Visualizing Engineering Design with Process Analytics Based on CAD Software

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WHERE DISCOVERIES BEGIN

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Subject/Problem

Engineering design is part of the Next Generation Science Standards.

NEXT GENERATION SCIENCE STANDARDS

For States, By States

The question is…

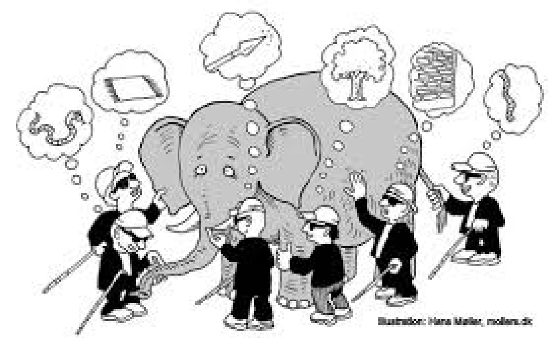
How do we assess engineering design learning?

Why is Assessment for Engineering Design Difficult?

In the K-12 context, engineering design is a complex, multifaceted cognitive process that consists of:

- **Problem-based learning**: Students must solve authentic problems using STEM concepts and skills such as scientific inquiry while making design decisions.
- **Project-based learning**: Students must solve these interconnected problems systematically to meet the goals, criteria, and constraints of a project.
- **Systems thinking**: Students must consider relationships among multiple elements and how they contribute to system performance.
- **Constructionist learning**: Students must try to construct successful products to show that their designs really meet the specifications.
- **Collaborative learning**: Students commonly work in a team and/or influence each other's work through communication.
- …

And we don't seem to have a clear agreement on what makes a good assessment for engineering design.

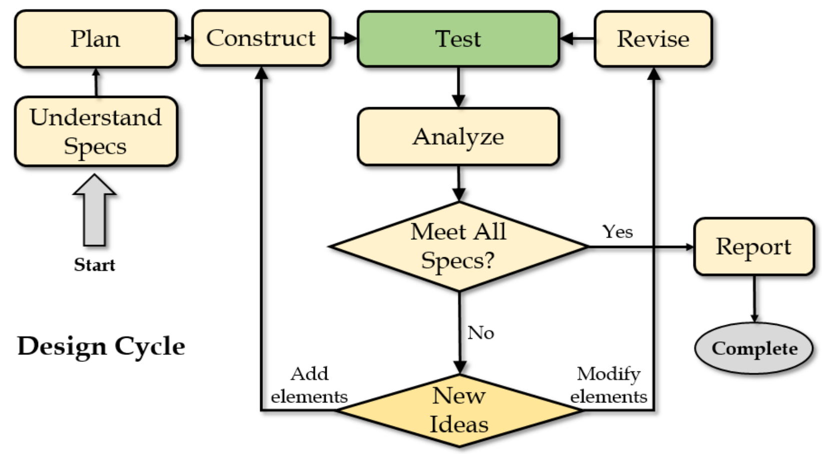


Process Analytics

Engineering design *is* a learning process.

We need to analyze its process.

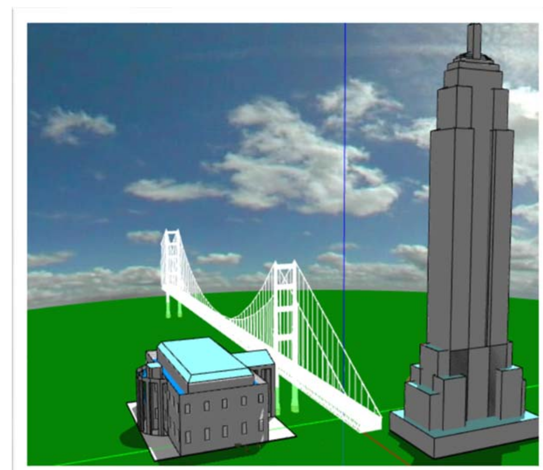
Our research focuses on process analytics.



Our definition: Process analytics is a type of learning analytics that aims to find patterns and relationships from the fine-grained learner data logged by a learning technology, with the goal to understand what learner-technology interaction is responsible for a specific learning outcome.

Research Goals

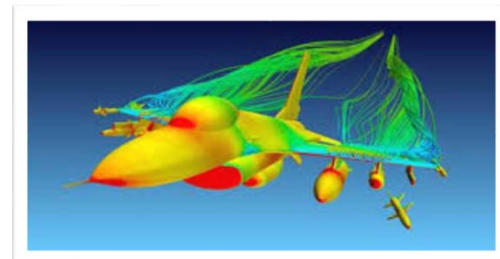
- **Designer modeling**: Understand how students design with technology (e.g., what are the common patterns of their design behaviors?)
- **Intervention**: Investigate how design behavior can be altered and design thinking can be learned (e.g., how do we stimulate iteration in the right direction?)
- **Adaptive feedback**: Develop intelligent systems that personalize learning and assist teaching
- **Creativity**: Can computers spur design creativity and engineering innovation?
- ...



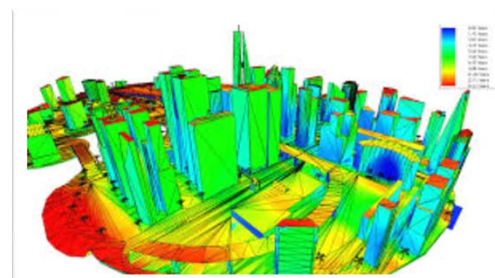
To transform learning science into a data science, we move to a cyberlearning platform.

CAD Software as Design Learning Platforms

Not your father's computer-aided drafting tools!

