

# Roles of Engagement: Networks in PER

Physics Department Colloquium - Rowan University

Eric Brewe

Drexel University

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# Hurricane Sandy

## What caused Hurricane Sandy?

- Global Warming
  - Increased oceanic temperatures
  - Disruption of climate patterns
  - Sea level rise
- But this is a system of causes, not a singular direct cause.



Figure: Jersey Shore Post Sandy

# Learning

## What causes learning?

- Active Learning
  - Curriculum
  - Pedagogy
  - Instructors
  - Mindset



Figure: Active Learning at Drexel

See where this is heading?



# Learning

## What causes learning?

- Active Learning
  - Curriculum
  - Pedagogy
  - Instructors
  - Mindset
  - Context
  - Blood sugar levels
  - etc...

See where this is heading?



Figure: Active Learning at Drexel

# Direct and Systemic Causation

## Direct Causation in Education

- Supposes that learning happens through:
  - singular,
  - direct causes
- Research design is built around this idea



## Systemic Causation in Education

- Supposes that learning happens through:
  - a network of interconnected,
  - probabilistic elements,
  - with built-in feedback loops.
- But how to design research to investigate this?

# Network Definitions

## What is a **Network**?

Collection of Object-like things that are connected.

- Nodes: Object-like things (Nouns)
  - Students in a class
  - Words in a book
  - Concepts
- Can have attributes.



# Network Definitions

## What is a **Network**?

Collection of Object-like things that are connected.

- Ties/Edges/Links: Connections between nodes (Verbs)
  - Talked to each other
  - Are adjacent
  - Used together
- Directional
- Weighted
- Multiplex





# Fundamentals of Network Analysis

Network Analysis is for the analysis of **relational data** There are four basic assumptions:

- 1 Actors (nodes) and interactions are interdependent\*
- 2 Ties (edges) all flow (information, resources, etc) between actors.
- 3 Network models on individuals both constrain and provide opportunity for individual action.
- 4 Network models conceptualize structures as representations of lasting patterns of relations between actors.



\*Violates basic assumption of inferential statistics.

# Ego Analyses

## What can we do based on one node?

- Ego density
- Number of Neighbors
- Number of Connected Neighbors

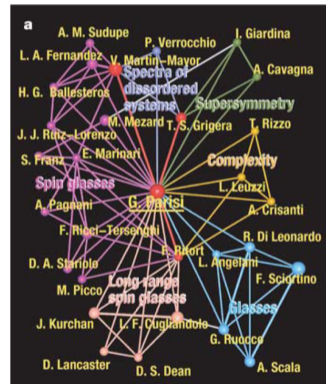


Figure: Ego Diagram for Giorgio Parisi

# Node-level Analyses

## Centrality - Family of metrics of importance of single node

- Degree Centrality
- Geodesic Distance (Kevin Bacon)
- PageRank
- Target Entropy



Figure: PER Citation Network

# Graph-level Analyses

## Analyses of whole network

- Density, Average path length, Giant component
- Clustering
- Homophily
- Modeling
  - Block modeling
  - Small World

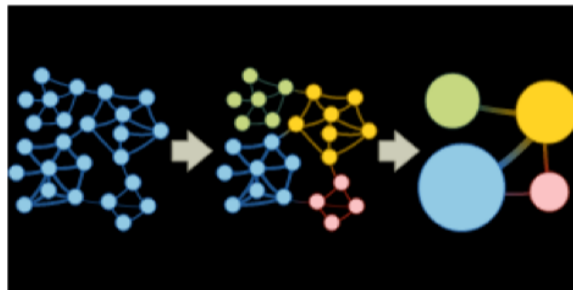


Figure: Infomap Clustering

# Historical Foundations of Network Analysis

- Joseph Moreno & Helen Hall Jennings (1932)
  - Established foundations of SNA
- Quantitative Sociology/Anthropology
  - Davis Southern Women's Club (1941)
  - Small World Problem (1967)
  - Zachary's Karate Club (1977)
- Seminal Articles
  - Milgram, Stanley "The small world problem" *Psychology Today* 2:1, (1967)
  - Grannovetter, Mark S. "The strength of weak ties" *American Journal of Sociology* (1973)



# Modern Foundations of Network Analysis

- Socio-physics (1990s)
  - Mathematics of graph theory, applied to complex systems
  - Information theory
  - Computing power
  - Internet
  - Power Grid
  - Transportation
- Seminal Articles
  - Watts & Strogatz "Collective dynamics of small world networks" *Nature* (1998)
  - Page, Brin, Motwani, & Winograd "The PageRank citation ranking: Bringing order to the web" *Stanford InfoLab* (1999)



# Important Takeaways from History

- Two main camps
  - Statistical - hypothesis testing
  - Graph Theoretic - network models compared with simulated data

They don't often agree, there is some open disdain. They have different languages, journals, conferences.



