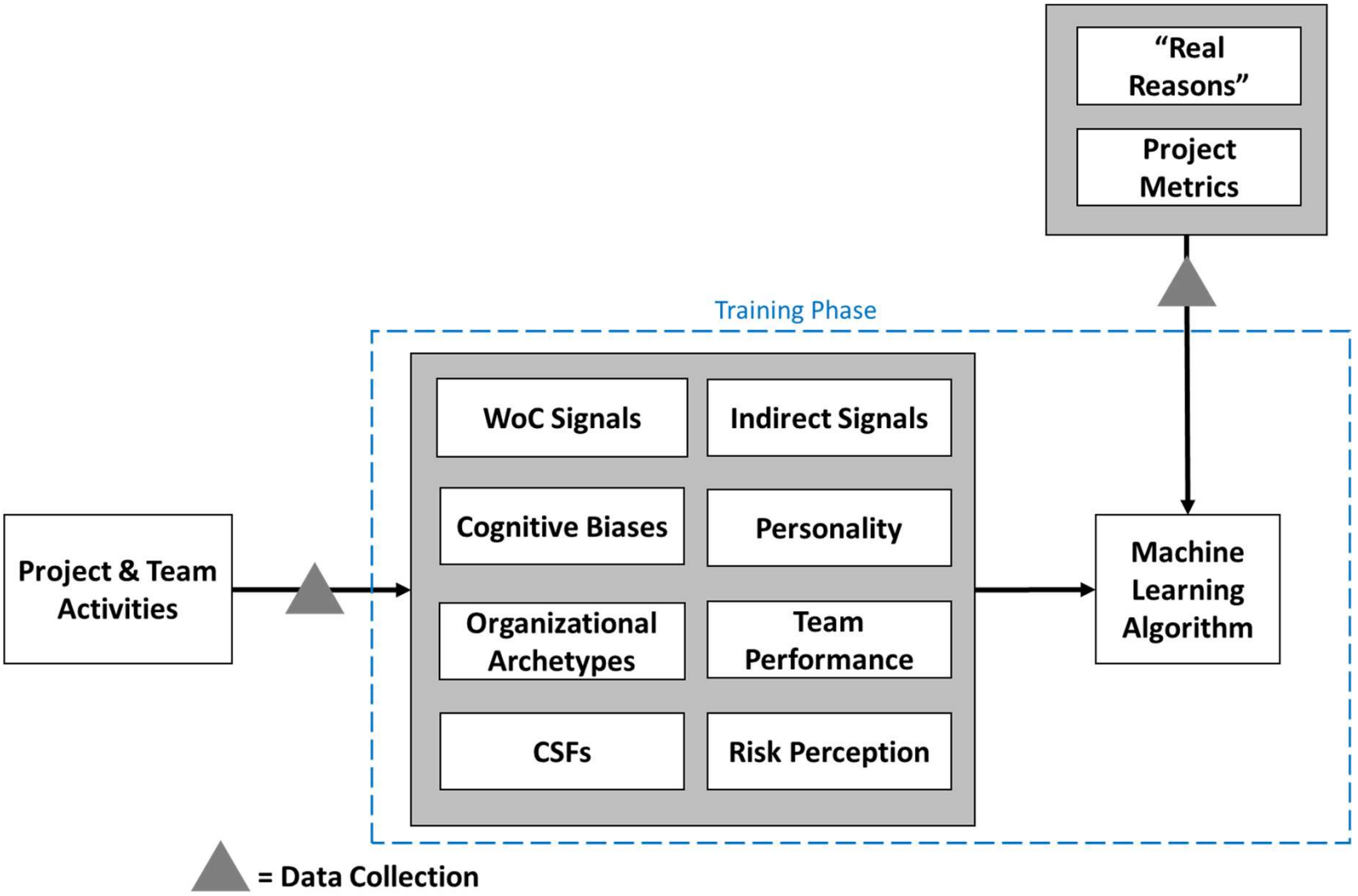
- During the past week, how many times did you attempt to get involved with your project-related task that was outside your immediate responsibility?