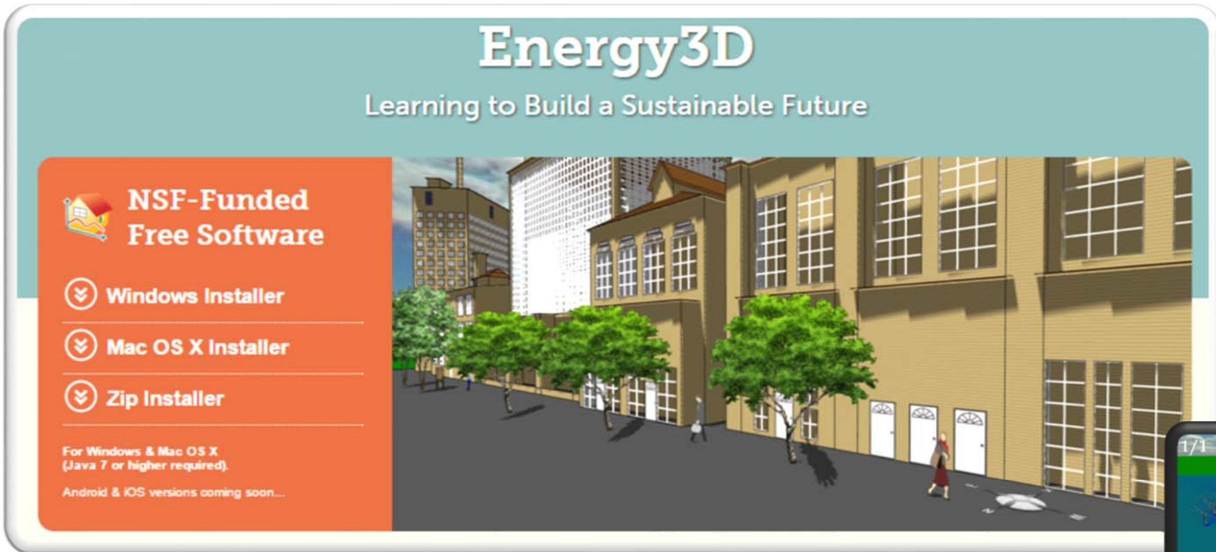


- **3D graphics and visualization** (even holograms with HoloLens)
- **Scientific simulation and analysis** (multiphysics modeling, etc.)
- **Conceptual design** (WYSIWYG, digital sculpting/sketching, etc.)
- **Artificial intelligence** (knowledge engineering, etc.)
- **Computational design** (automatic search for solutions, etc.)
- **Digital fabrication** (3D printing, etc.)
- …

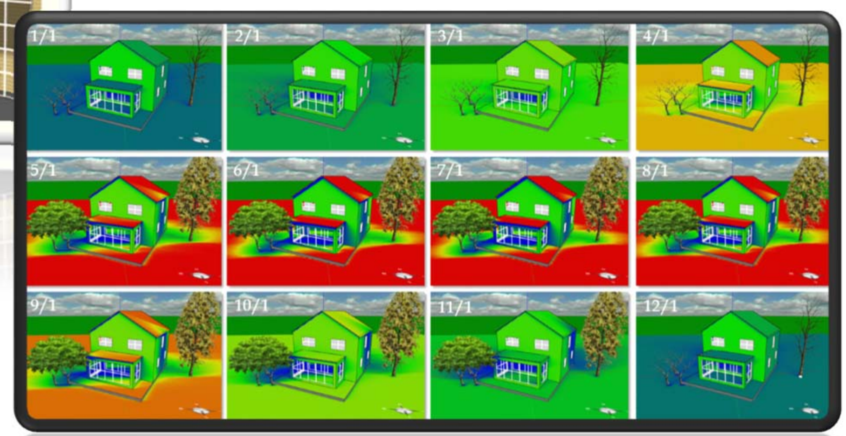


Virtual prototyping allows design ideas
to be explored entirely within cyberspace.

An Open-Source CAD Platform for Research on Engineering Design

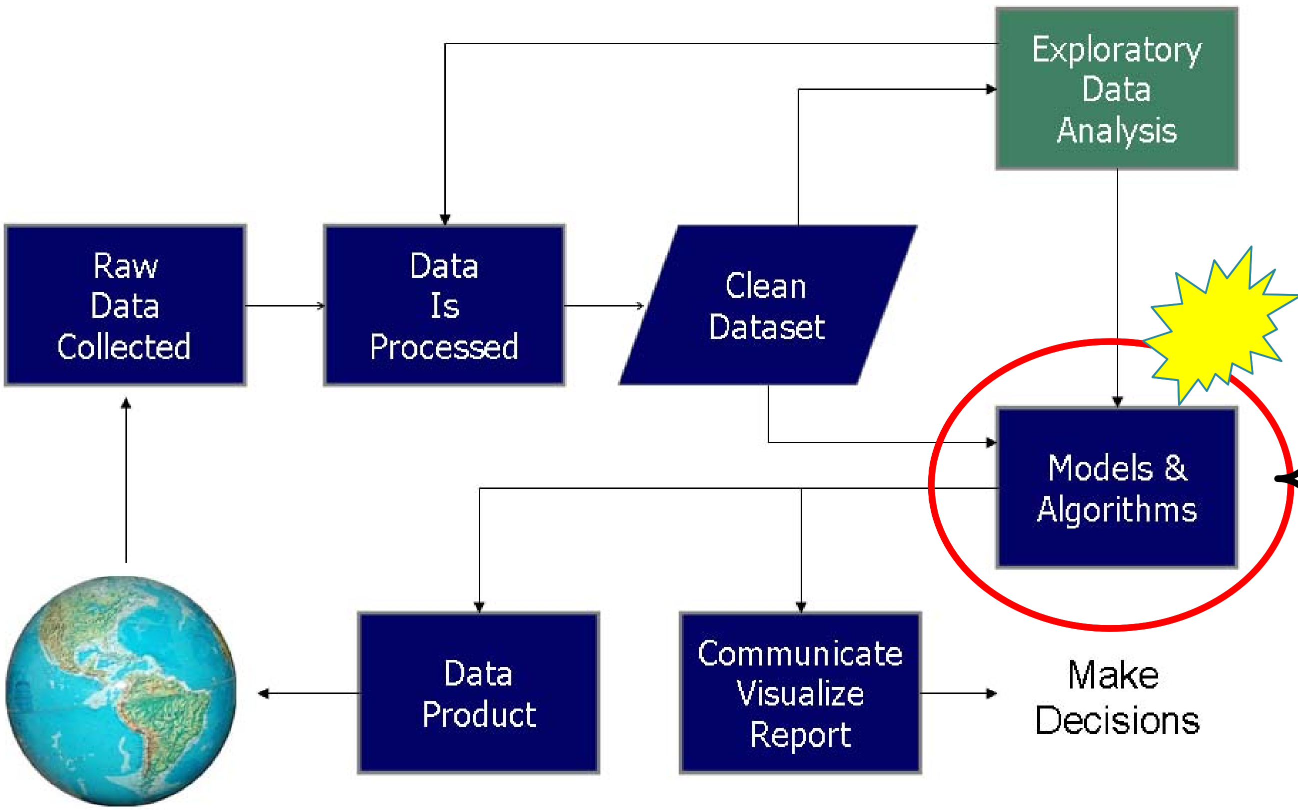


- Architectural engineering
- Solar engineering
- Energy engineering
- Urban planning
- Structural engineering
- ...