# Studies of Classroom Engagement

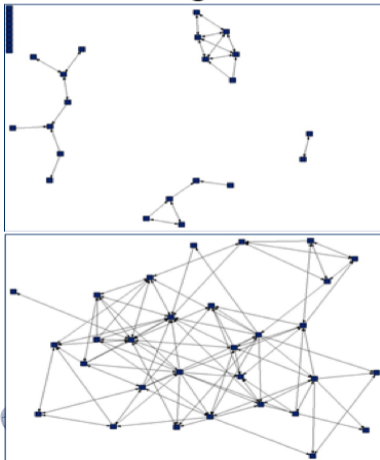
## Study #1: Pedagogy structures student engagement



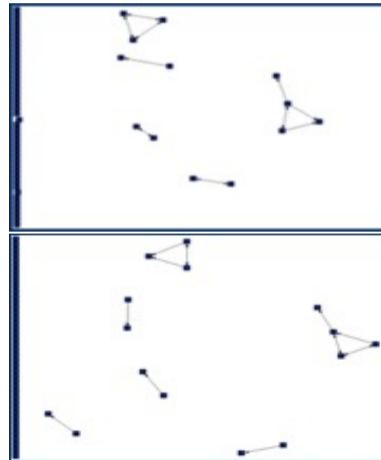


# Classroom Networks in Modeling Instruction

## Modeling Instruction



## Lecture Instruction



Pre  
Post

# Studies of Classroom Engagement

## Study #2: Student Networks Influence Learning



# Using Centrality to Predict Grades

- University of Copenhagen - Physics 1
  - 178 Students
  - Weekly Electronic Survey
    - Hvem diskuterede du fysikkoncepter med i denne uge?
    - Hvem diskuterede du fysikopgaver med i denne uge?
    - Hvem snakkede du med socialt - og altså ikke om fysik - med i forbindelse med undervisningen?



# Using Centrality to Predict Grades

- University of Copenhagen - Physics 1
  - 178 Students
  - Weekly Electronic Survey
    - Whom did you discuss physics concepts with this week? (CD Network)
    - Whom did you discuss physics problems with this week? (PS Network)
    - Whom did you talk to socially – not about physics – in class this week? (ICS Network)
- Grades in Physics 1 + FCI as attributes
- Linear model to predict future grades



# Using Centrality to Predict Grades

## Centrality Measures

- In-degree ( $k_{in}$ )
- In-Strength ( $s_{in}$ )
- PageRank ( $PR$ )
- Hide ( $H$ )
- Target Entropy ( $T$ )

From: Bruun & Brewé (2013)

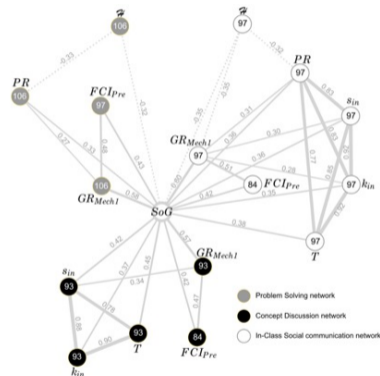


Figure: Grade Correlation Network

# Using Centrality to Predict Grades

- Linear Modeling to predict grade in combined Physics II + Math in three networks (CD, PS, ICS)
  - Problem Solving Network: Grades  $\sim$  FCI Pre
  - Concept Discussion Network: Grades  $\sim$  Target Entropy
  - **In-Class Social Network: Grades  $\sim$  FCI Pre + Target Entropy + Hide**



# Studies of Classroom Engagement

## Study #3: Students Responses on Conceptual Inventory are Relational



# Module Analysis of Multiple Choice Responses

## Force Concept Inventory

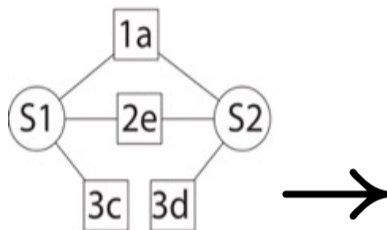
- Intended to be a diagnostic instrument
- Common analyses include:
  - Percent Correct
  - Normalized Gain
- Curiously reliable
- Psychometricians **HATE** it
- Factor Analysis is challenging



