Detecting Iterative Cycles of Engineering Design from Student Digital Footprints in Computer-Aided Design Software

Zhihui Helen Zhang, Charles Xie, Saeid Nourian, Concord Consortium, Concord, MA, USA
Email: hzhang@concord.org, qxie@concord.org, snourian@concord.org

Abstract: As engineering design has been extensively incorporated in the Next Generation Science Standards, the need for understanding student design processes has never been greater. This paper demonstrates an innovative approach: computational process analytics (CPA) to analyze students' fine-grained digital footprints while using a computer-aided design tool to complete a solar urban design. CPA reveals critical student design patterns such as iteration and fixation, which provides researchers and teachers with invaluable insights about student learning.

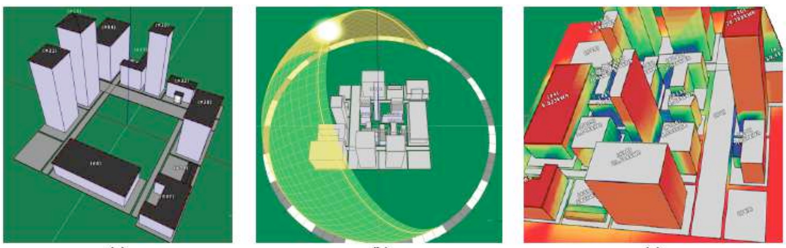
Introduction

Ever since the National Research Council included engineering components in the national science standard framework (National Research Council, 2011), there has been an upsurge in attention on K-12 engineering education. Yet little research has investigated students' design processes and learning trajectories (Carr, Bennnnett IV, & Strobel, 2012). In this paper we propose to analyze students' process data when they are engaged in engineering design tasks using a novel computational process analytics (CPA) approach (Xie, Zhang, Nourian, Pallant, & Hazzard, 2014).

In particular, we investigate how CPA can provide multifaceted evidence to detect design fixation and iteration. Researchers have observed design fixation- as the design becomes more detailed, designers tend to develop inertia to revise the design (Purcell & Gero, 1996). Design fixation is detrimental because it limits iteration, an essential process to engineering design (Kolodner et al., 2003). Identifying design fixation is of utmost importance to researchers and teachers because a student who completes a design with no or few iterations will learn poorly from the design. This pilot study explores using CPA to detect design fixation and iteration during students' design of an urban area using passive solar strategies to optimize solar radiation heating in the winter and in the summer.

The Solar Urban Design Challenge

The Solar Urban Design Challenge requires students to construct at least four buildings on a square city block (100*100 square meters) surrounded by existing buildings of different heights. Students need to maximize the use of solar energy and to achieve optimal energy efficiency of the new construction. They also need to consider alternatives and generate at least three different design solutions. Students used Energy3D, a simplified computer-aided design (CAD) tool, to design the buildings within the city block. Two features of Energy3D – the Heliodon Simulator and the Solar Heating Simulator, provide students with real-time feedback about the solar performance of their designs (see Figure 1 for the design template and the features).



(a) (b) (c)

Figure 1. a) the design template; b) the Heliodon Simulator shows the sun path at the given location and time; c) the Solar Heating Simulator shows the heat map of daily solar radiation on the surfaces of buildings.

