Performance Assessment of Engineering Design Using Process Analytics Based on CAD Software

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Subject/Problem

Engineering design is part of the Next Generation Science Standards (K-12).


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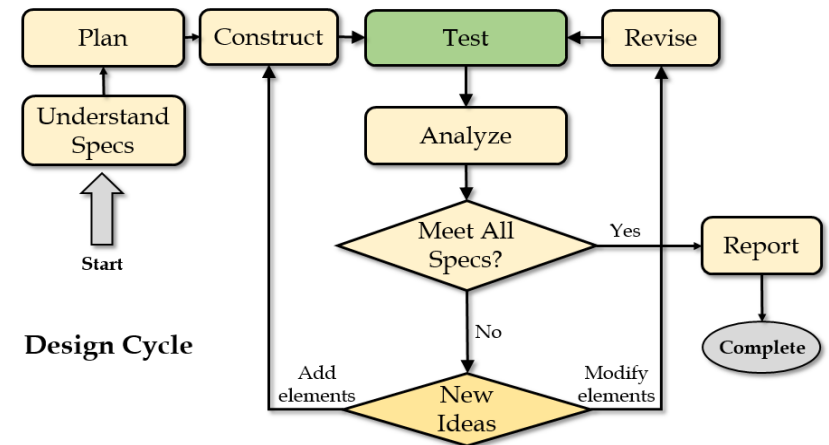- …
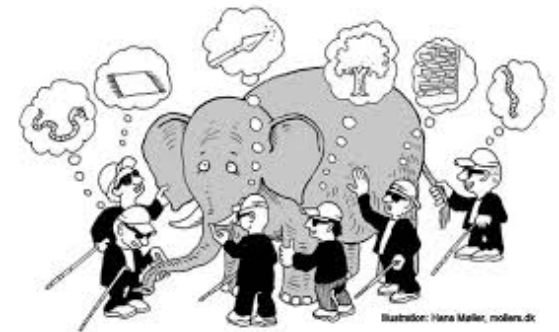
And we don't seem to have a clear agreement on what makes a good assessment for engineering design.

Goal: Develop Automatic Assessment Based on Process Analytics

Engineering design *is* a learning process.

We need to analyze its process.

This study 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.