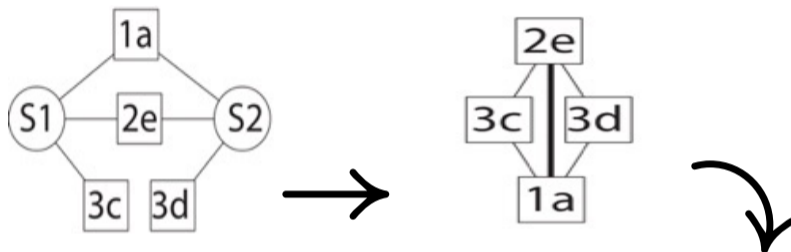
from Brewe, Bruun & Bearden (2016)



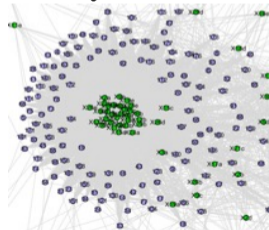
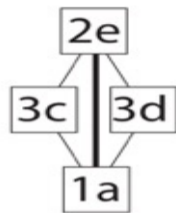
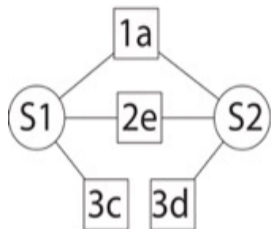
# Module Analysis of Multiple Choice Responses



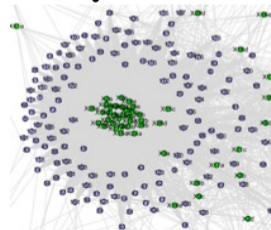
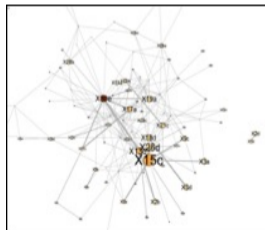
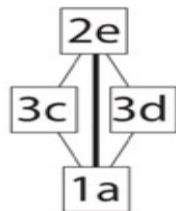
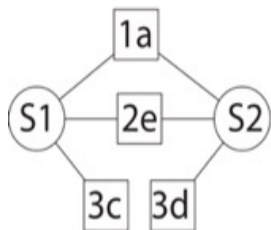
# Module Analysis of Multiple Choice Responses



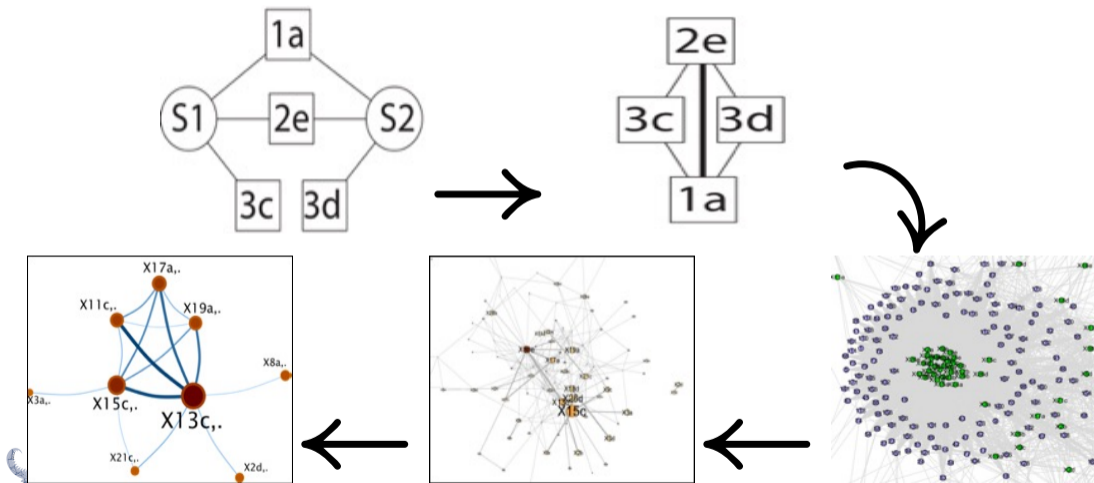
# Module Analysis of Multiple Choice Responses



# Module Analysis of Multiple Choice Responses



# Module Analysis of Multiple Choice Responses



# Interpreting a Module

## Impetus Cluster

- Two primary nodes are impetus
- Others consistent with impetus

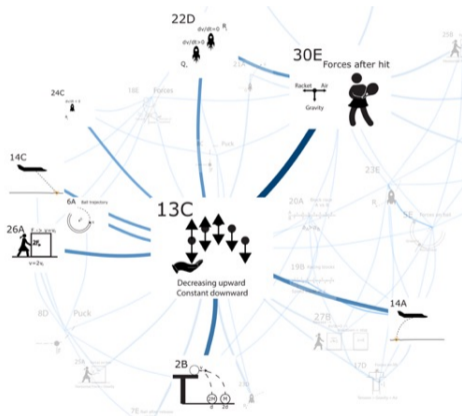


Figure: Impetus Module

# Interpreting a Module

## Module 3

- Constant  $\vec{v}$  requires  
Constant  $\vec{F}$
- or...is it  $\vec{a}$  and  $\vec{v}$  not  
discriminated