Instead of asking “Are you communicating properly?”

We ask:

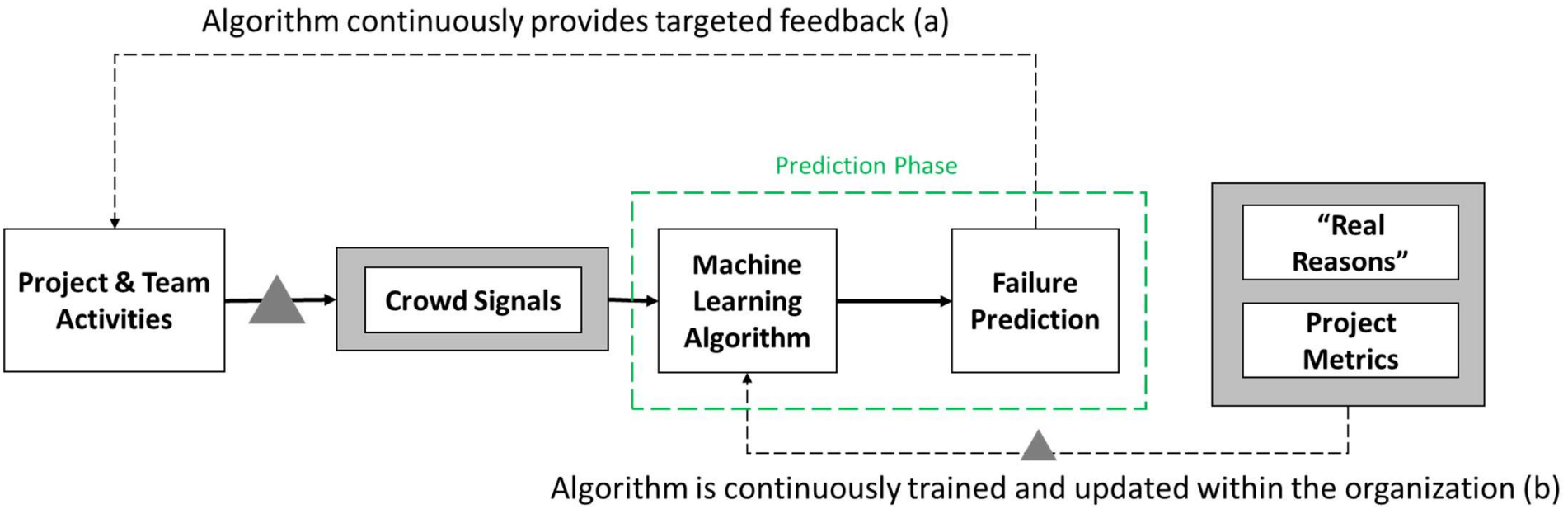
- During the past week, how often did you notice a “silent room” while you were working with your team?