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.)
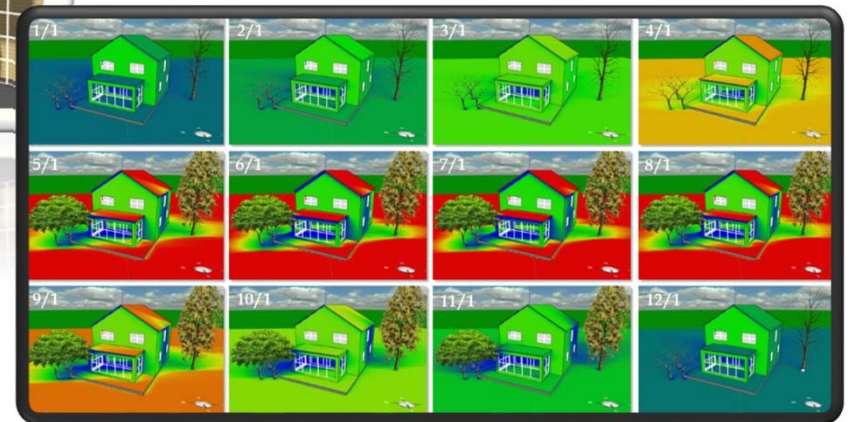- **Digital fabrication** (3D printing, etc.)
- …
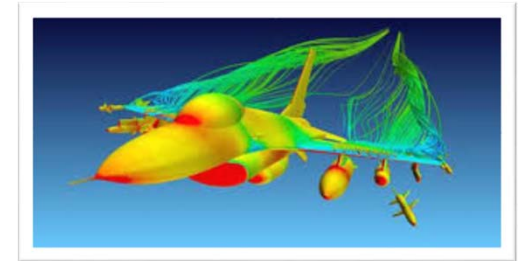
Virtual prototyping allows design ideas
to be explored entirely within cyberspace.
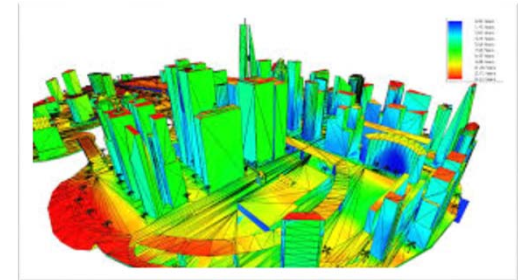
An Open-Source CAD Platform
