The Concord Consortium

Engineering Education Research Group

A time series analysis method for assessing engineering design processes using a CAD tool

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http://energy.concord.org

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WHERE DISCOVERIES BEGIN

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Engineering Performance Assessment Methodologies

- Pre/post tests
- Design journals & reports (e.g., latent semantic analysis)
- Oral presentations (e.g., verbal protocol analysis)
- Portfolio assessment
- Video analysis
- Interviews
- Product analysis
- Process analysis
- ……

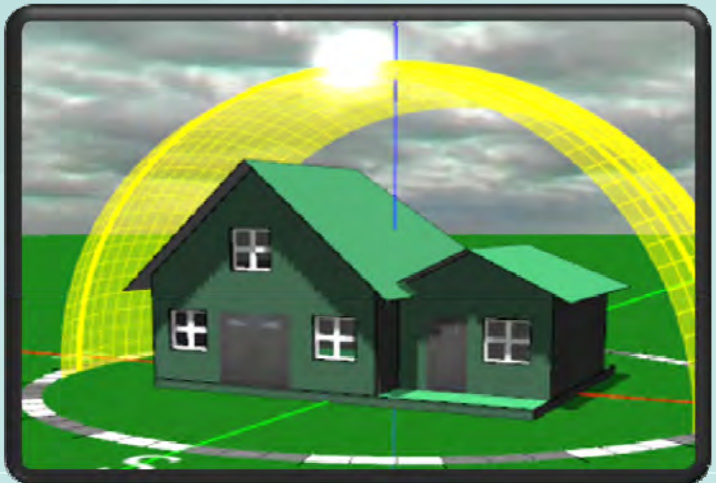
Rationale: Why Process Analysis?

- Engineering design IS a process of *doing things*.
- Measure quality of processes (unsuccessful design ≠ unproductive learning).
- Evaluate student actions and workflows, not just their words and products, to provide comprehensive, fair assessment.
- To generate accurate real-time feedback to students and teachers, we must analyze design processes first.

The "Apple vs. Orange" Problem: A Common Uncertainty in Product Analysis

176 high school students in eight classes from one high school (2012)

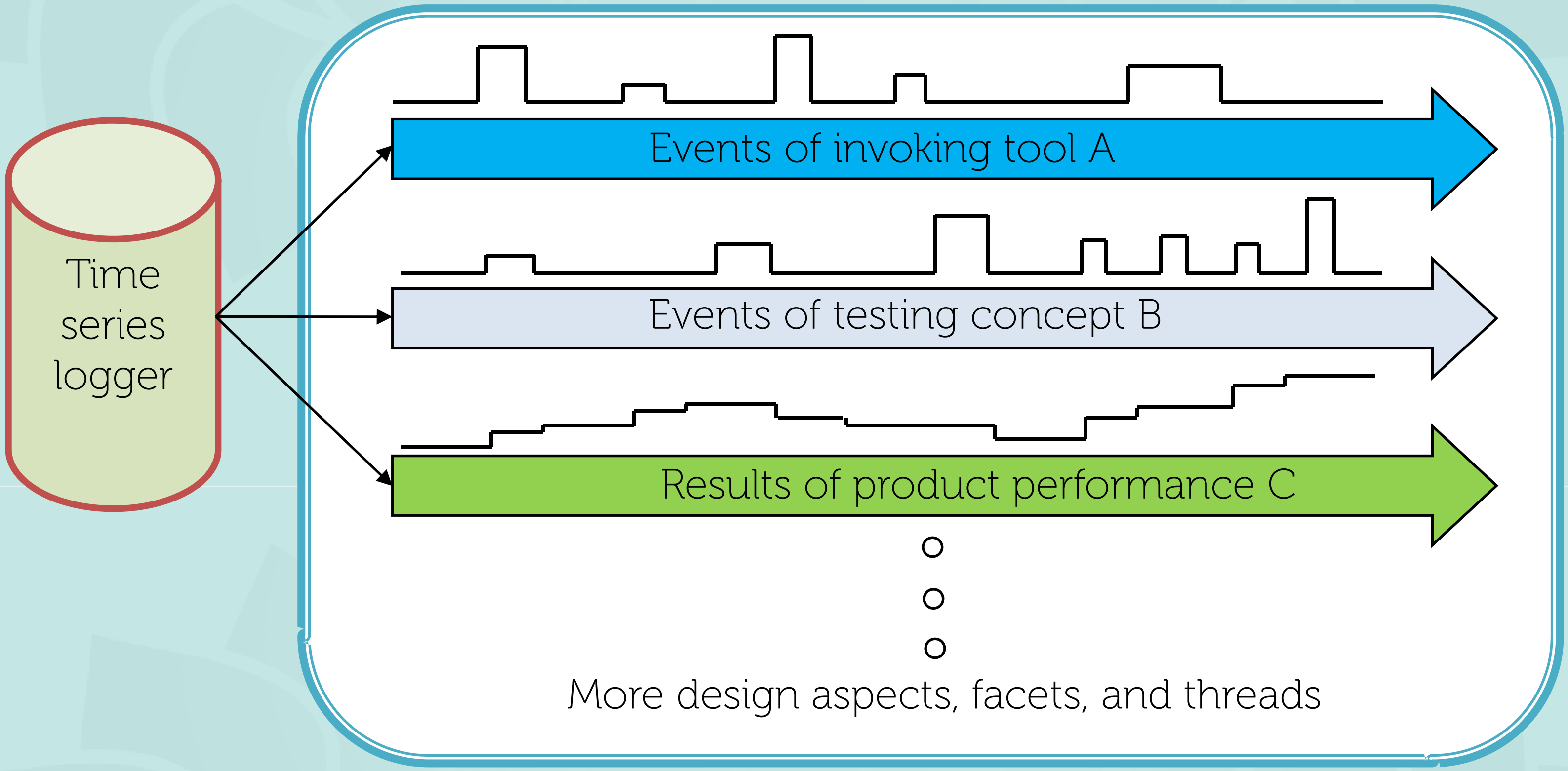
Moving Engineering Design to Computer



Energy3D: http://energy.concord.org/energy3d

A simplified computer-aided design (CAD) and fabrication tool
for kids to design and make model buildings