http://energy.concord.org/energy3d
CAD of educators, by educators, for educators

A Data Science Process



Multidisciplinary

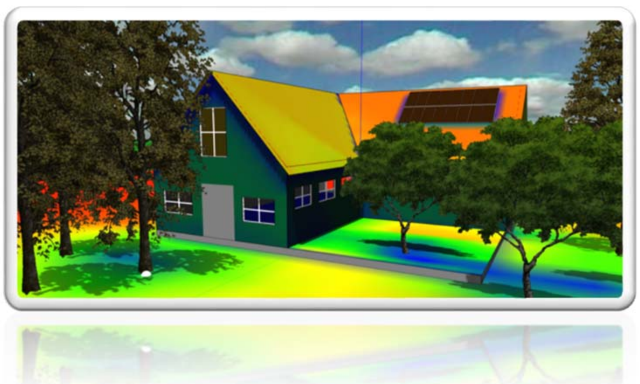
- Computational Science
- Cognitive Science
- Learning Science

Cognitive computing?

http://en.wikipedia.org/wiki/Data_science

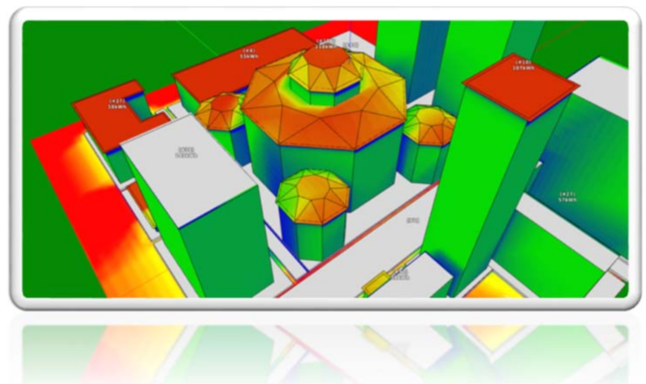
Research Subjects and Settings

Year	#students	Class	Grade	State	Design Challenges
2012	20	Engineering	Mixed	MA	Solar Urban Design
2013	63	Engineering	Mixed	MA	Solar Urban Design
2013	68	Physics	9	MA	Solar Urban Design
2014	67	Physics	9	MA	Energy-Plus Home Design
2015	110	Physics	9	MA	Energy-Plus Home Design + Solar Urban Design



Energy-Plus Home Design

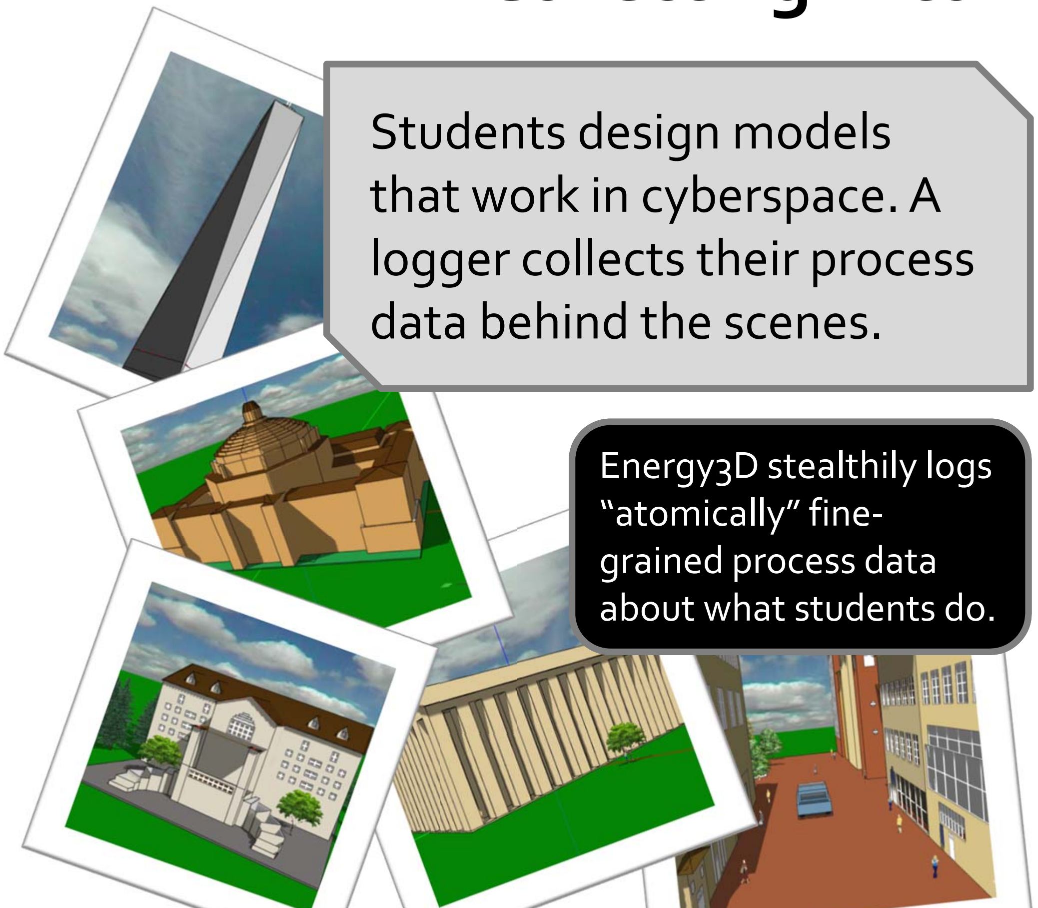
Design a house that generates more renewable energy than it consumes over the course of a year



