Large-scale Research on Engineering Design in Secondary Classrooms: Big Learner Data Using Energy3D Computer-Aided Design

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Abstract

Through a five-year collaborative project, the Concord Consortium and Purdue University are applying a data-intensive approach to study one of the most fundamental research topics in learning sciences: "How do secondary students learn and apply science concepts in engineering design processes?" We have collected 2GB of structured data from secondary school students in Indiana and Massachusetts through automatic, unobtrusive logging of student design processes enabled by a unique CAD tool that supports the design of energy-efficient buildings using Earth science and physical science concepts. Data includes fine-grained information of student actions, experimentation results, electronic notes, and design artifacts. These process data are used to reconstruct the entire learning trajectory of each individual student with high resolution. Our research evaluates how these learning analytics applied to these process data can be the computational counterparts of traditional performance assessment methods. Combining these process data with pre/post-tests and demographic data, we have investigated the common patterns of student design behaviors and how they are associated with learning outcomes with a specific focus on how students deepen their understanding of science concepts involved in engineering design projects and how often and deeply students use scientific experimentation to make a design choice. So far we completed two small-scale studies in Massachusetts and one study in Indiana using classroom observations and expert evaluations. We are collecting data with student interviews to validate metrics. Preliminary evidence suggests that for science learning to occur, design projects used in classrooms should (1) allow and emphasize trade-off analysis and include time and resources for experimenting and data gathering; (2) provide instructional scaffolding and formative feedback to guide student design.

Introduction

Our understanding of what K-12 students learn from engineering design is limited (Katehi, Pearson, & Feder, 2009). Many K-12 engineering education projects lack data that can provide reliable evidence of student learning process or inform learning progressions (Svihla & Petrosino, 2008; NRC, 2010). One challenge is that engineering design is a complex cognitive process in which students *learn* and *apply* science concepts to solve open-ended problems with constraints to meet specified criteria.

The complexity, open-endedness, and length of an engineering design process often create a large quantity of learner data that makes learning difficult to discern using traditional assessment methods. For example, a pattern that looks like "gaming the system" in an inquiry activity (Baker, Corbett, & Wagner, 2006) may be a legitimate search in a vast problem space for meaningful alternatives in a design project. An idea that sounds ridiculous initially may lead to the most creative design at the end. Students may learn more from failed designs than from successful ones because failure promotes the need to explain and revise.

The focus of engineering design assessment is not simply on whether or not students "get the right answer," but on how they acquire science and engineering knowledge and skills in the quest

for optimal design solutions. Engineering design assessment thus requires innovative solutions that can track and analyze student learning trajectories over a significant period of time. Sophisticated data mining technologies originally developed for scientific and business applications provide such solutions.

Year 1 Project Goals and Activities

OBJECTIVE #1: Advance the data collection capability of a CAD platform to create a "gold mine" of educational data. The Concord Consortium team has expanded the logging capacity of Energy3D to generate varieties of learner data. These efforts helped transform the CAD software into an open, versatile experimental platform to serve data-intensive research on engineering education. The Purdue project team provided user input on the revisions of the platform. The software is available at concord.org/energy3d. For details on this objective, refer to the Concord Consortium Year 1 Report.

OBJECTIVE #2: Generate the research data and develop the process analytics. The first set of data collection occurred in Spring 2014 both in Indiana (Eggers Middle School and Hammond High School) and in Massachusetts (Lowell High School and Arlington High School). These data are used to inform process analytics.

OBJECTIVE #3: Calibrate the research tools and validate the research design. In Year 1, Purdue Team focused on the validation of the research instruments, and the Concord Team focused on calibration of the process analytics. These initial qualitative studies were designed to inform the larger study in three ways. First, the classroom observations, interviews, and discussions with the teachers allow a deeper understanding of student cognition. These then inform the design of pre/posttests. Second, the qualitative analyses of student design behaviors and reflective notes captured through Energy3D provide information on students' approaches to design. Third, these combined insights help inform the development and validation of models for the process analytics such as time series mining, association rule mining, and combined action-note analysis. The initial design of pre/post-tests has been open-ended questions aimed to measure student prior knowledge and learning gains in science and engineering concepts. In Spring 2014, these data have been expanded with interviews with students before and after the project. The purpose of the pre/post-test data will later be integrated with the process data to identify relationships between actions and knowledge and provide explanations of learning outcomes.

Results

The data analysis and publication confirmed that the design replays supported with detailed student reflective notes provide sufficiently detailed information for characterizing student design thinking and design behaviors (Purzer et al, under review). We have also identified a notable progression of student behaviors that started with knowledge building and idea generation and evolved into a trade-off analysis. We found evidence of meaningful application of science learning when students attempted to balance design benefits and trade-offs.

The classroom research composed of observations and interviews with students and teachers is underway to provide evidence of student cognition. These studies will inform the development of pre/post-project assessment efforts.

Future Work

The project team will continue to work on calibrating the research tools and validating the research design. We will carry out six small-scale classroom studies (two rounds for each of the three design challenges to calibrate the research instruments and the process analytics. Each study will involve a class of students. The Informed Design Teaching and Learning Matrix recently synthesized by Advisory Board member Crismond and Co-PI Adams based on a meta-analysis of literature (Crismond & Adams, 2012) will be used to validate the research design and the process analytics. The Matrix defines nine engineering design strategies and associated patterns that contrast beginning versus informed design behaviors. A subset of them will be used to test the analytics. While the large-scale data collection is underway in Years 3-5, the team will start to analyze the datasets as soon as they are available. The process analytics will continue to be refined as needed.

Acknowledgement

References

Baker, R. S. J. D., Corbett, A. T., & Wagner, A. Z. (2006). *Human Classification of Low-Fidelity Replays of Student Actions.* Paper presented at the The Educational Data Mining Workshop at the 8th International Conference on Intelligent Tutoring Systems.

Goldstein, M. H., Purzer, S., Adams, R. S., Xie, C. (2015). "High School Students' Ability to Balance Benefits & Tradeoffs while Engineering Green Buildings." Conference Proceedings: *American Society of Engineering Education Annual Conference & Exposition,* Seattle, WA June 2015.

Goldstein, M. H., Purzer, S., Adams, R. S., Xie, C. (2015). "Where Design Meets Science: High School Students' Approaches to Balancing Design Trade-offs." Conference Proceedings: Research in Engineering Education Symposium (REES), Dublin, Ireland July 2015.

Katehi, L., Pearson, G., & Feder, M. (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. Washington DC: National Academy of Engineering.

National Research Council (2010). *Standards for K-12 Engineering Education?* Washington, DC: The National Academies Press.

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

Purzer, S., Adams, R., Goldstein, M., Xie, C., & Nourian, Z. (under review) "Design Quality at the Intersection of Scientific Explanation and Design Optimization." International Journal of STEM Education.

Svihla, V., & Petrosino, A. J. (2008). *Improving our Understanding of K-12 Engineering Education*. Paper presented at the The International Conference on Engineering Education.