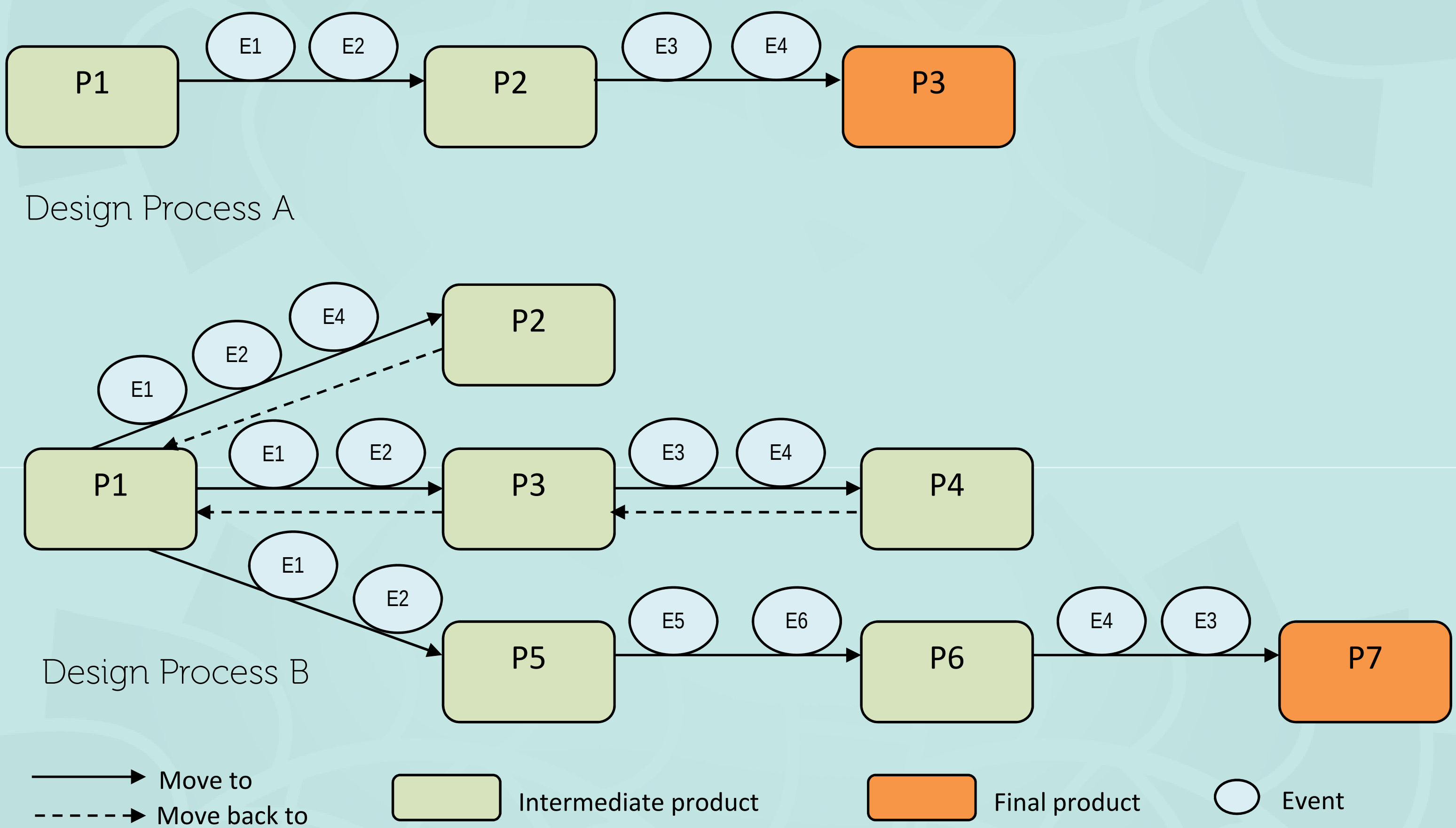
A Computational Approach to Analyzing Computer-Aided Design Processes



Applying computational thinking to educational research: A time series model of complex engineering design processes

(All time series can be logged by the computer.)

Logging Every Design Action & Every Change of Property to Reconstruct Complete Processes



Design replay from CAD logs

What can CAD Logs Show?

a. To what extent do students follow instructions? Are they engaged in the design challenge?

b. Are there any common student behaviors and patterns that can be identified by analyzing logs?

c. Can we find evidence of iterative design cycles in the design logs?

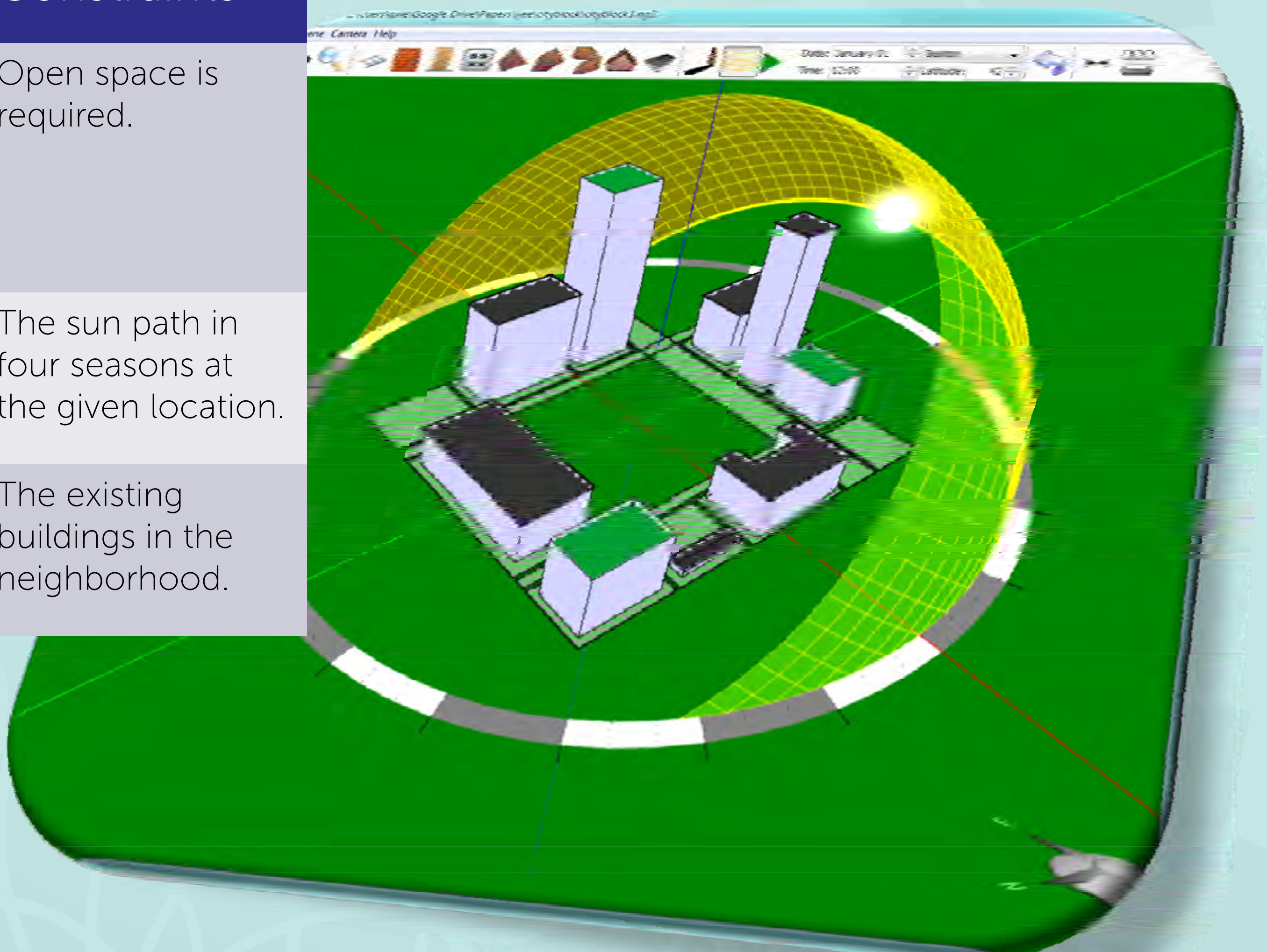
d. Can we find evidence of divergent-convergent thinking in the design logs?