for Research on Engineering Design
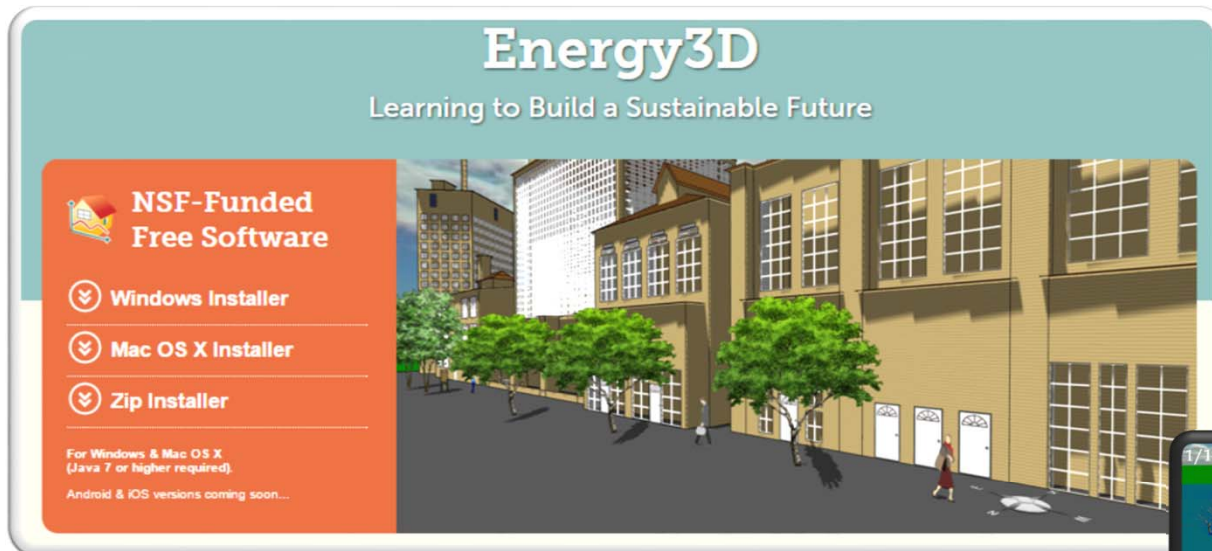
- Architectural engineering
- Solar engineering
- Energy engineering
- Urban planning
- Structural engineering
- ...

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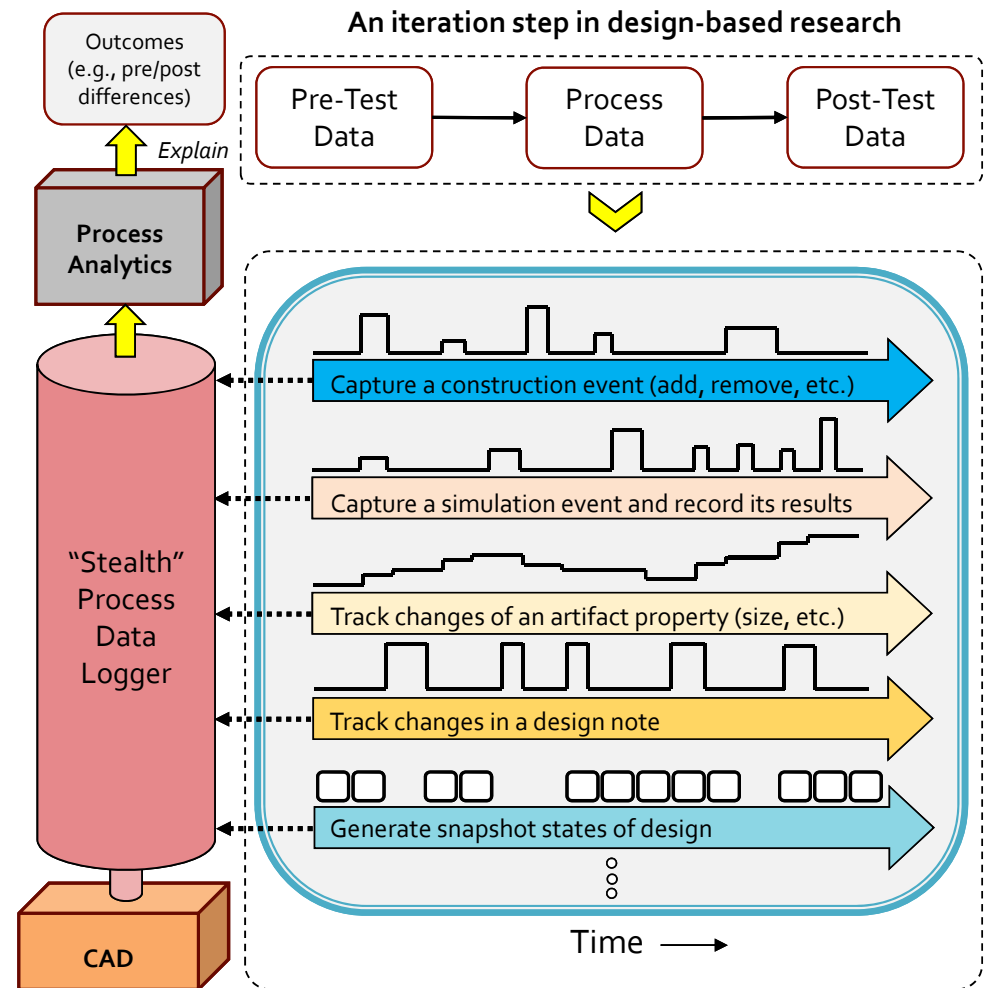CAD of educators, by educators, for educators