Solar Urban Design

Design a city block with high-rise buildings that have optimal solar gains in different seasons

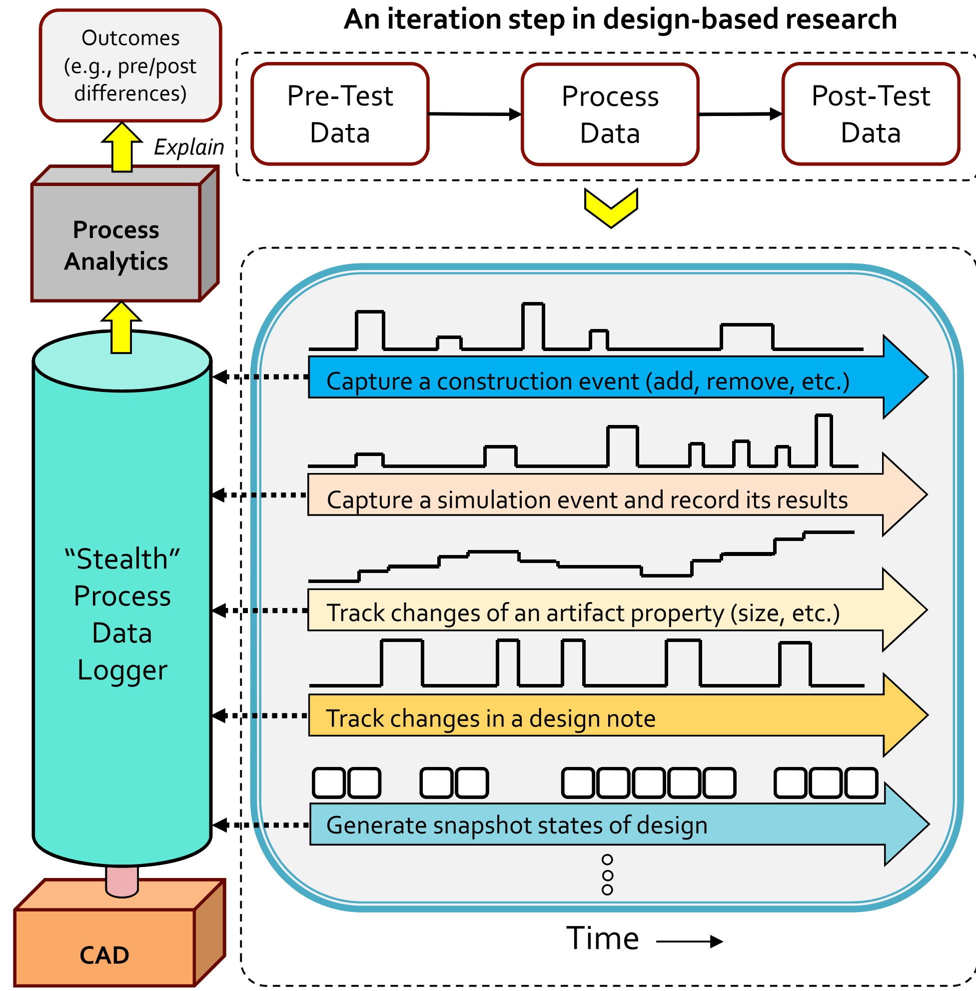
Collecting "Atomic" Process Data



Students design models that work in cyberspace. A logger collects their process data behind the scenes.

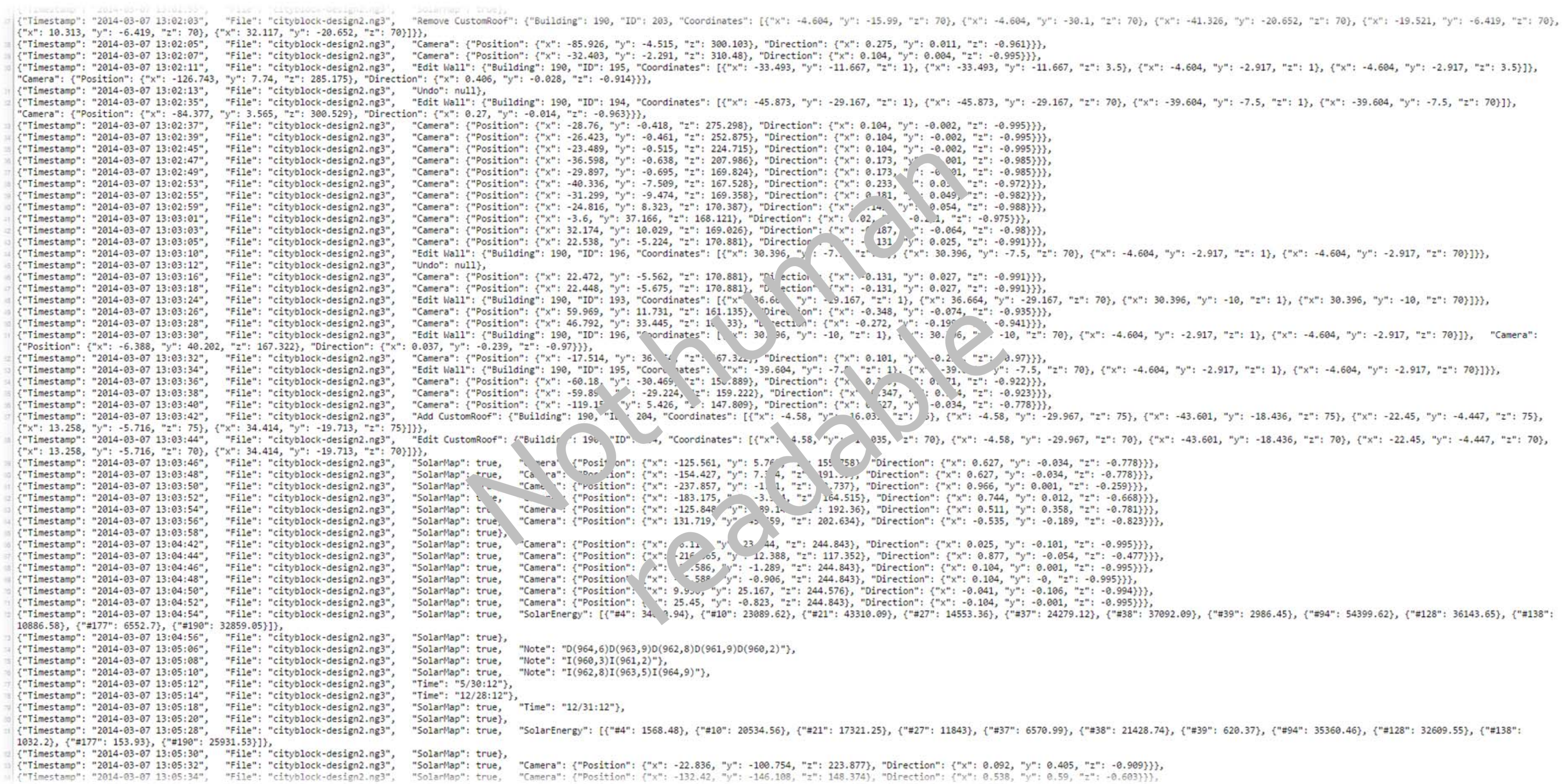
Energy3D stealthily logs "atomically" fine-grained process data about what students do.