e. Can the logged data provide a measure of the design space explored by a student?

f. ……

A Solar Urban Design Challenge

Goals	Constraints
New constructions: 1) a high-rise office building; 2) a high-rise apartment building; 3) a shopping area.	Open space is required.
Optimize solar penetration to the new buildings.	The sun path in four seasons at the given location.
Minimize obstruction of sunlight to the existing buildings.	The existing buildings in the neighborhood.



Research Settings

20 students: 4 females and 16 males (worked individually)

High school engineering/technology class (engineering teacher)

Grade level: 10-11 (honors), Duration: 4-6 days

Requirements: Each student must come up with at least three different alternative designs and choose one as the final design.

Results

Design Actions ("Microsteps")

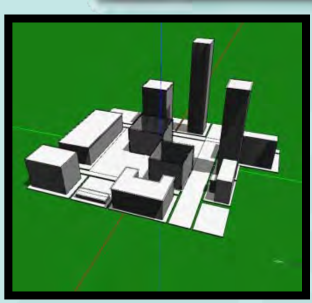
What tools do students use to design what features?

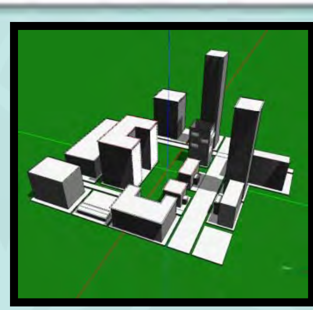
Construct	Revise	Switch
b1: build a foundation	r1: revise a foundation	o1: Open another design or template
b2: build a wall/walls	r2: revise a wall (resize, delete)	
b3: build a roof	r3: revise a roof (reshape)	
b4: build a window	r4: revise a window (resize, delete)	
b5: build a door	r5: resize a door	
b6: build a floor	r6: revise a floor	
b8: build a sidewalk	r7: revise a building (resize, move, or add)	
	r8: revise a sidewalk	

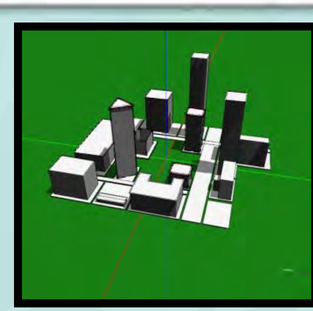
All actions cached in the undo/redo manager of the CAD software can be stored and retrieved.

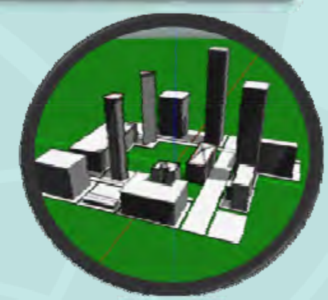
Design Process Reconstruction

Visualizing student design actions and workflows: compressed timeline graph (Example #1)



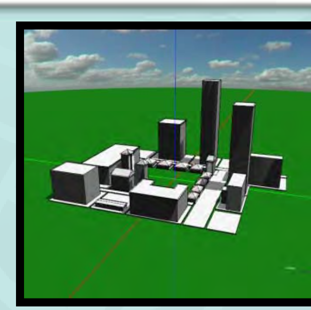


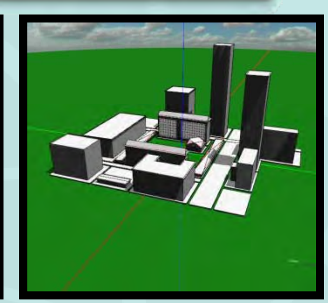




Design Process Reconstruction

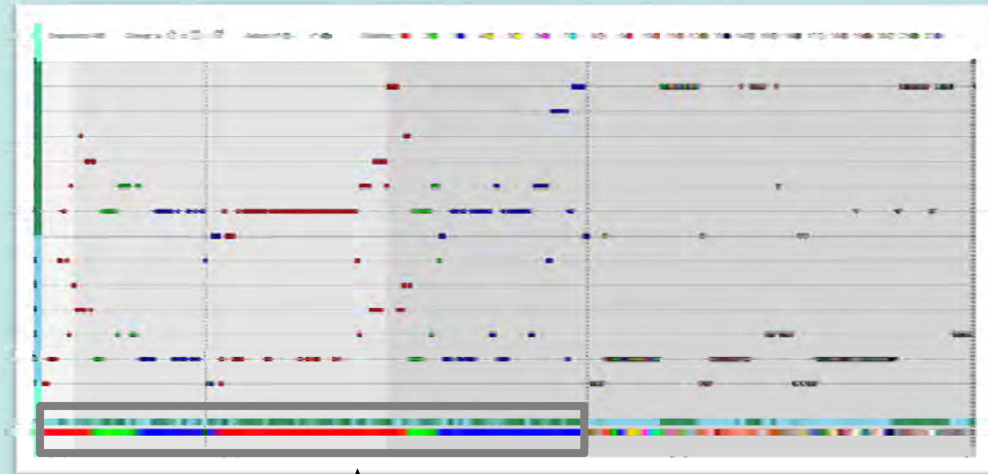
Visualizing student design actions and workflows (Example #2)





Visualizing Design Iteration

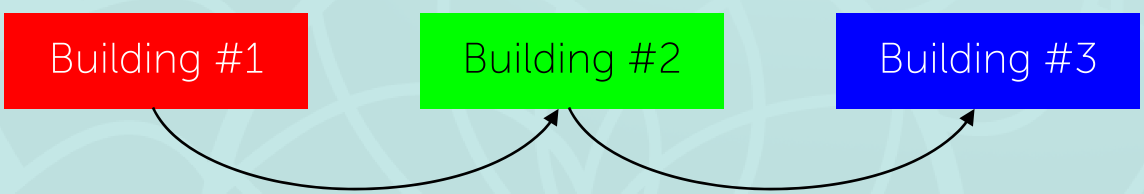
Do students consider the interactions among buildings?



