Visualizing Engineering Design with Process Analytics Based on CAD Software

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Subject/Problem

Engineering design is part of the Next Generation Science Standards.

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

- Raw Data Collected
- Data Is Processed
- Clean Dataset
- Exploratory Data Analysis
- Models & Algorithms
- Make Decisions
- Communicate Visualize Report
- Data Product

Multidisciplinary
- Computational Science
- Cognitive Science
- Learning Science

Cognitive computing?

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

Research Subjects and Settings

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<th>Year</th>
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<th>Class</th>
<th>Grade</th>
<th>State</th>
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<td>Engineering</td>
<td>Mixed</td>
<td>MA</td>
<td>Solar Urban Design</td>
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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)

An iteration step in design-based research

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

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

Process Analytics

CAD
A JSON Data Schema that Encodes Energy3D Design Process

How do the data look like?
Data-Intensive Research (aka “Big Data”)

How big is our data?

- 3,000 students
- 20,000 hours
- 60 gigabytes

- 4,000-6,000 actions
- 300-500 snapshots
- 500-1,000 words per student per project

3,000

Population dimension

Time dimension

What can we do with these process data?

What can we find from these process data?

High-dimensional data in the design space
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.

Ratios of Post/Pre-Instruction Action Densities

- Rotate View
- Edit Wall
- Add Wall
- Move Building

Time →

Instruction

Action
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!