A New Paradigm of Research*

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.

* T. Hey, S. Tansley, & K. Tolle, *The Fourth Paradigm: Data-Intensive Scientific Discovery*, Microsoft Research, Redmond, Washington, 2009.

An iteration step in design-based research

Pre-Test Data → Process Data → Post-Test Data

Outcomes (e.g., pre/post differences)

Explain

Process Analytics

"Stealth" Process Data Logger

CAD

Capture a construction event (add, remove, etc.)

Capture a simulation event and record its results

Track changes of an artifact property (size, etc.)

Track changes in a design note

Generate snapshot states of design

Time →

A JSON Data Schema that Encodes Energy3D Design Process

How do the data look like?

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A New Paradigm of Assessment?
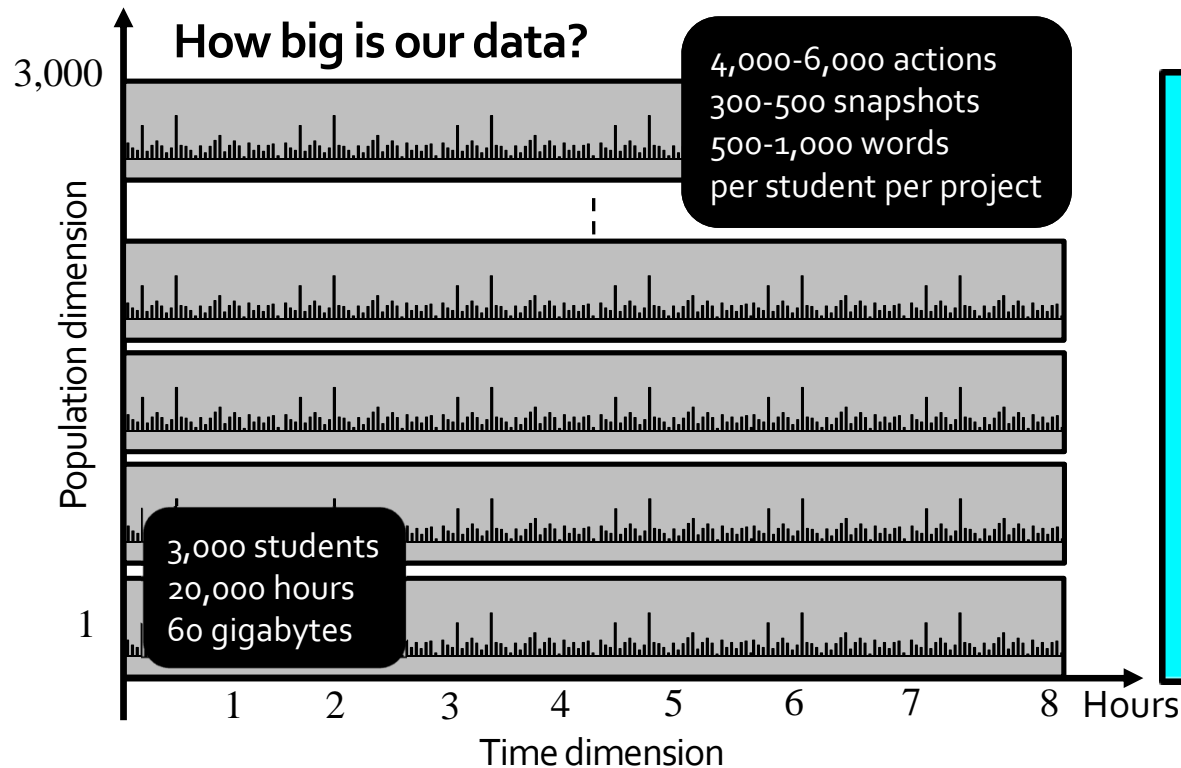
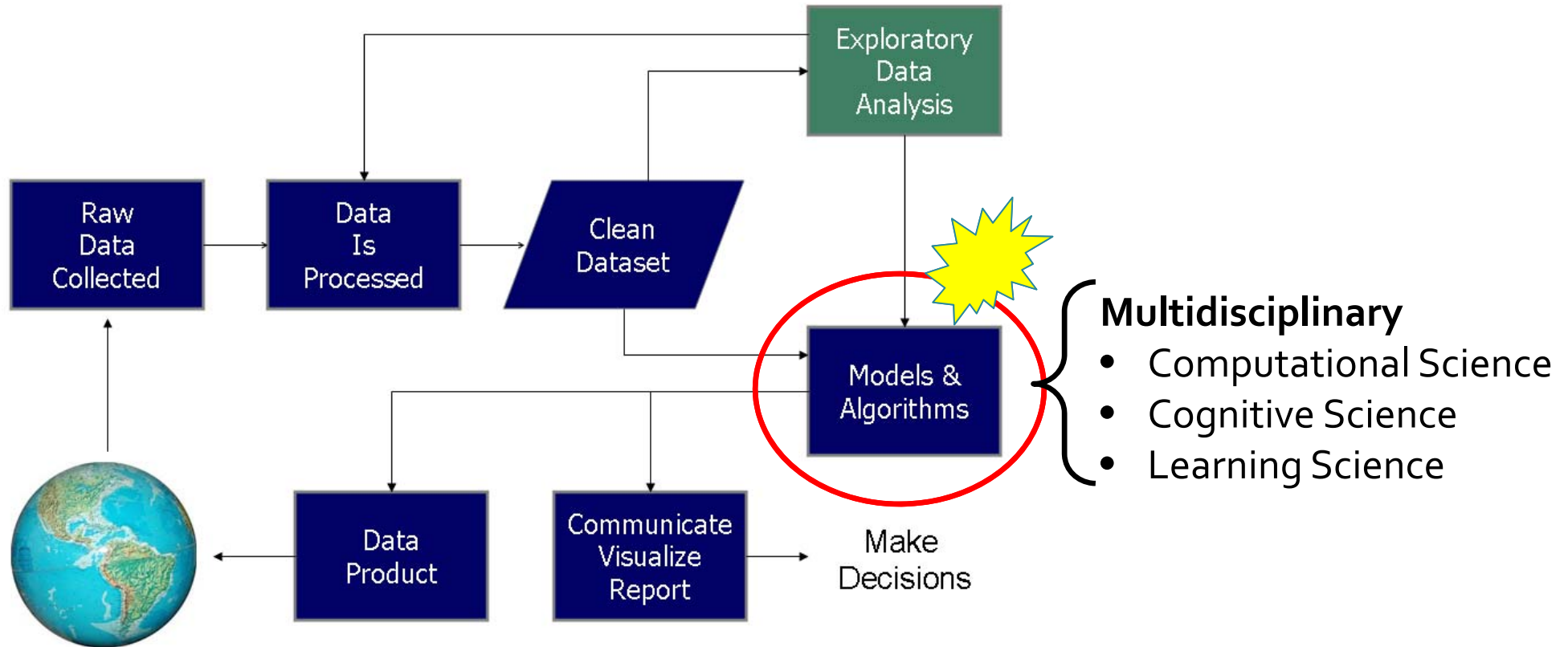**Automatic Portfolio Assessment**
Everything students do is automatically collected and processed using a "big data" approach.

The validity and reliability of this type of assessment is being tested using this database.