Our Envisioned Prototype – Training Phase



Our Envisioned Prototype – Prediction Phase

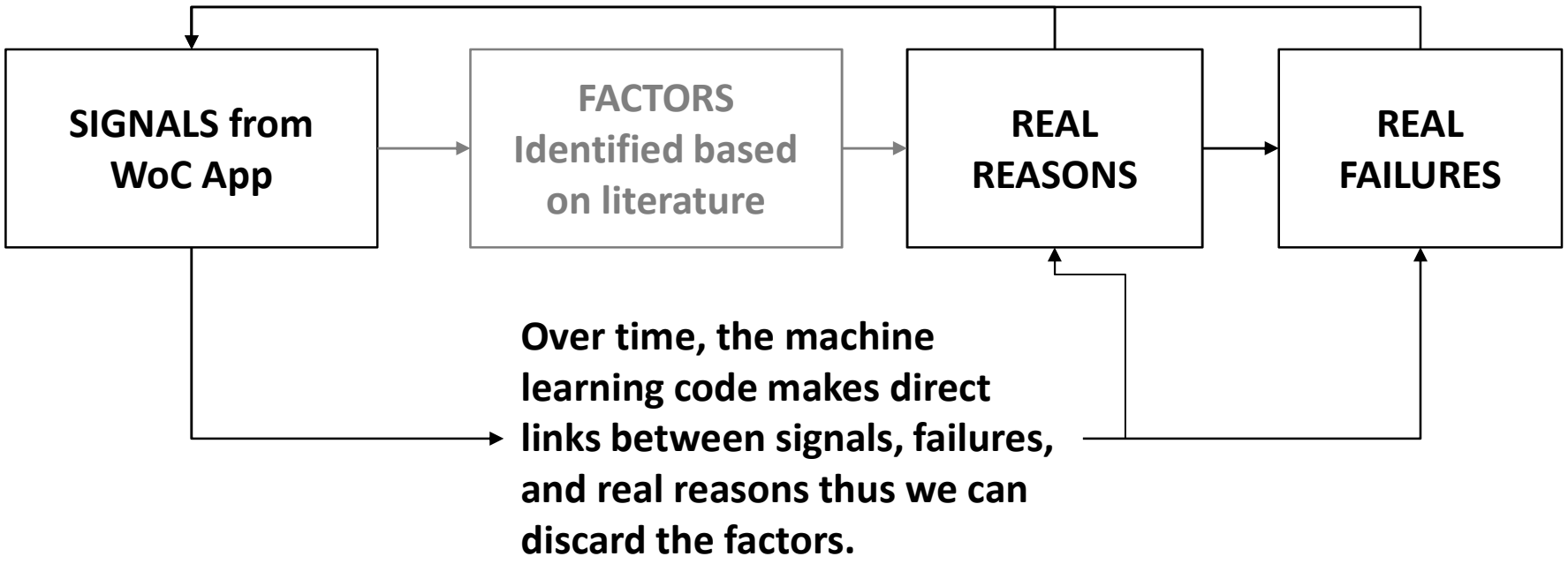
Adaptable



Direct Links between Failures and Signals at Particular Organization

Adaptable

Use student organization data to train first generations of machine learning algorithm and tailor set of input signals.



We intend for our approach to be easier & faster than “compiling spreadsheets in each department”

- People are simply answering questions about their team activities
- Convenient collection via an online-app
  - —Currently using Qualtrics
- Does not require any financial or other special knowledge

Test Case: Project Budget

Can students *individually* identify what is going on with the project budget?

