External Representation Design-for-Sustainability Intervention in an Engineering Graphics Course

Dr. Raghu Pucha, Georgia Institute of Technology

Dr. Raghu Pucha is a Senior Lecturer at the Woodruff School of Mechanical Engineering, Georgia Institute of Technology, in the area of CAD/CAE and Manufacturing. Dr. Pucha teaches computer graphics and design courses at Georgia Tech., and conducts research in the area of developing computational tools for the design, analysis and manufacturing of advanced materials and systems. Dr. Pucha has three provisional U.S. patents and co-authored over 60 research papers. He is honored with Undergraduate Educator Award in 2012 and Geoffrey G. Eichholz Faculty Teaching Award in 2015 from the Center for Enhancement of Teaching and Learning (CETL) at Georgia Tech.

Dr. Kata Dosa, Georgia Institute of Technology

Dr. Kata Dosa is a postdoctoral scholar in the Center for Teaching and Learning. She earned her Ph.D. in Environment and Resources from the University of Wisconsin-Madison, where Dosa conducted discipline-based education research looking at environmental decision-making and reasoning processes. During this time, she also completed the DELTA Certificate for Research, Teaching and Learning. Dosa holds a master's degree in environmental science and environmental biology from Eotvos Lorand University. She is currently working on developing workshops for faculty and graduate students, and supports future faculty and teaching assistant development programs. Dosa's current research interests are teaching-as-research, incorporating sustainability across the curriculum, team science, and competency development in higher education.

Dr. Meltem Alemdar, Georgia Institute of Technology

Dr. Meltem Alemdar is Associate Director and Senior Research Scientist at Georgia Tech's Center for Education Integrating Science, Mathematics, and Computing (CEISMC). Dr. Alemdar has experience evaluating programs that fall under the umbrella of educational evaluation, including K-12 educational curricula, K-12 STEM programs after-school programs, and comprehensive school reform initiatives. Across these evaluations, she has used a variety of evaluation methods, ranging from a multi-level evaluation plan designed to assess program impact to methods such as program monitoring designed to facilitate program improvement. She received her Ph.D. in Research, Measurement and Statistics from the Department of Education Policy at Georgia State University (GSU).

Dr. Sunni Haag Newton, Georgia Institute of Technology

Sunni Newton is currently a Research Associate II at the Georgia Institute of Technology in the Center for Education Integrating Science, Mathematics, and Computing (CEISMC). Her research focuses on assessing the implementation and outcomes of educational interventions at the K-12 and collegiate levels. She received her MS and Ph.D. in Industrial/Organizational Psychology from Georgia Tech in 2009 and 2013, respectively.

External representation design- for-sustainability intervention in engineering graphics course

Introduction

Introduction to *Engineering Graphics and Visualization* is a freshman-engineering course in many universities. In 1999, when Georgia Tech converted from quarter to semester curricula, the College of Engineering created a three credit hour introductory engineering graphics course for undergraduates [1]. The fifteen-week course included four weeks of sketching and eleven weeks of three-dimensional, constraint-based, solid modeling. In 2002, the course was revised using the "backward design" approach [2] with formative and summative assessments in lecture and lab activities. In later years project-based and learning-centered instructional approaches with creative ideation and sketching [3] were introduced. Such approaches follow a natural cycle of Kolb's learning model [4], which includes abstract conceptualization, active experimentation / application, concrete experience, and reflective observation. Our university has recently launched a campus-wide academic initiative aimed at preparing undergraduate students in all engineering majors to use their disciplinary knowledge and skills to contribute to the major societal challenge of creating sustainable communities. This paper presents ongoing sustainability intervention strategies in a freshman engineering graphics course with a contextualized project-based learning approach. University training in problem solving is primarily done using decontextualized textbook problems with a one-size-fits-all approach in exploring subject domain concepts. Teaching abstracted concepts as well-defined independent entities leads to learning with fixed meaning and immutable concepts. A situated approach to teaching and learning is currently used in this course, where concept, authentic activity and context, guide student learning to produce useable, robust knowledge. Situated cognition leads to negotiable meaning and socially constructed understanding of the subject domain concepts.