A Data-Science Approach for Assessment

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
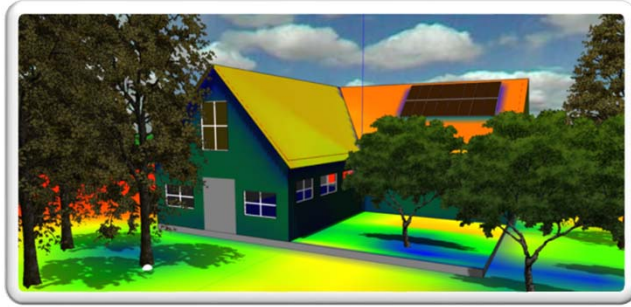
Energy-Plus Home Design
Design a house that generates more renewable energy than it consumes over the course of a year
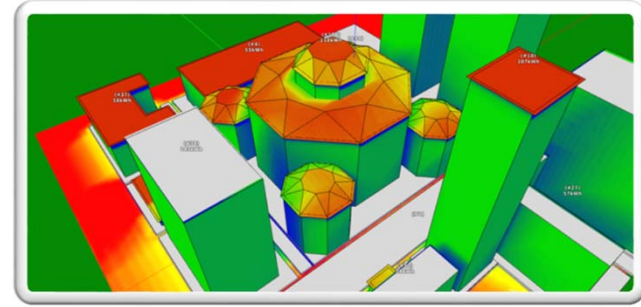
Solar Urban Design
Design a city block with high-rise buildings that have optimal solar gains in different seasons

Exploratory Data Analysis: Design Replay

Playing back a student's design process like running a slide show (and post-process it)
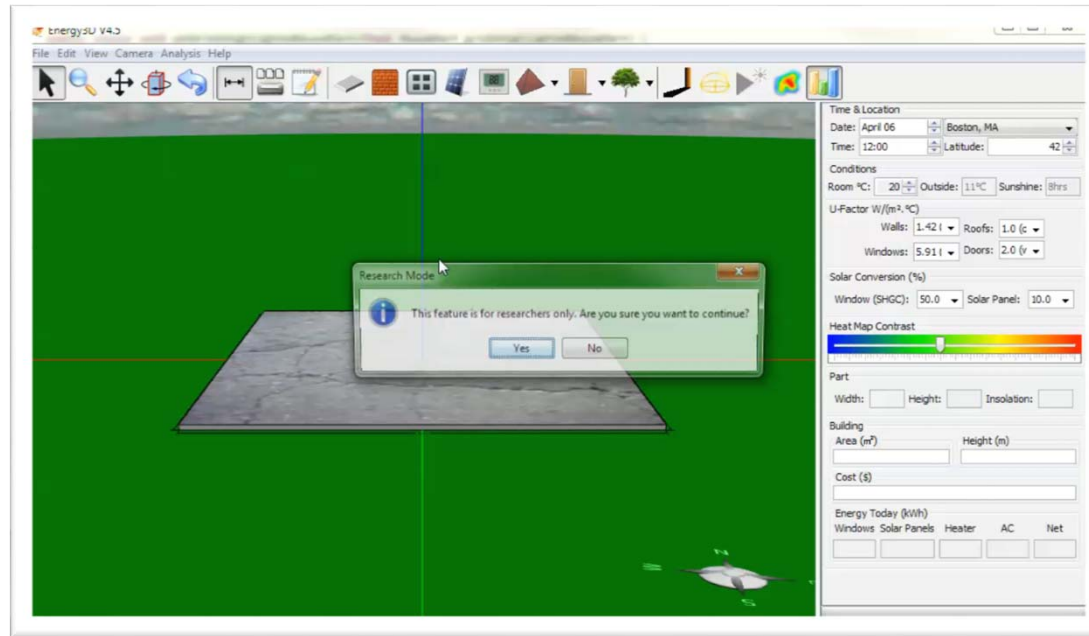
Compare with screencast, recording is based on events, not lapse of time.
(no event, no record.)