Our invention: A data logger based on Undo Manager and Track Change (more structured than mouse clicks)

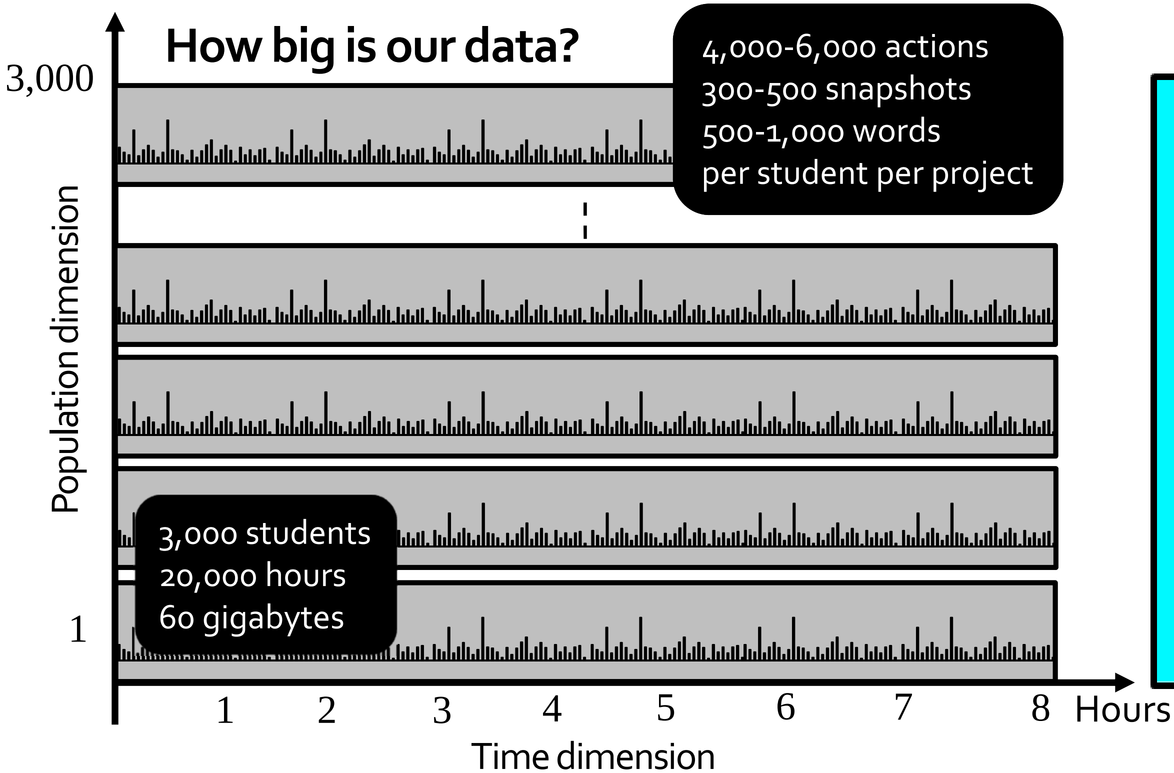


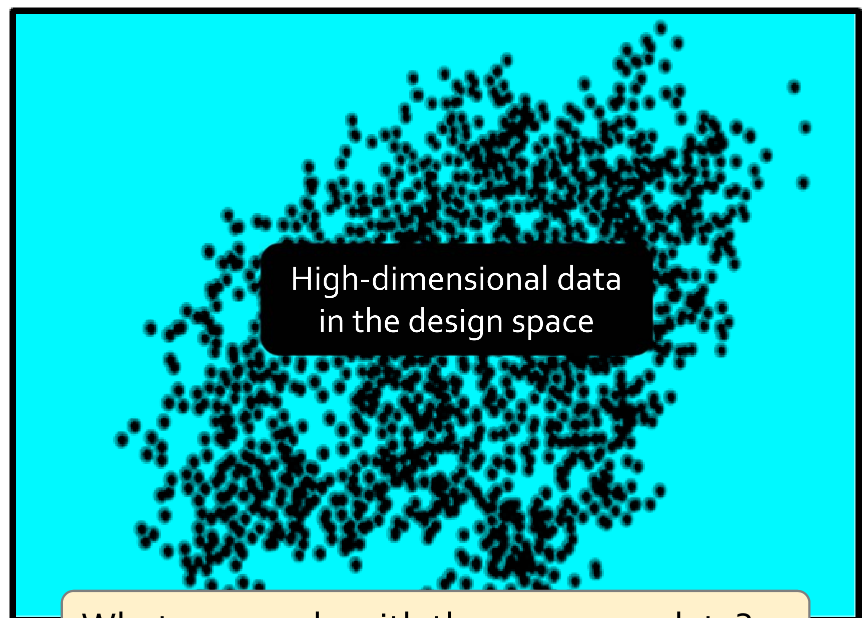
A JSON Data Schema that Encodes Energy3D Design Process

How do the data look like?