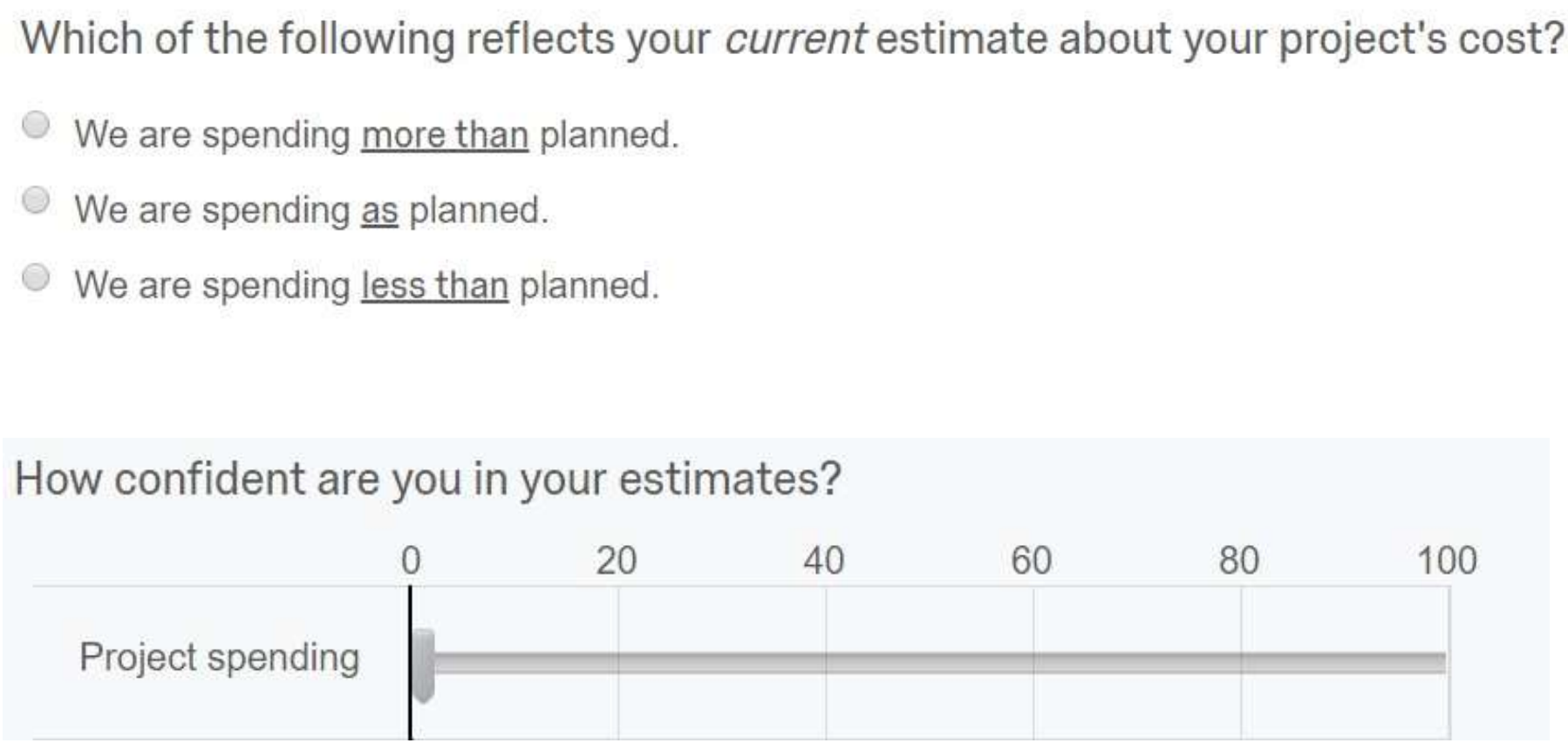
- Output: Probability that the student categorized the project budget as the instructor