High ratio of lossless compression

Technique: Time Series Analysis

Measuring student activeness, their design complexity, etc.
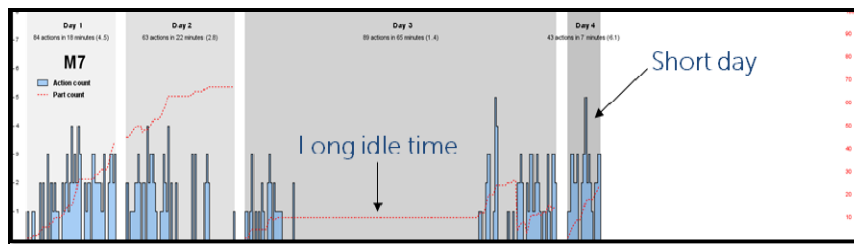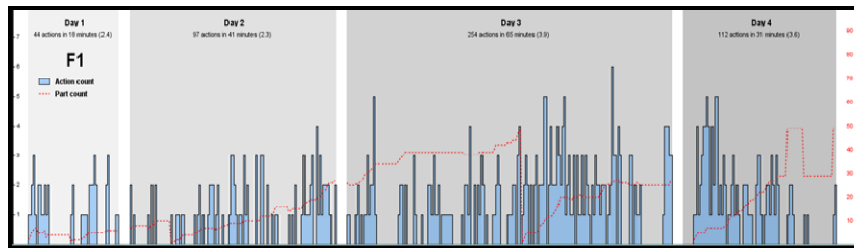
Action count
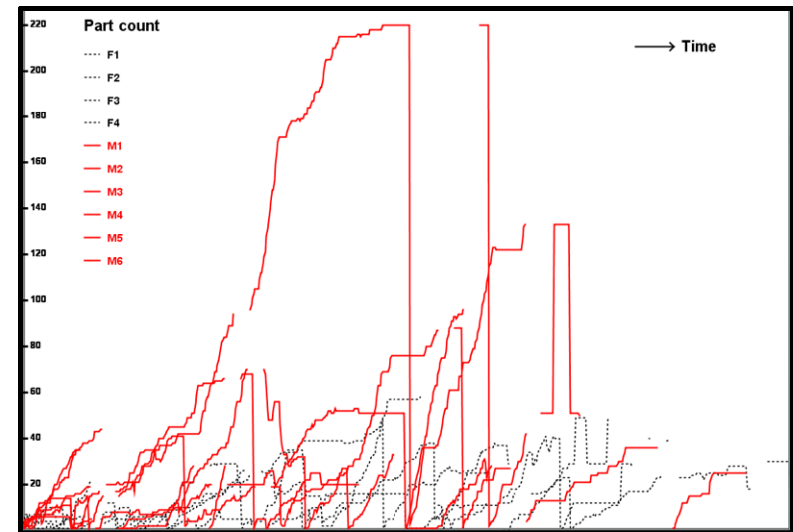
Artifact count

Technique: Design Decomposition

Measuring design space exploration, informed design, multitasking, etc.

Behavior change
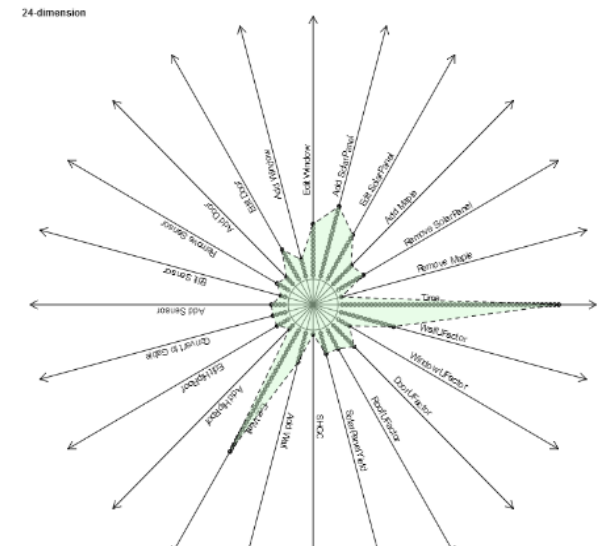
"Volume" of explored design space

High-dimensional process 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)