Data-Intensive Research (aka "Big Data")



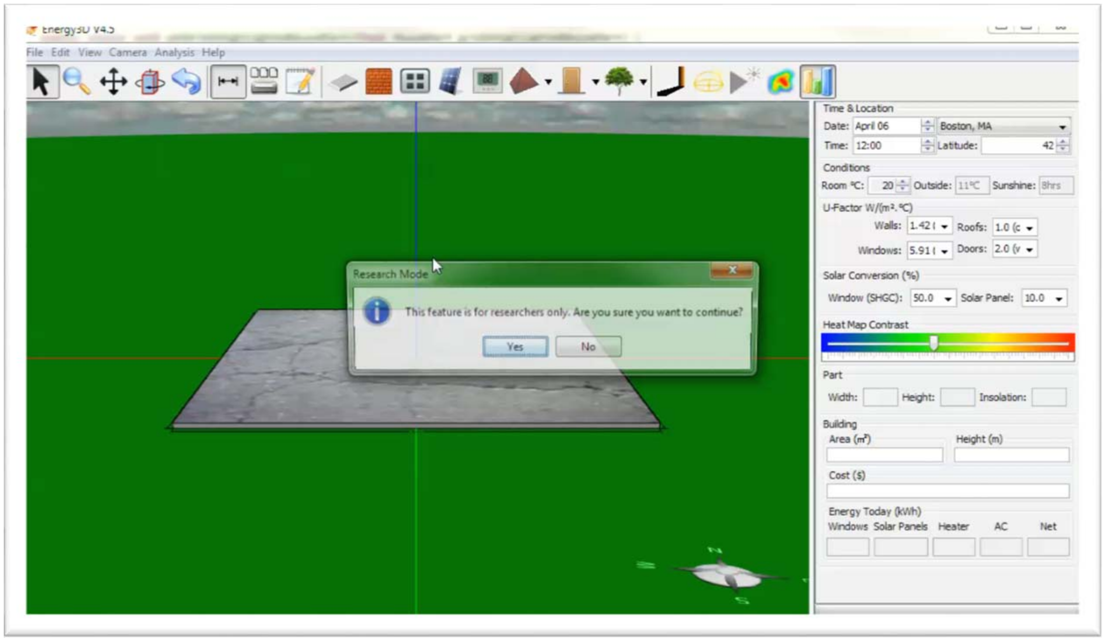


What can we do with these process data?

What can we find from these process data?

Exploratory Data Analysis: Design Replay

Playing back a student's design process like running a slide show and post-process it

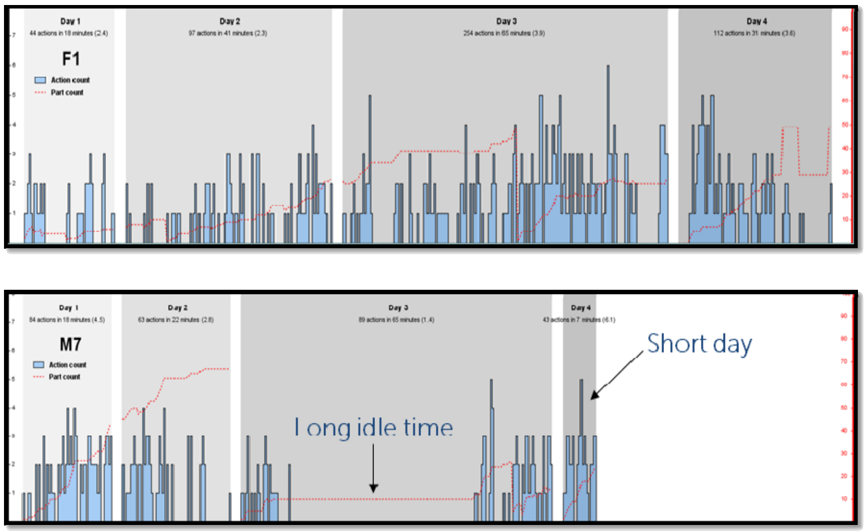


Compare with screencast, recording is based on events, not lapse of time.
(no event, no record.)

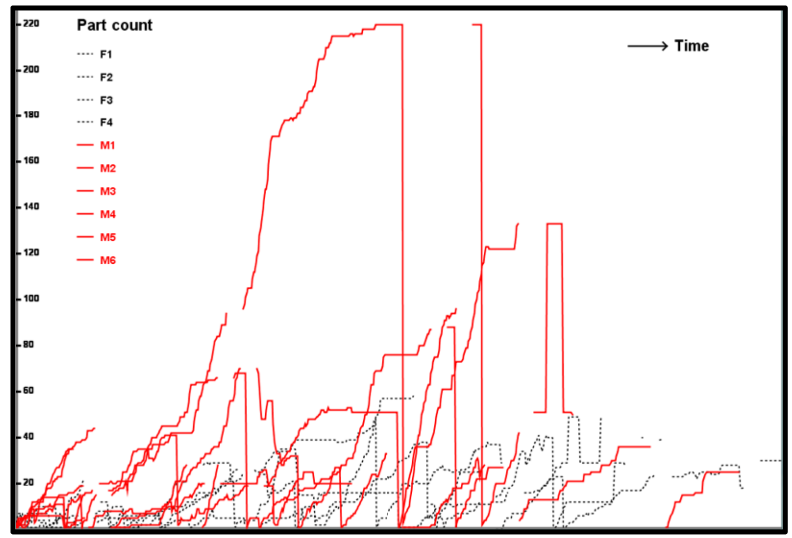
High ratio of lossless compression

Models and Algorithms: Time Series Analysis

Can we predict students' design behavior?