- Linear logistic regression model

- Include random effects to account for subject correlation

Predictors

- Individual estimates about the project budget

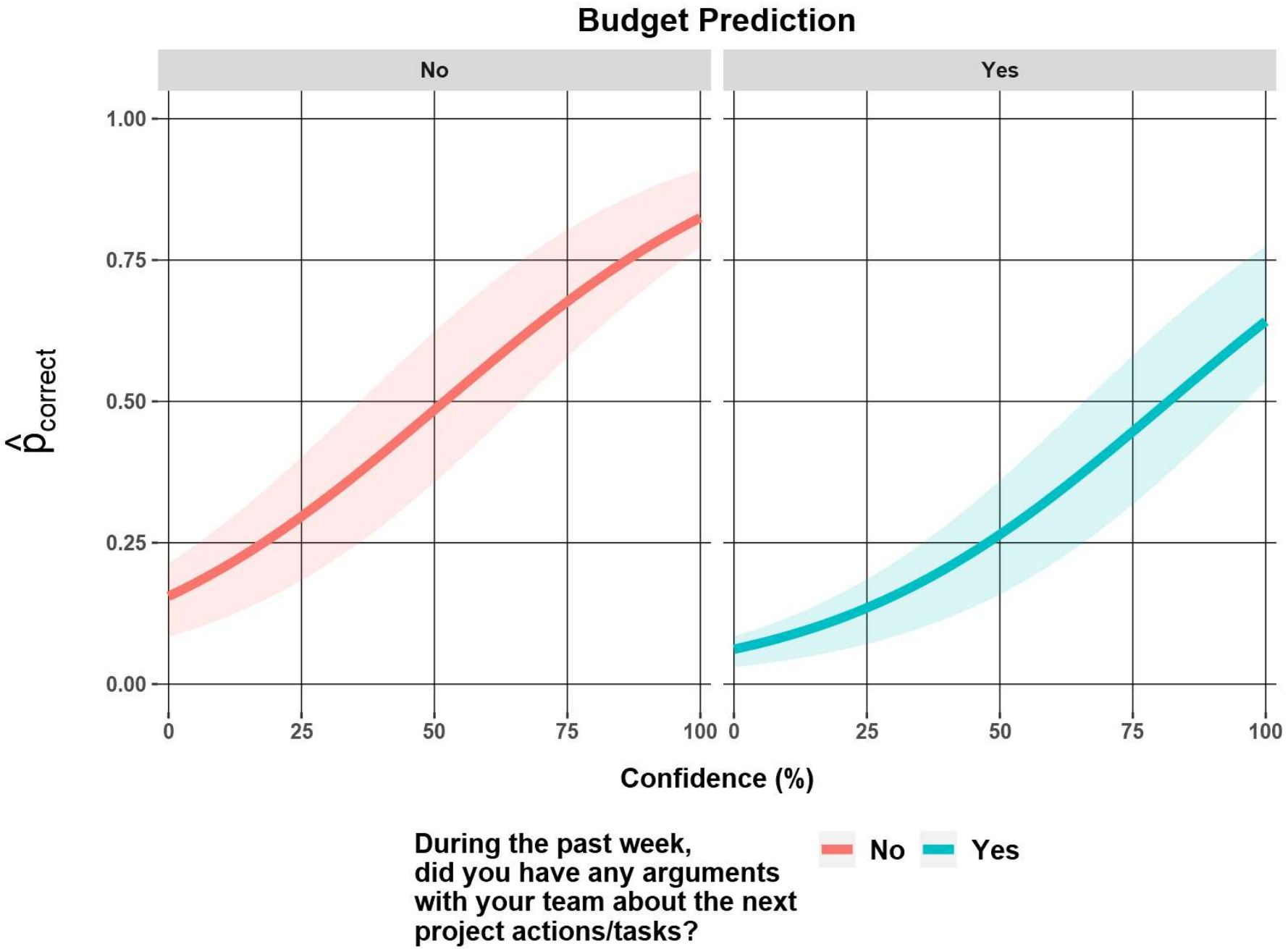


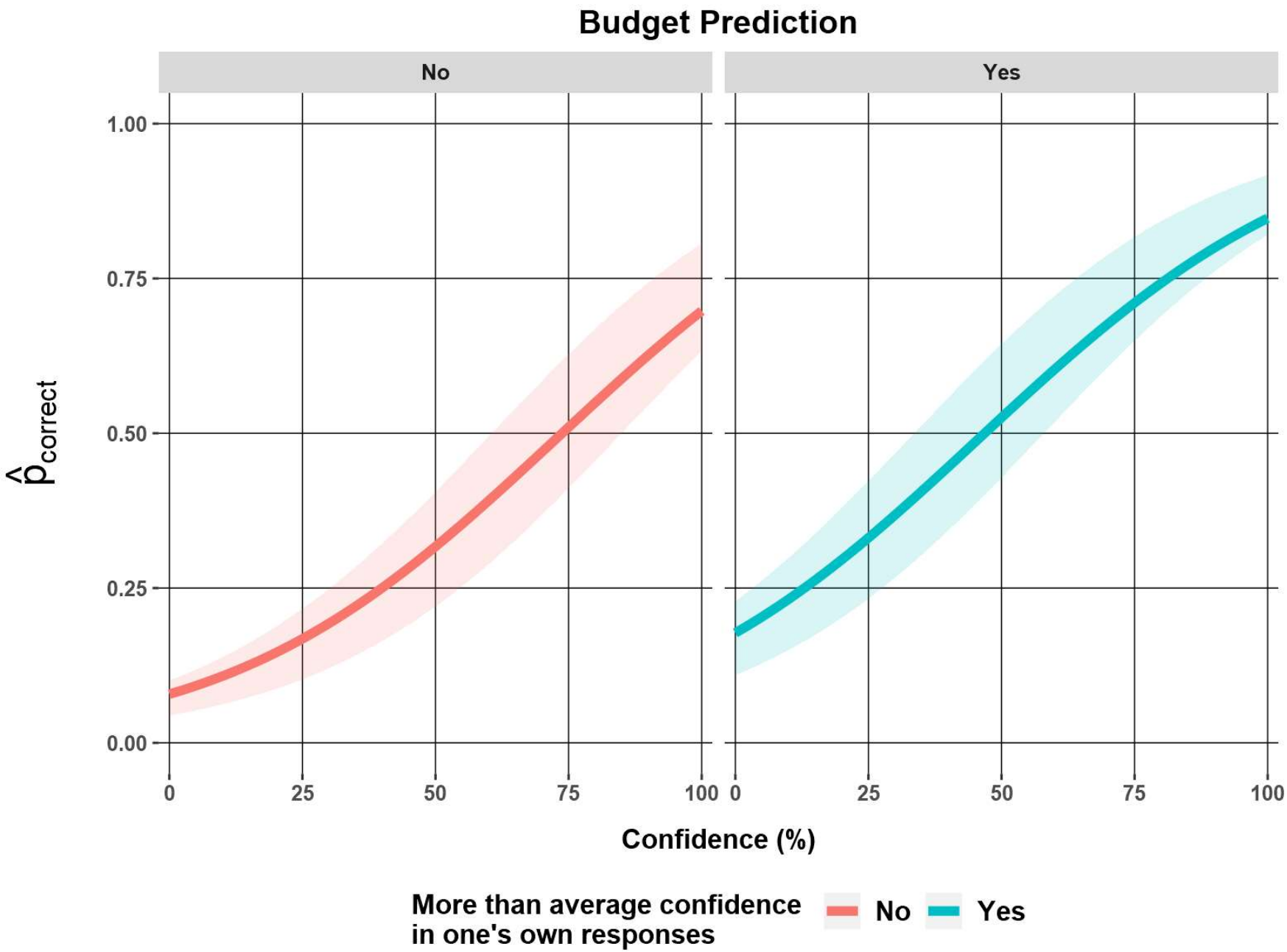
Predictors

- Questions from the cognitive biases category:

During the past week:

	Yes	No	Do not know/Does not apply
Did you disagree with an idea or decision because you thought you did not understand all potential implications?	○	○	○
Did you have any arguments with your team about the next project action/tasks?	○	○	○
Can you single out one project decision by your team as the most important?	○	○	○
Did you spend any time thinking about how things might go wrong for this project?	○	○	○
Did you get any new ideas about your project from other teams or people?	○	○	○
Did you learn any new things that surprised you, because of your involvement with this project?	○	○	○
Did your team spend significant time discussing what you thought as trivial matters about the project?	○	○	○


Budget Prediction
No
Yes
1.00
0.75
0.50
0.25
0.00
$\hat{p}_{correct}$
0
25
50
75
100
Confidence (%)
During the past week, did you have any arguments with your team about the next project actions/tasks?
No
Yes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Yes
1.00
0.75
0.50
0.25
0.00
$\hat{p}_{correct}$
0
25
50
75
100
Confidence (%)
More than average confidence in one's own responses
No
Yes

Test Case: Project budget

Can students of the same team *collectively* identify what is going with the project budget?