Interview: "The most thing that I focused on is this building and the windows. With the windows on all sides of it, it will always be able to get some sunlight, because I know the green space is more open, and the skyscraper is over there and the green space is on the opposite side. So in the afternoon and middle of the day, the green space will be under the sunlight. The skyscraper won't cast a shadow on the green space."

Non-Iterative

This student did not mention he considered the interplays among buildings in the interview.

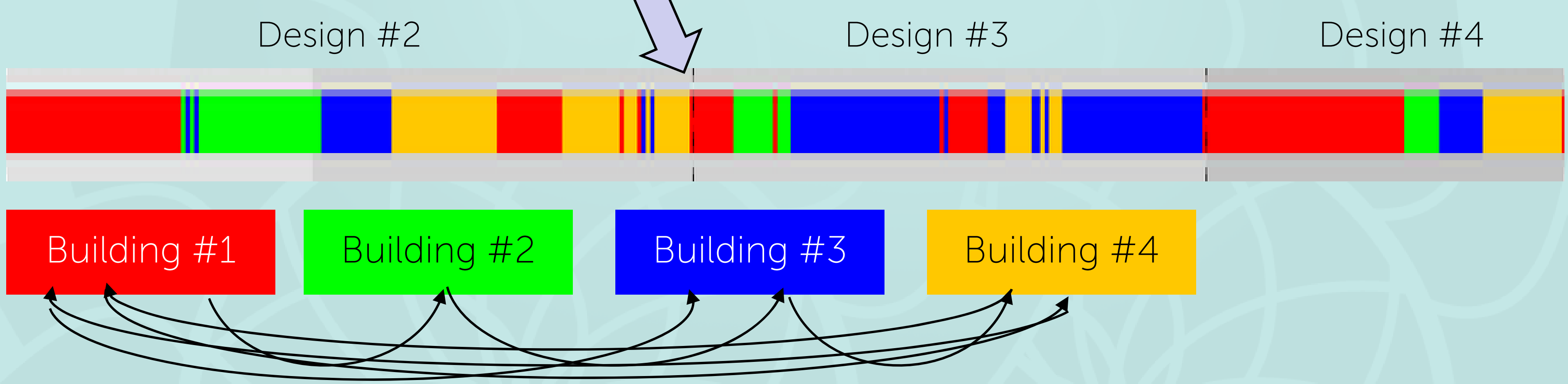


Visualizing Design Iteration

Evidence of system thinking?

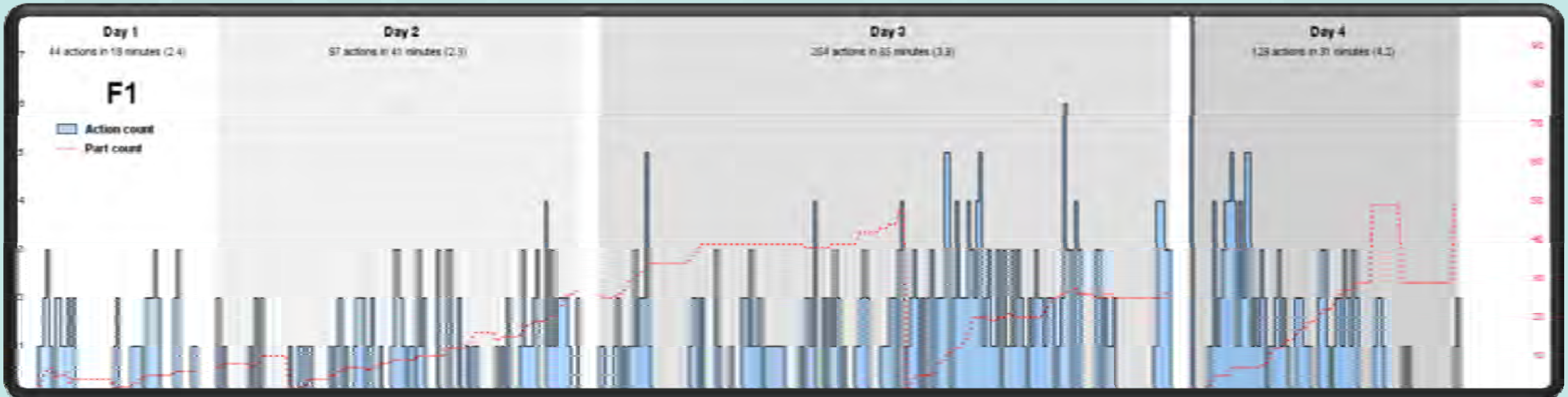
Interview: "I revised using the heliodon, I moved the buildings according to the heliodon. For example, this building is facing a different direction, so when the shadow is on, it completely blocks one of the surrounding buildings. Also I realized that because my building is so large, so the front of it would completely be in the shadow. So because of it, I was able to resize it and make it a smaller building. So that even though there's still a little shadow, but it is not completely covered by the other one. Let me show you this. See this building is huge, right now it is covered because it's in August. Then when it's in January, it's not covered any more. Because of the heliodon, I was able to see it. In the winter, it's not covered, but in the summer, I guess it's ok to be covered because it's hot outside. You don't want the sun to be on the building anyways."