Technique: Response Functions

Measuring how students respond to an intervention

(An intervention can be computer feedback, teacher instruction, or student discussion.)
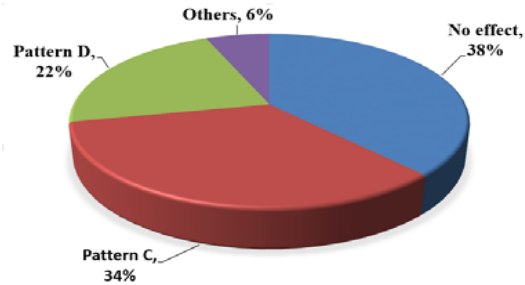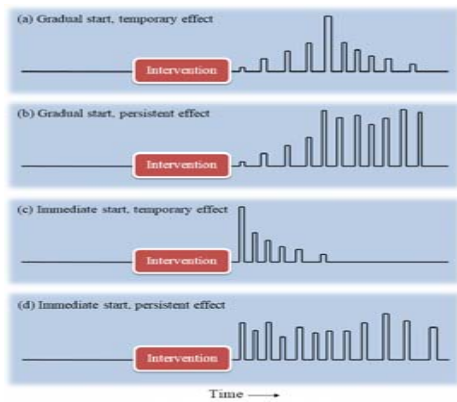
The distribution of response patterns of 65 students
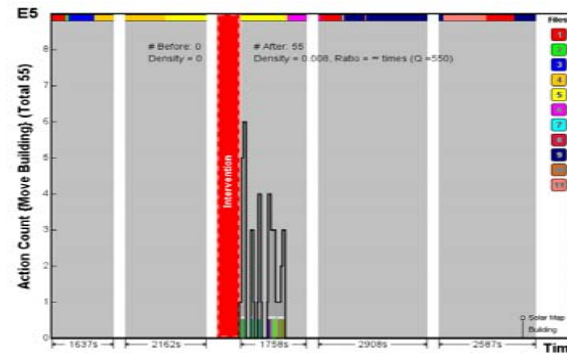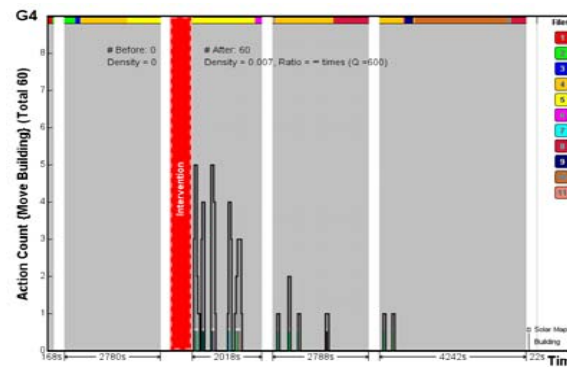
Pattern C: Decay
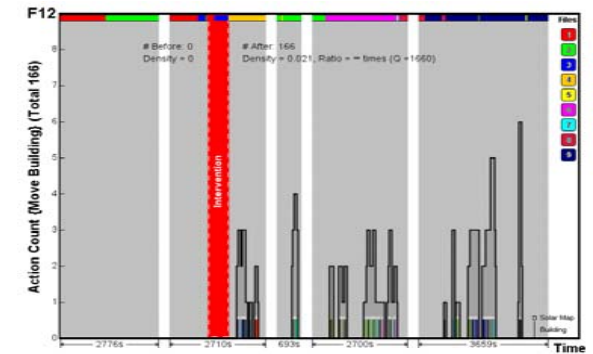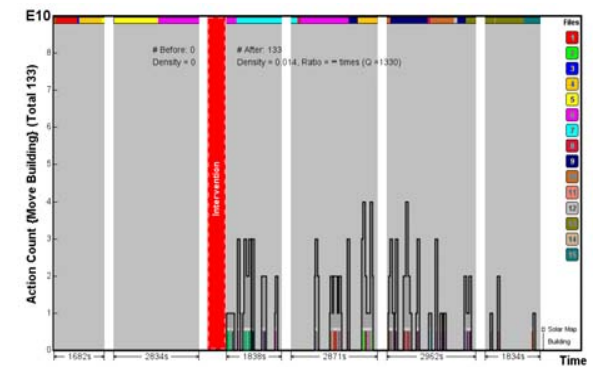
Pattern D: Persistent

Technique: Performance Trajectories
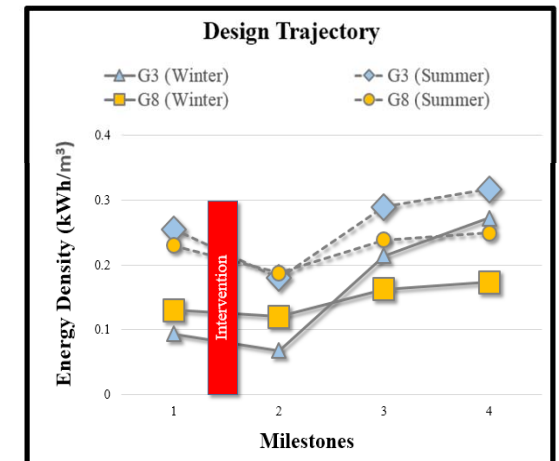
Measuring students' performance improvement