- Output: Probability that the team collectively categorized the project budget as the instructor

Aadded this explanation

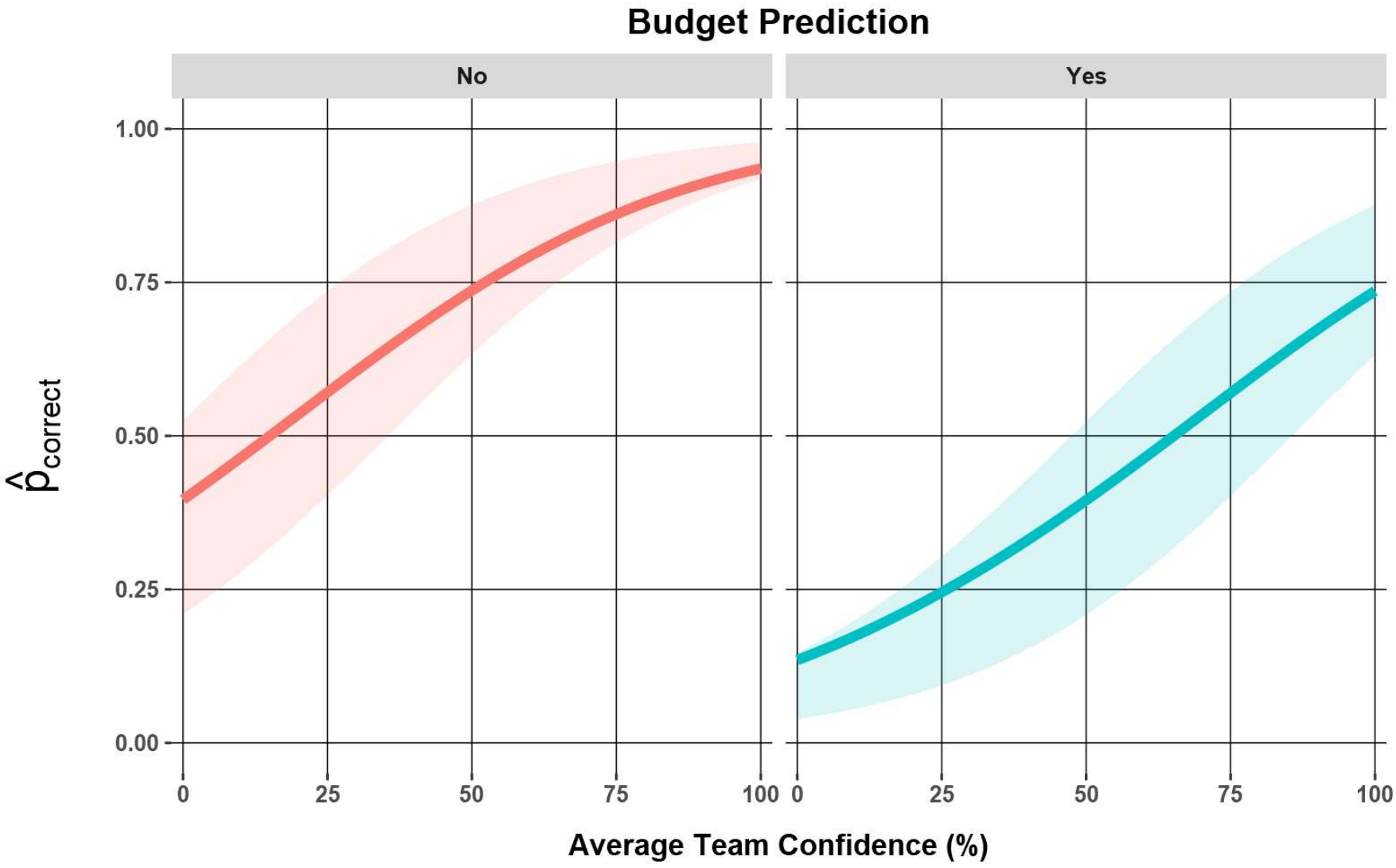
- Replace biases signals with safety archetypes signals as predictors
  - —Biases questions are about individual opinions and actions (e.g. one person thinks they learned something new)
  - —Archetypes can capture systemic facts that impact the whole team (e.g. signs of bureaucracy or witnessing poor fixes to problems)