Iterative

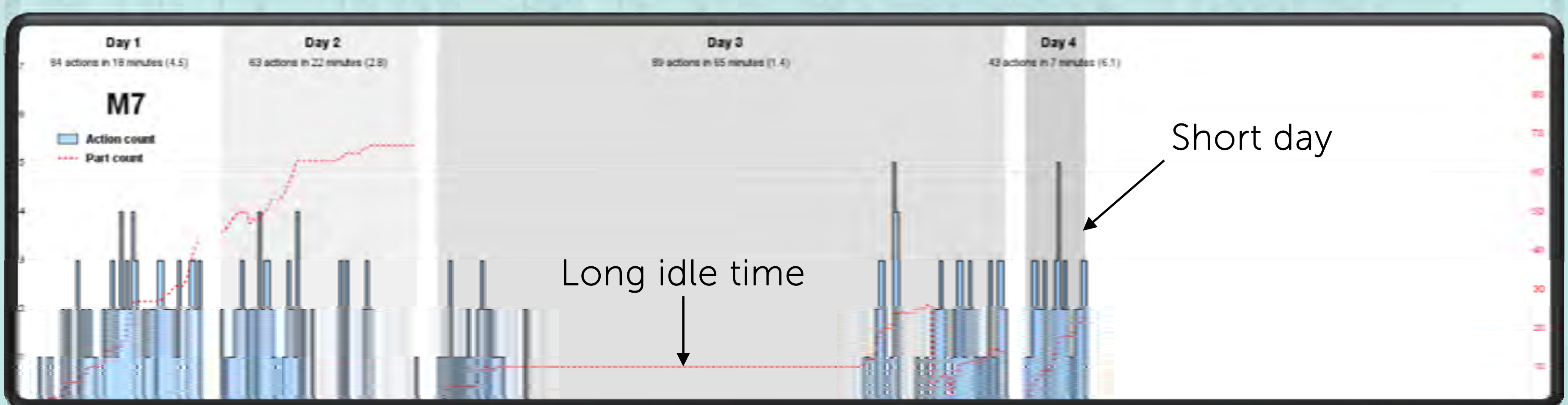


Level of Engagement

Comparison of aggregated action timelines between two students



High (serious student)



Low (absent-minded student)

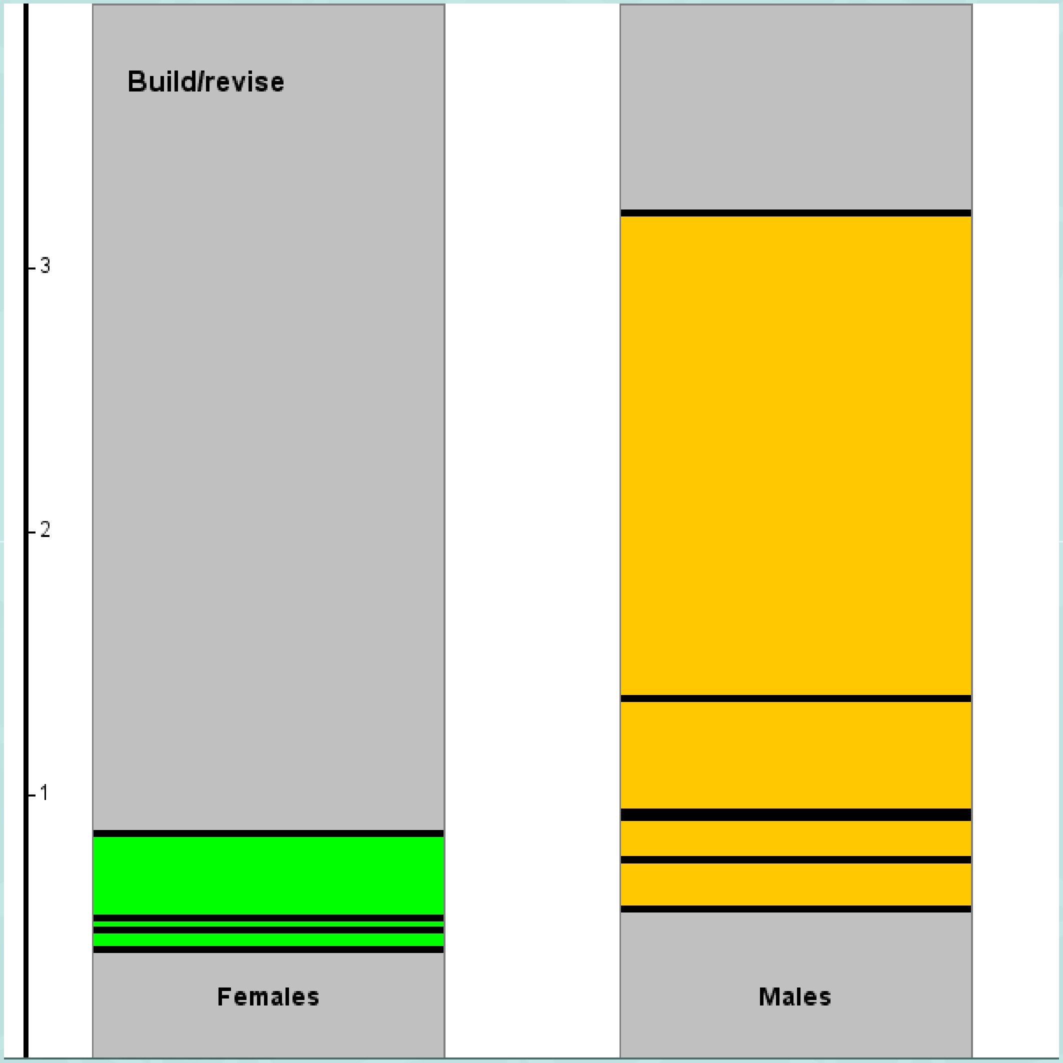
Action Analysis Suggests Gender Differences

	Total actions	Building	Revision	Ratio of building/revision	Number of designs	Most frequent action
F1	393	130	259	0.50	4	r2
F2	462	163	296	0.55	6	r2
F3	325	97	228	0.43	5	r2
F4	436	202	232	0.87	7	b2
M1	369	176	190	0.93	3	r2
M2	550	238	310	0.77	5	r2
M3	480	232	245	0.95	3	b2
M4	482	367	114	3.22	3	b2
M5	165	95	79	1.38	4	b2
M6	164	60	104	0.58	2	r2