Action count
Measuring student activeness

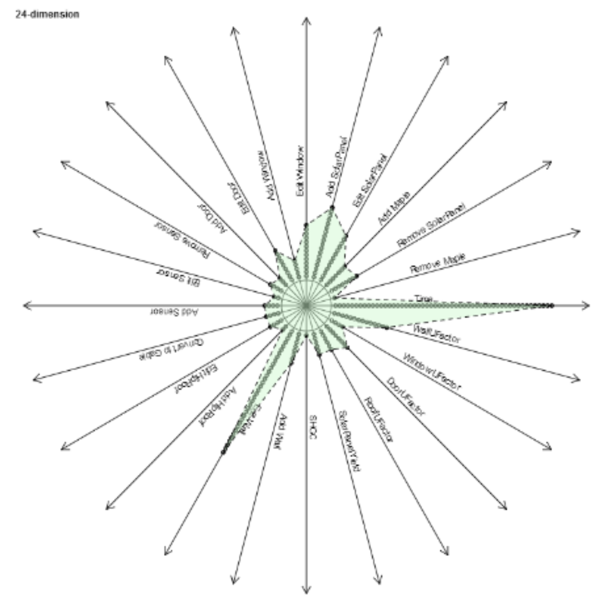


Artifact count
Measuring design complexity

Models: ARIMA, etc.

Models and Algorithms: Dimensionality Reduction

How do we analyze high-dimensional data?



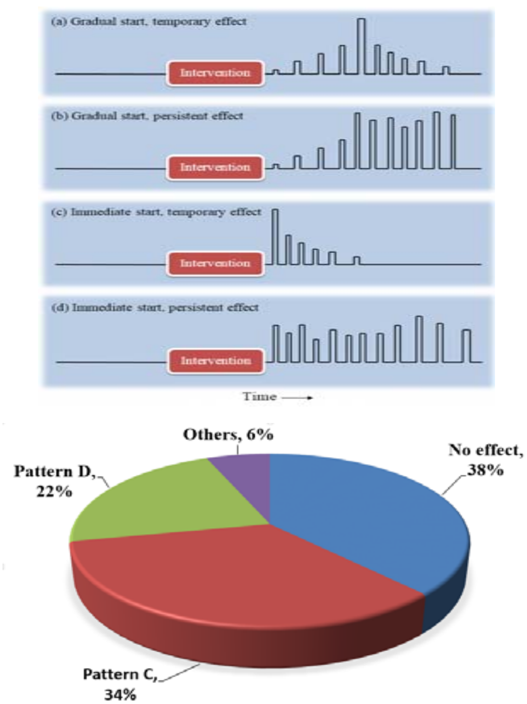
Decomposition: High-dimensional data in the design space can be projected onto the axis of:

- Each type of action
- Each object of a design
- Each design file (the container of a design)

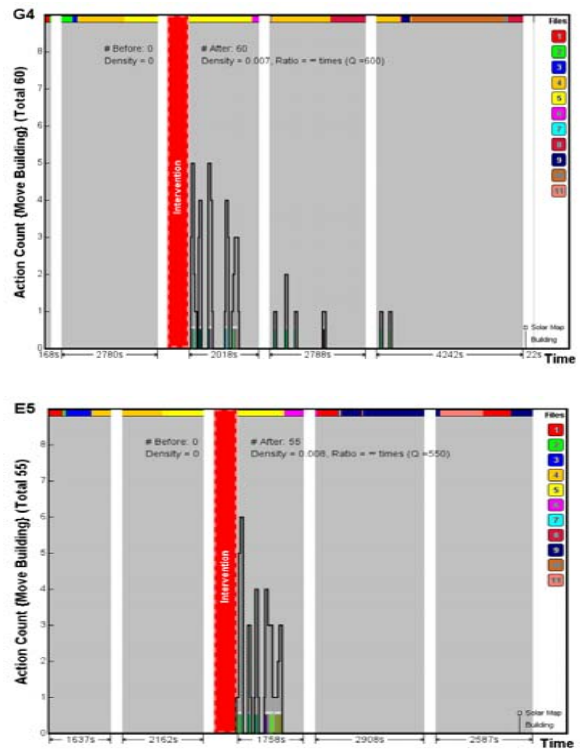
Models and Algorithms: Response Functions

How do students respond to an intervention?

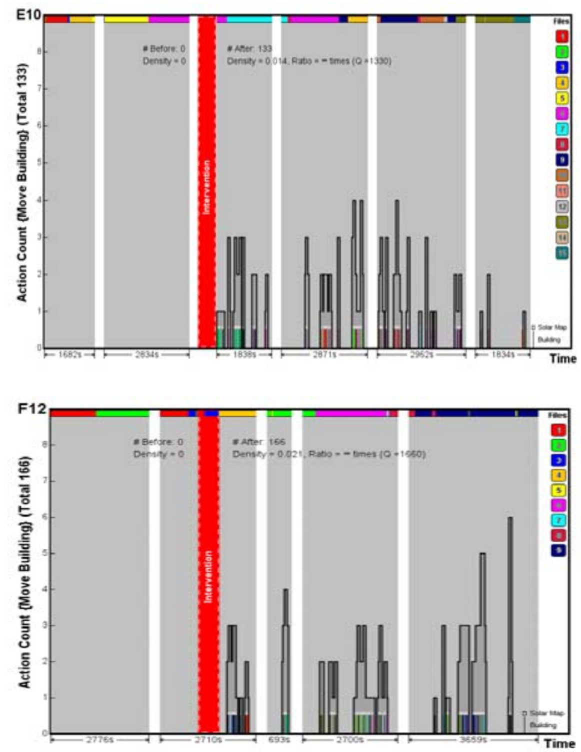
(Intervention can be computer feedback, teacher instruction, or student discussion.)



The distribution of response patterns of 65 students



Pattern C: Decay



Pattern D: Persistent

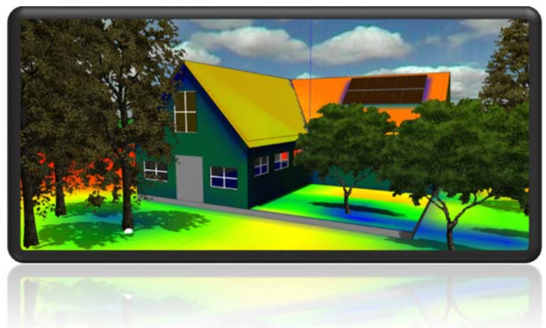
Models and Algorithms: Performance Trajectories

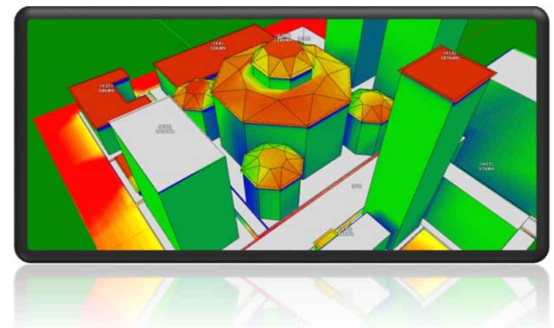
How do we measure students' performance improvement?