Predictors

- Questions from the system archetypes category:

	Yes	No	Do not know/Does not apply
If new problems occurred the past week, do you think they were handled appropriately?	○	○	○
During the past week, did your team consider new potential risks as a result of a new project task or update?	○	○	○
During the past week, were you disappointed because a problem that your team thought had been fixed, had instead continued or gotten worse?	○	○	○
During the past week, were you frustrated about any rule or constraint that was out of your control?	○	○	○

- Averaged team confidence in the estimate

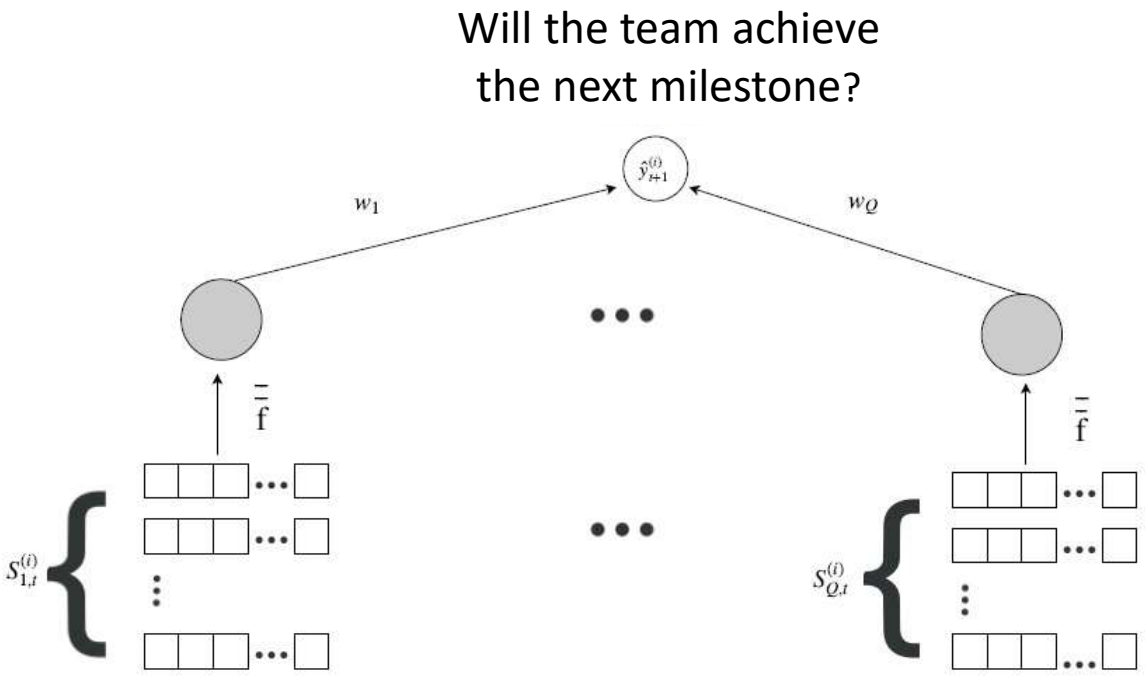


During the past week,
were you disappointed because a problem that your team thought had been fixed,
had instead continued or gotten worse?

No Yes

Future: Neural Networks using Janossy Pooling

- Problem: To predict if a team successfully completes their next milestone
  - —Deep learning does not have the correct blocks to make this prediction
  - —Co-PI Ribeiro has developed an architecture that can learn while exploring dependencies between signals



Next Steps

- Expand the data collection in more student projects and outside engineering
  - —Software design courses
- Build models that predict the occurrences of “real reasons” and project mishaps
- Include indirect questions that we suspect are related to student performance in the analysis
- Reduce the number of questions and keep the ones that are better predictors