Summary of the design action analysis results of ten selected students

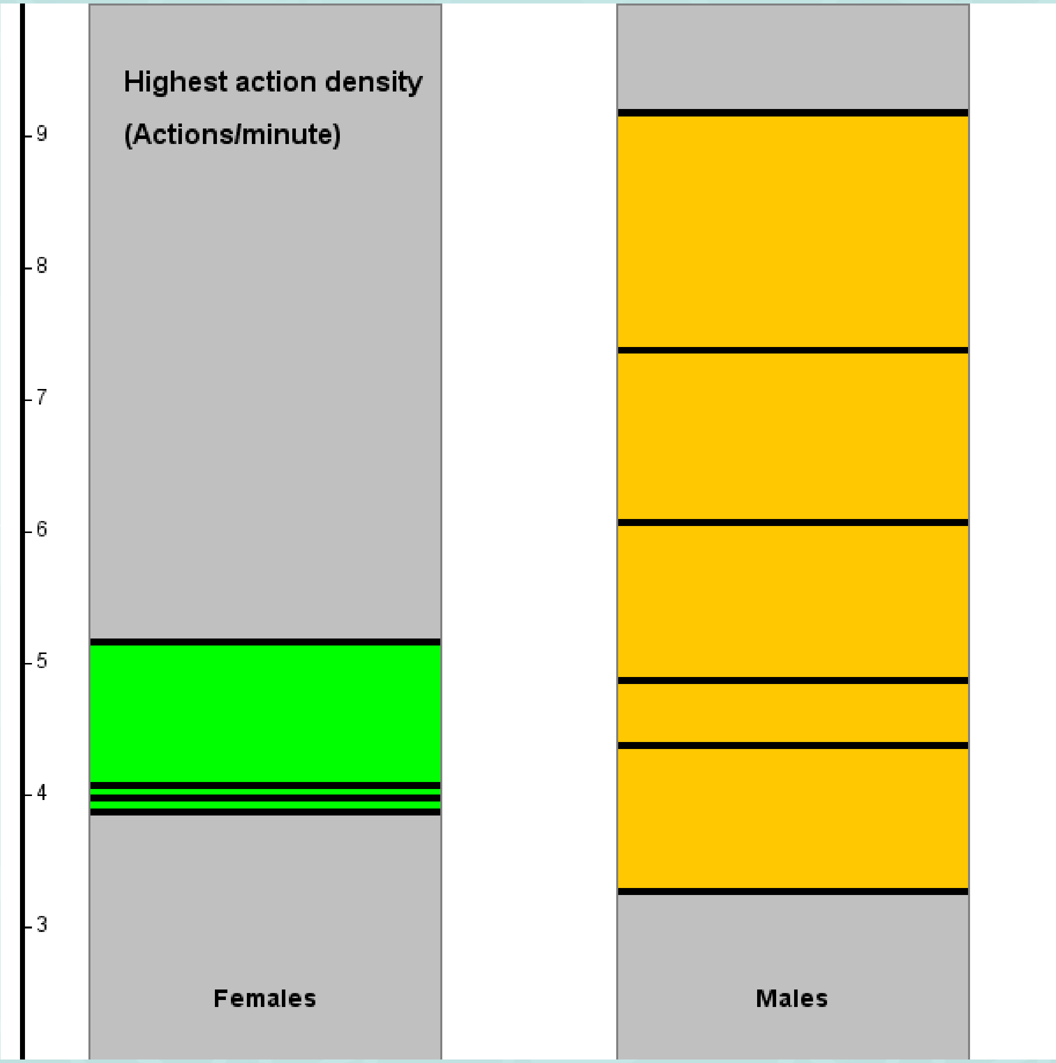
Low fidelity?

Student Behavior:
The Construction/Revision Ratio



The male students generally spent more time on construction than on revision.

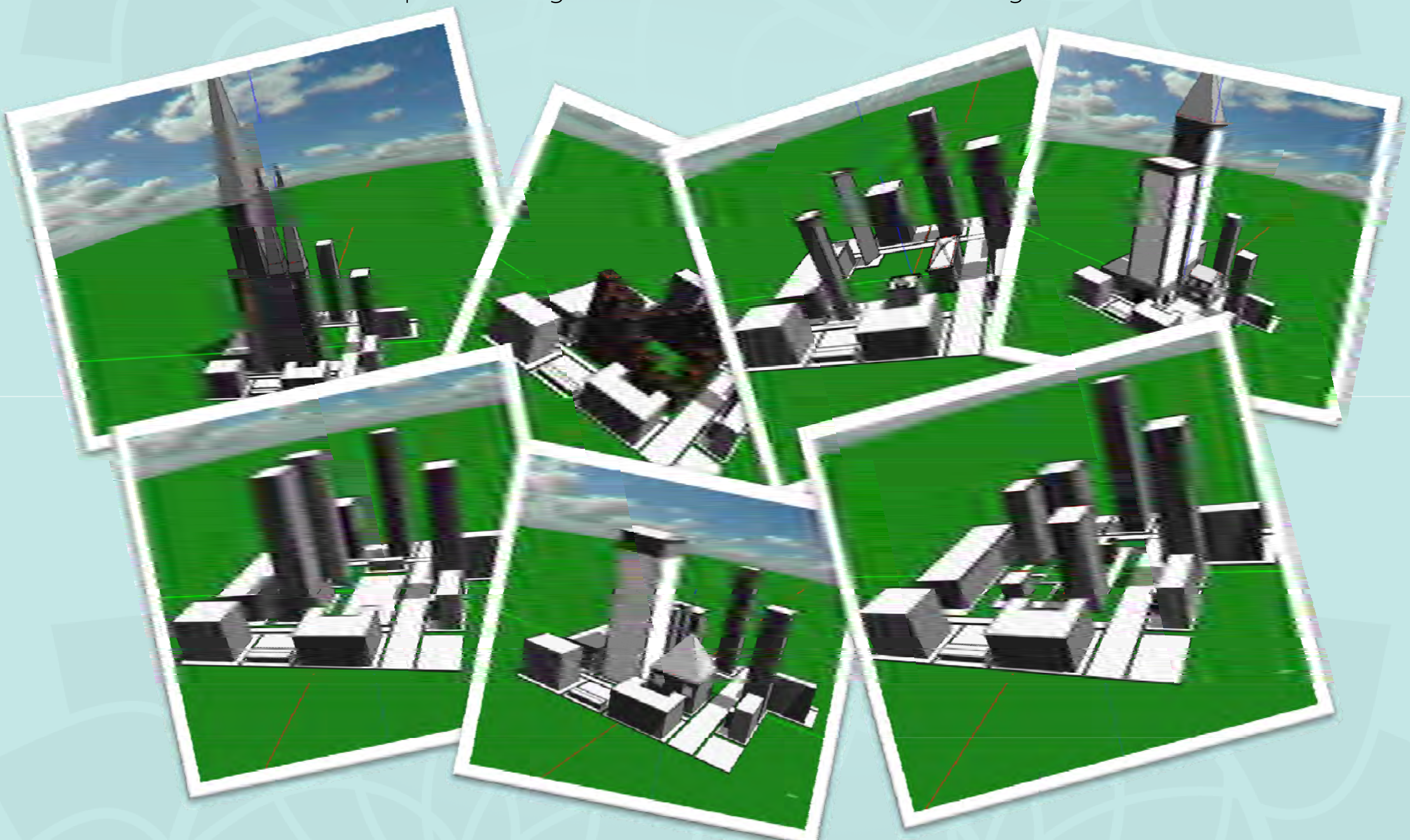
Student Behavior: Highest Action Frequency in a Class Period