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

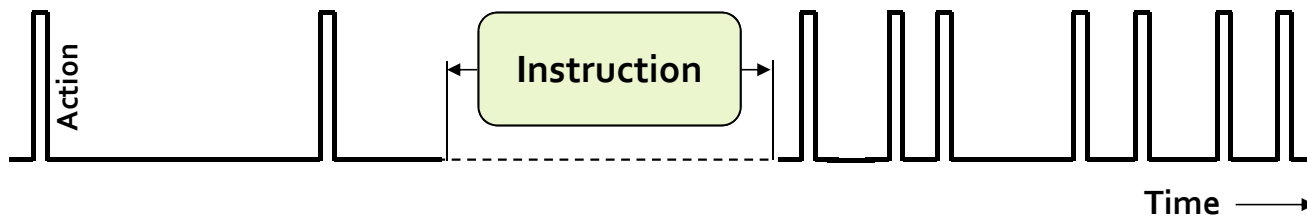Simulation and analysis based on computational physics
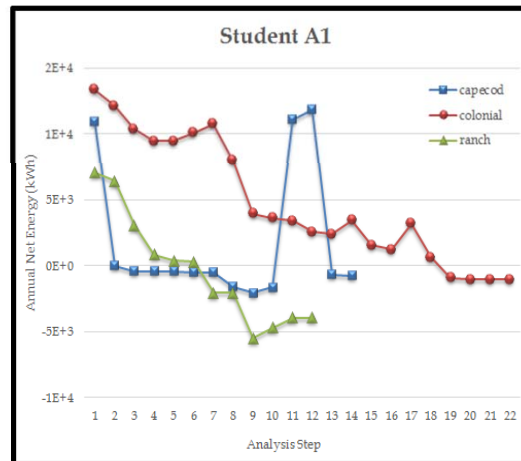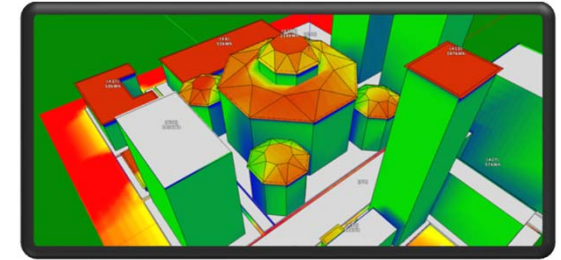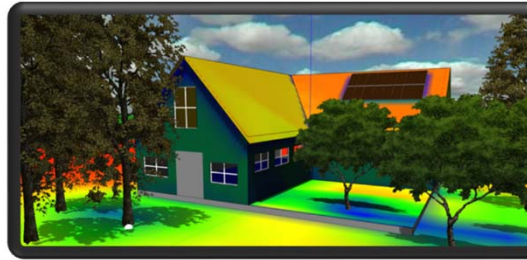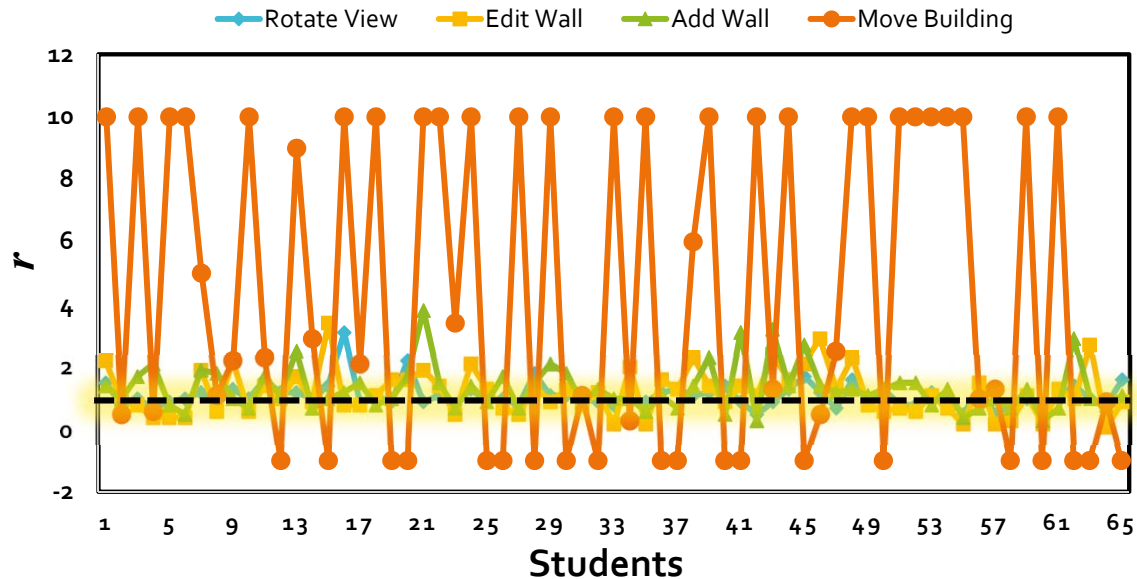

Annual energy usage

Solar radiation gains

Instructional Sensitivity

Are the data logs instructionally sensitive?

Ratios of Post/Pre-Instruction Action Densities

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;

- Stealth assessment based on CAD logging integrates learning and assessment and could eliminate the time for tests and their side effects;

- These process data are instructionally sensitive and can be influenced by interventions occurred outside the CAD software.

Future Work

- 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!