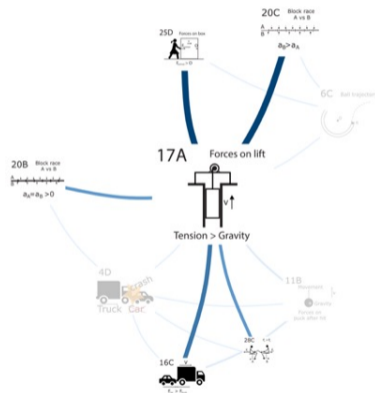


Figure: Module 3

# Network Method for Analysis of Conceptual Inventory

- Data driven approach to identifying student conceptions
- Latent models are hard to interpret
- Goes beyond right/wrong





# Studies Beyond Students

## Study #4: Instructional Fingerprinting



# Instructional Fingerprinting

Framework for Interactive Learning in Lectures (FILL) Wood et al., 2016

- Observational protocol, marks shifts between activity types, scaled by time.

Data:

- Class #1 - Instructors A, B
- Class #3 - Instructor A (different class)



# Class #1 Instructors A & B

## FILL Network

Course 1, Instructor A

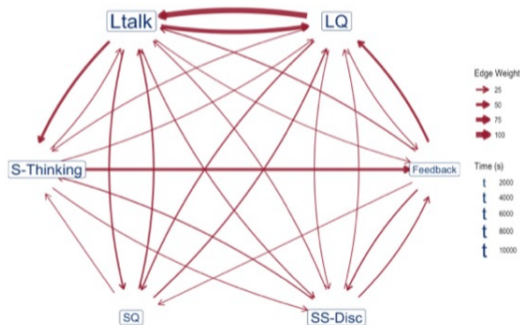


Figure: Instructor A

## FILL Network

Course 1, Instructor B

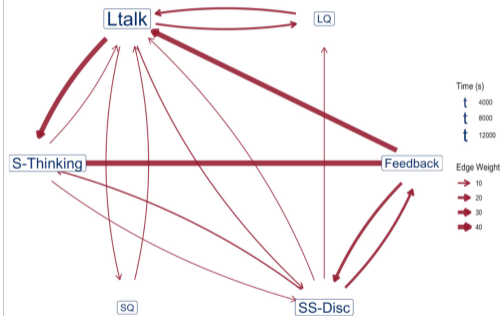


Figure: Instructor B

# Instructor A, Classes 1 & 3

## FILL Network

Course 1, Instructor A

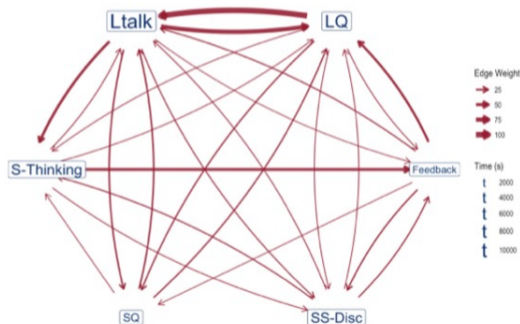


Figure: Instructor A - Course 1

## FILL Network

Course 3, Instructor A

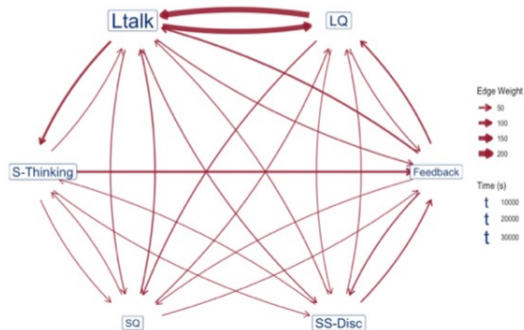


Figure: Instructor A - Course 3

# Key Findings

- Useful in distinguishing pedagogies
- Reveals role of engagement in student outcomes
- Reveals latent conceptual modules in student responses
- Reveals structural patterns of interaction in teaching



# Take Aways

- Network Analysis is a robust theory / methodology with wide applicability
  - Informs structure of classrooms, departments, and spaces
  - Reveals latent structure and complex dynamics
  - New direction in PER & education broadly
- Not the only tool for PER



# How to design for systemic causation?

- Continue with correlational studies
  - Consider networks of causation
- Keep interactional designs in mind
  - Consider whether data are truly independent
- Design for complexity



# Thank you!