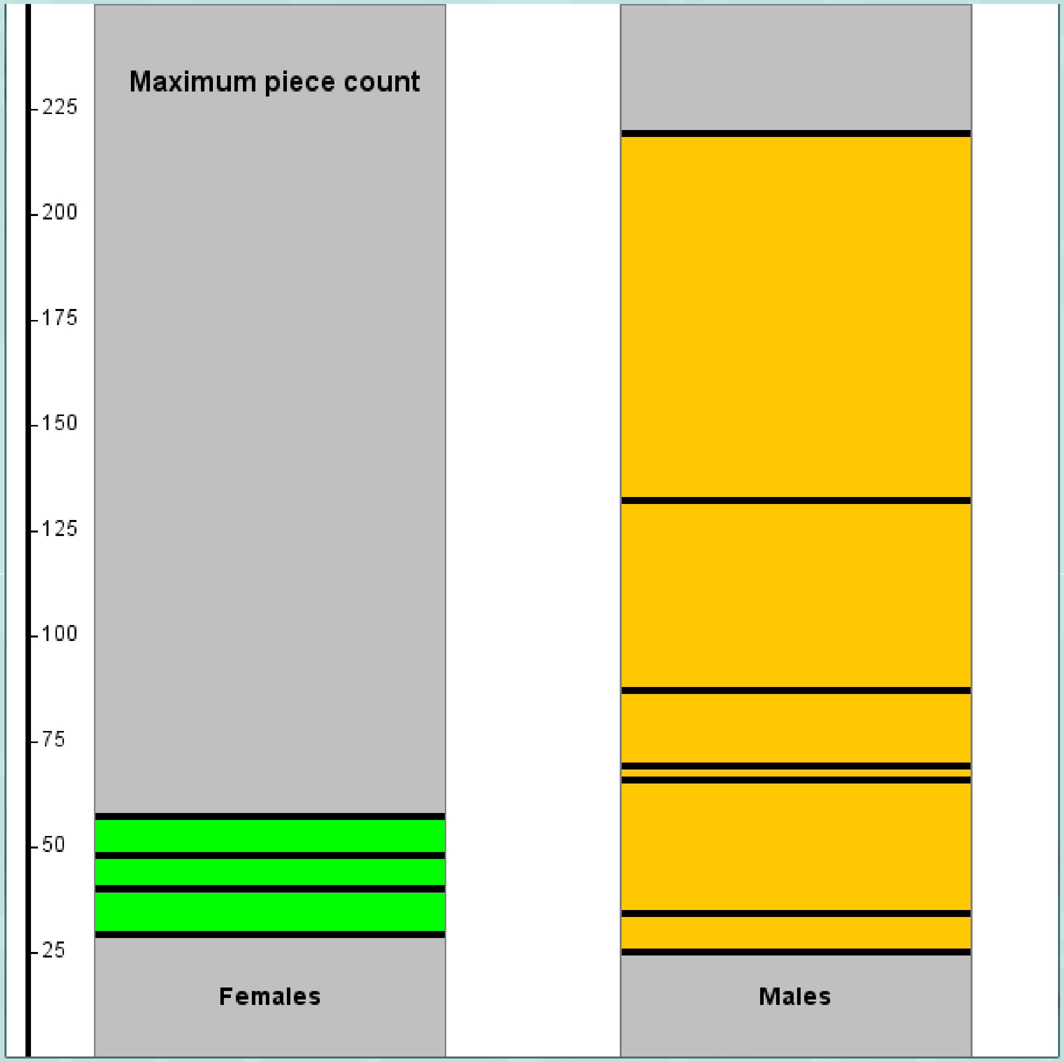
The male students generally had higher action frequencies.

Artifact Analysis Also Suggests Gender Differences

Not a surprise: Design artifacts are the results of design actions.



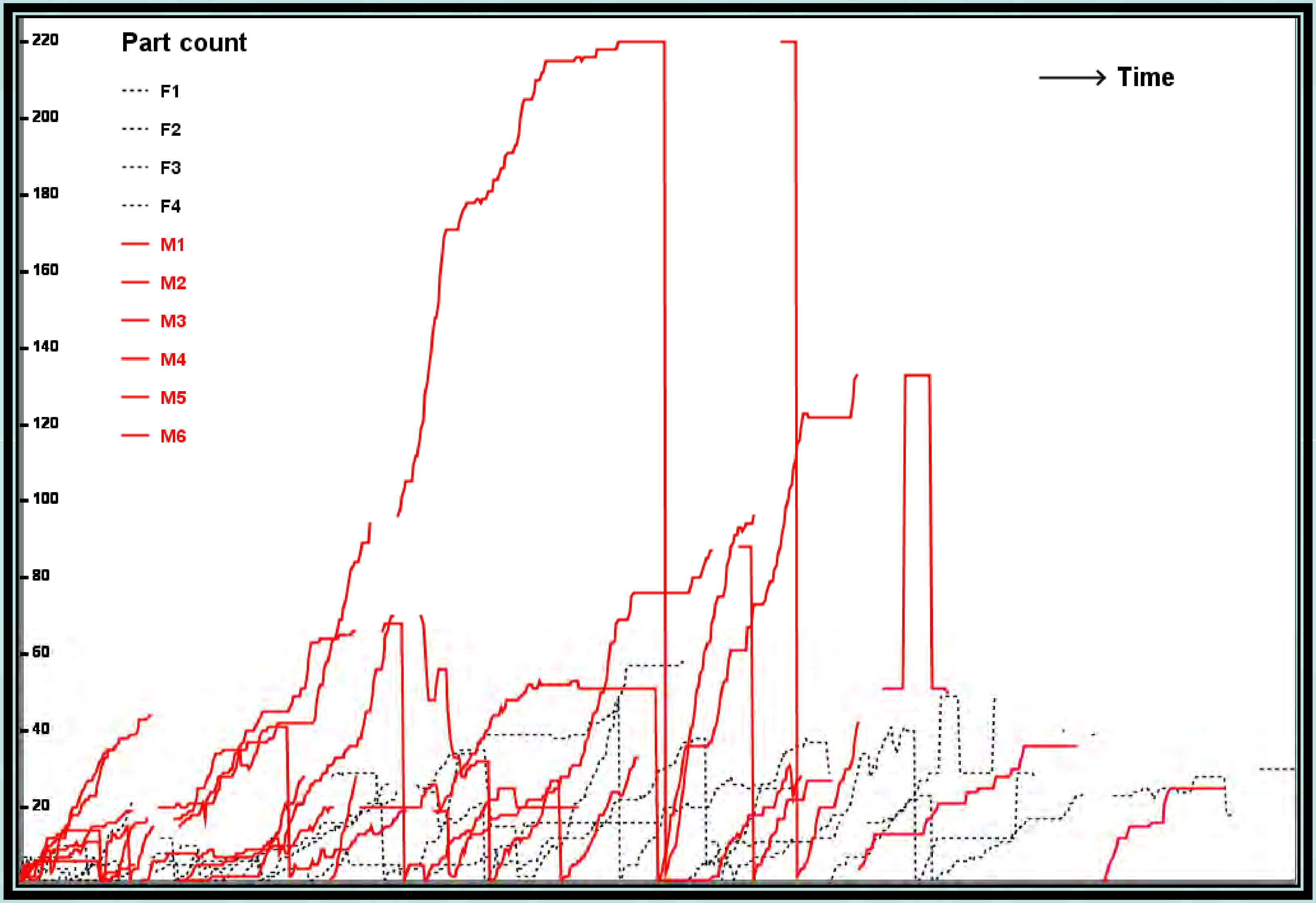
Maximum Number of Parts in a Design



The male students generally added more parts in their designs.

