

6-14-2015

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Senay Purzer
Purdue University

Robin Adams
Purdue University

Molly Goldstein
Purdue University

K. Anna Douglas
Purdue University

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Purzer, Senay; Adams, Robin; Goldstein, Molly; and Douglas, K. Anna, "Large-scale Research on Engineering Design in Secondary Classrooms: Big Learner Data Using Energy3D Computer-Aided Design" (2015). *School of Engineering Education Faculty Publications*. Paper 26.
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Large-scale Research on Engineering Design in Secondary Classrooms: Big Learner Data Using Energy3D Computer-Aided Design

Dr. Senay Purzer, Purdue University, West Lafayette

Senay Purzer is an Assistant Professor in the School of Engineering Education. She is the recipient of a 2012 NSF CAREER award, which examines how engineering students approach innovation. She serves on the editorial boards of *Science Education* and the *Journal of Pre-College Engineering Education (JPEER)*. She received a B.S.E with distinction in Engineering in 2009 and a B.S. degree in Physics Education in 1999. Her M.A. and Ph.D. degrees are in Science Education from Arizona State University earned in 2002 and 2008, respectively.

Dr. Robin Adams, Purdue University, West Lafayette
Molly H Goldstein, Purdue University, West Lafayette

Molly Goldstein is a Ph.D. student in the School of Engineering Education at Purdue University, West Lafayette. She previously worked as an environmental engineer specializing in air quality influencing her focus in engineering design with environmental concerns. Her research interests include how students approach decision making in an engineering design context. She obtained her B.S. in General Engineering and M.S. in Systems and Entrepreneurial Engineering from the University of Illinois.

Dr. K. Anna Douglas, Purdue University, West Lafayette

Anna earned her M.S. Ed in School Counseling and PhD in Educational Psychology from Purdue University. Her research interests are related to measurement and assessment in engineering education.

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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

This work presented in this manuscript is based upon work supported by the National Science Foundation under Grant DUE #1348547 and DUE #1348530. Any opinions, findings, and conclusions or recommendations expressed in this paper, however, are those of the authors and do not necessarily reflect the views of the NSF.

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