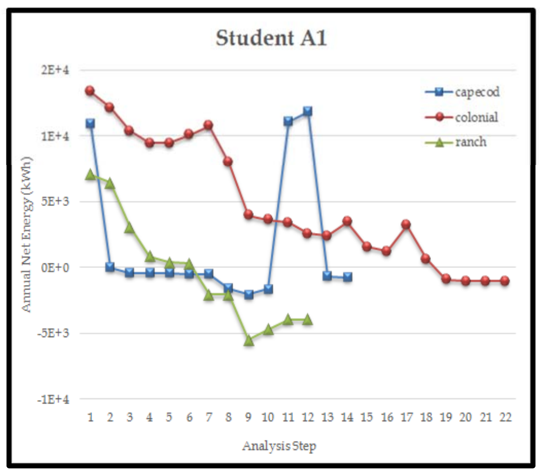
Performance of Product ≈ Performance of Designer

Monitoring the time evolution of the product performance to determine whether students arrive at their final products through systematic exploration, or just by chance

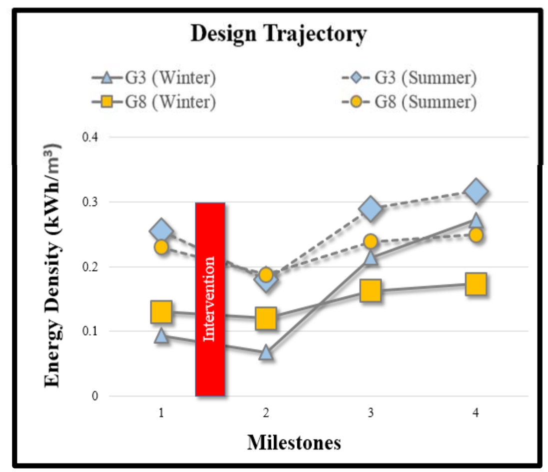
Simulation and analysis based on computational physics







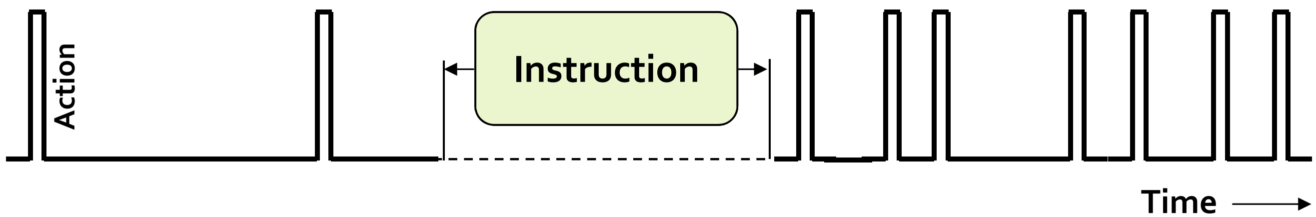
Annual energy usage

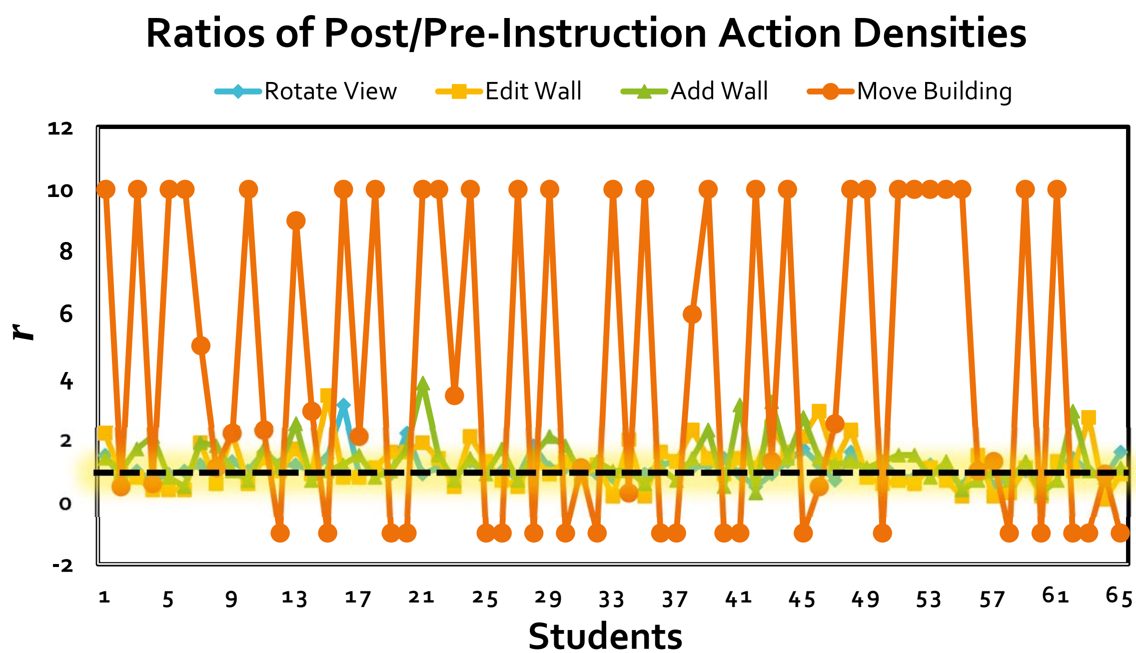


Solar radiation gains

Instructional Sensitivity

Are the data logs instructionally sensitive?





Comparing actions relevant and irrelevant to specific instruction

Conclusions

- Fine-grained process data in the CAD log encode rich temporal information that sheds light on the dynamics of cognition and learning;
- These process data are instructionally sensitive and can be influenced by interventions occurred outside the CAD software;
- More advanced process analytics needs to be developed to characterize student learning through engineering design;
- Findings need to be validated by establishing the correlation between student design patterns and conventional assessment results.

Thank you!

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