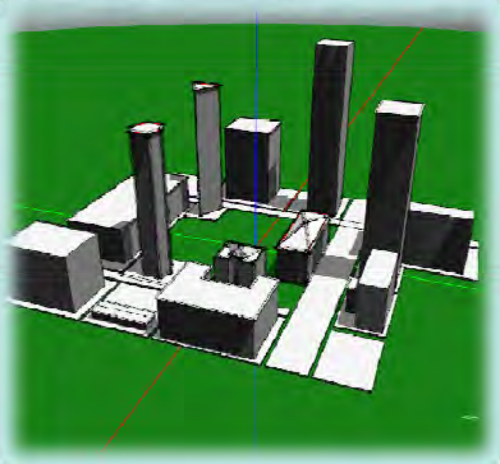
Assembled Time Series of Part Counts

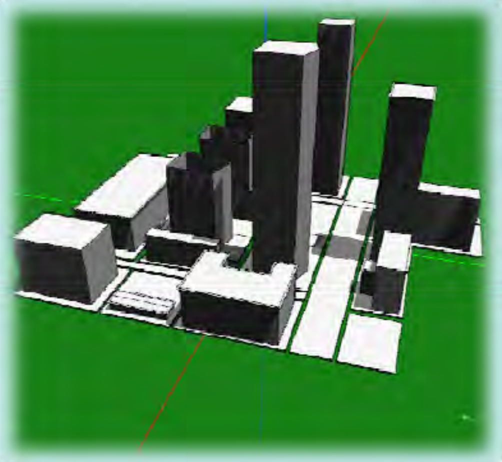
The exponential growth curves vs. the linear growth curves

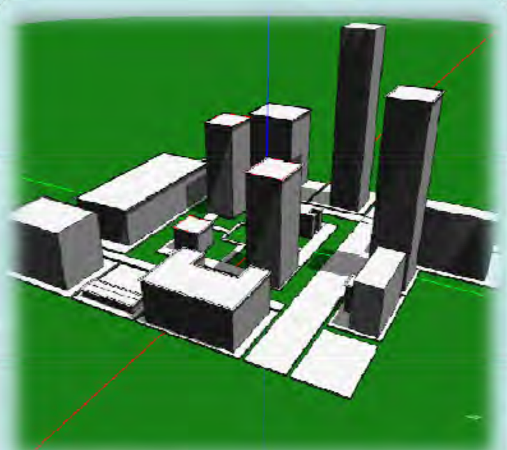


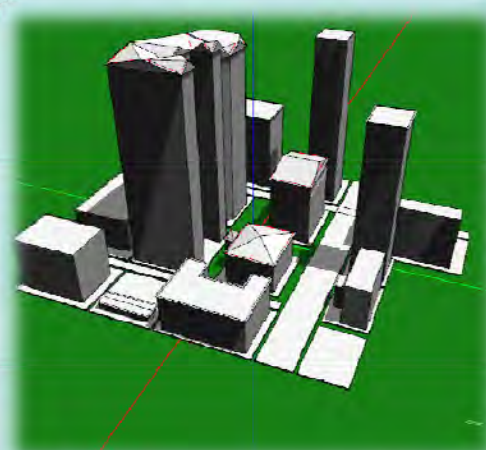
Do their Final Designs Meet the Specs, After All?

Female students: F1, F2, F3, F4



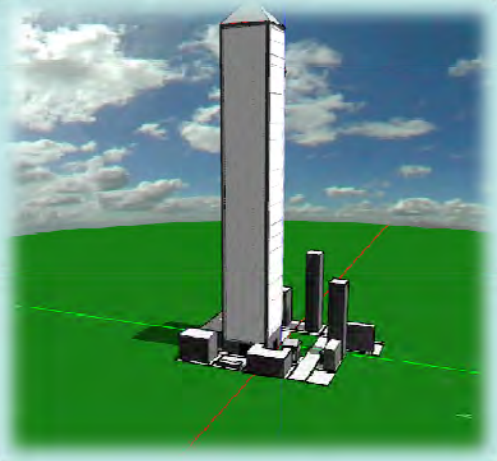


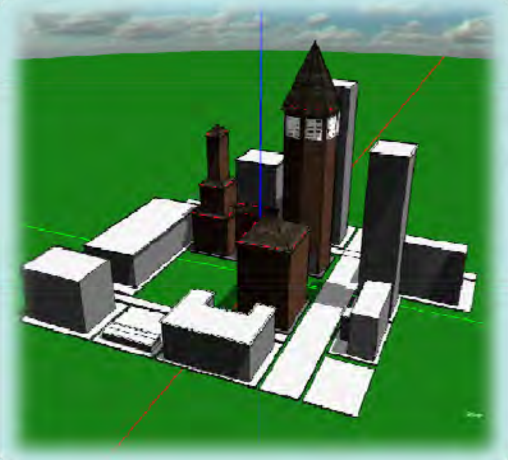


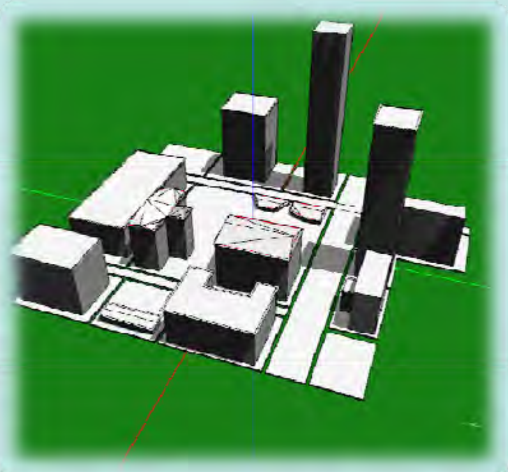


Do their Final Designs Meet the Specs, After All?

Male students: M1, M2, M3, M4







Conclusions

I. Time series logging embedded in CAD tools provides a high-resolution method for probing and visualizing engineering design processes in great details.

II. Analysis of CAD logs can show student patterns and gender differences in engineering design.

III. This pilot study demonstrates the feasibility of automatic analysis of student design processes, possibly in real time. This is important to the development of dynamic, adaptive feedback in intelligent tutoring systems for teaching engineering design.

Thank you!