Methods

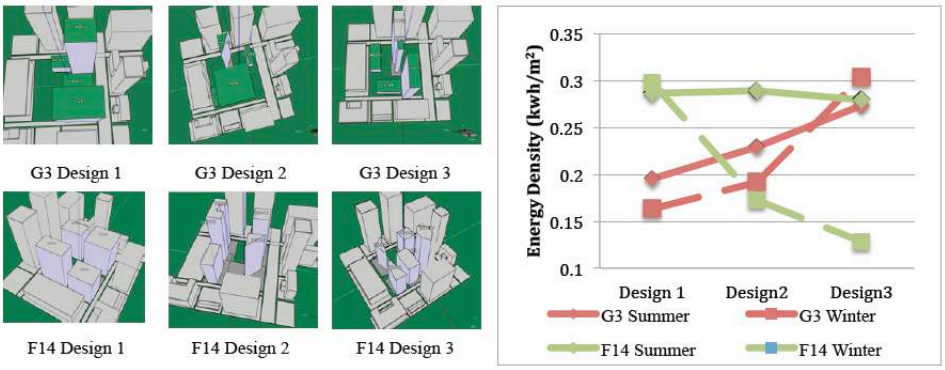
Sixty-four high school students (9^{th} graders) in Massachusetts, USA participated in the study. They used laptop computers to run Energy3D and worked individually on the Solar Urban Design Challenge for seven instructional periods (approximately 45 minutes per period). Energy3D is capable of automatically log what students do (actions), make (artifacts), and say (articulations) to provide fine-grained process data for assessments. An artifact folder typically contains 400 intermediate files and an action file typically contains 3,000-5,000 lines of event data. To analyze this sheer volume of data, a visual analytics program based on CPA was written to automatically process the students' design actions and artifacts and rapidly visualize the results with graphs.

Finding 1: Detecting Fixation and Iteration through Analyzing Design Behavior

Energy3D logs the timestamp, type, target, and parameters of the actions performed by each student. We focused on two types of iterative actions that lead to changes in solar performance of the buildings: 1) revision action that alters an element of the construction such as moving and resizing building; 2) time switching action that changes the time and date set up in the system, e.g., changing the time to Dec. 30 12pm. The CPA program can automatically calculate the percentage of these iterative behaviors. Dependent procedures such as quartile split can detect students who made fewer iterative actions. As an example, student G15 completed the design challenge with 2867 actions in total, among which 72 actions (2.51%) switched the seasons from winter to summer or vice versa and no actions moved or resized buildings. G15 probably has experienced premature fixation and her design likely would result in poor solar performance.

Finding 2: Detecting Fixation and Iteration through Analyzing Artifact Performance

Another way to detect design fixation is through examining the solar performances of students' designs. CPA program automatically calculates the average daily solar energy density (ρ) over the new construction. Naturally ρ is low in the winter and high in the summer for buildings in the northern hemisphere. In solar urban design, a design with optimal solar performance should receive maximal daily sunlight in the winter and minimal daily sunlight in the summer. Therefore, the difference between ρ in the winter and in the summer ($\Delta\rho$) should be smaller in a good design than that in a bad design. Further, we consider solar performance as an indicator of design iteration because it is hardly possible for a student to complete a design with small $\Delta\rho$ without iterations. The smaller $\Delta\rho$ is, the more iterative cycles the students may have gone through. To illustrate this, Figure 2 shows the intermediate designs and the energy densities completed by two students, G3 and F14. As they progressed in the project, the $\Delta\rho$ of G3's designs became smaller whereas that of F14's designs became larger. G3 probably has completed multiple cycles of iterations during the design project whereas F14 has experienced design fixation.



<u>Figure 2.</u> The intermediate designs completed by G3 and F14 and the daily energy density of the designs in winter and summer.

Conclusion

Based on using CPA to analyze student process data during an engineering design project, the iterative cycles of design can be studied. This allows researchers and teachers to determine the degree of iteration and fixation of student design processes. Future work will explore what interventions would be effective to promote iterations.

References

Carr, R. L., Bennnnett IV, L. D., & Strobel, J. (2012). Engineering in the K-12 STEM Standards of the 50 U.S. States: An Analysis of Presence and Extent. *Journal of Engineering Education, 101*(3), 1-26.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., . . . Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design(tm) Into Practice. *Journal of the Learning Sciences, 12*(4), 495-547.

National Research Council. (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.

Purcell, A. T., & Gero, J. S. (1996). Design and other types of fixation. *Design Studies, 17*(4), 363-383.

Xie, C., Zhang, Z., Nourian, S., Pallant, A., & Hazzard, E. (2014). A Time Series Analysis Method for Assessing Engineering Design Processes Using a CAD Tool. *International Journal of Engineering Education, 30*(1), 218-230.