This paper presents

i. a socio-technical project-based teaching model with contextualized design problems that incorporate social, environmental and economic sustainability through both individual and team projects to engage students throughout the course;
ii. an external representation design for-sustainability intervention in students projects that address human wasteful behavior of resources and environmental sustainability;
iii. a brief note on ongoing assessment methods to quantify learning outcomes and students' perceptions on interventions in learning graphics and visualization tools through design problems in a sustainability context.

Background Literature and Pedagogy

Contextual teaching and learning and situated cognition models

Table 1. Characteristics of situated cognition and contextual Teaching and learning models [5]. [6].

Situated Cognition Model	**Contextual Teaching & Learning (CTL) Model**
Concept, context and authentic activity are involved in student learning.	Making learning meaningful to students by connecting to the real world
Negotiable meaning & socially constructed understanding.	Student work include many real, believable problem-solving situations.
Resolving ill-defined problems.	Cultivate an attitude that says, "I need to learn this"
Produce useable robust knowledge	Students participate in interactive groups and decision-making

Situated cognition [5], [6] emphasizes the importance of context in establishing meaningful linkages with the learner's experience and in promoting connections among knowledge, skill, and experience. Situated learning emphasizes higher order thinking rather than the acquisition of facts, encourages reflection on learning, and focuses on application rather than retention. Contextual learning [7] engages students in meaningful, interactive, and collaborative activities that support them in becoming self-regulated learners. Various characteristics of situated cognition and contextual teaching and learning models, listed in Table1, are used in this work through external representation design for-environmental sustainability interventions.

Environmental decision-making and reasoning in the context of sustainability development: Many of the decisions we make have implications for our environment, particularly those concerning natural resources and waste. Taking account of environmental factors in decision making can be both complex and challenging [8]. Wasteful behavior patterns are often cognitively easier to perform for humans. To change wasteful behavior, incentives alone to motivate people to make good choices are not sufficient. Environmental decision-making and successful behavioral decision enactment involves significant post-decision factors [9] that requires increased cognitive effort. These factors during decision enactment include (i) remembering the decisions (ii) recognizing the opportunity for decision enactment (iii) activating and coordinating goal-directed behaviors and (iv) maintaining the motivation through planning, monitoring the progress, overcoming impediments and resisting temptations. Increased cognitive effort is required to persist with good choices and actions day after day for sustainable resource use.

Designing products with external representation for a sustainable environment

The task environment of sustainable resource-use is highly unstructured and involves many uncoordinated and asynchronous actions as discussed above. Designing products with external representation [10] to improve the decision process using distributed cognition theories in structured problem-domains has been studied in the past to reduce the cognitive load of individuals or groups (ex: speed bugs in aircraft cockpit control design). Application of distributed cognition in the design of consumer products with external representation to promote sustainability is still in its infancy as the design problem-domain is unstructured. Product design with external representations promoting sustainable resource-use are intended to (i) make hidden information explicit in the design, (ii) motivate people to make decisions that sustain resources, and (iii) help people persist with this behavior by lowering the cognitive load involved in sustainability decisions.

This paper presents various interventions, in an experimental section of graphics and visualization course, related to student projects on environmental sustainability that involve product designs with external representations. The implementation and assessment of intervention activities, student reflections, pre and post-survey data results are presented. Students' perceptions on engineering design using project-based learning with sustainability theme projects in experimental sections of the course is discussed.

Socio-technical project-based learning model and external representation design for sustainability intervention:

Traditionally, engineering has been viewed purely as a technical problem-solving discipline [11], pushing engineers into the real world with a "one-size-fits-all" approach. Consequently, advanced technological solutions to problems around the world are being carried out with little understanding of the solution's local economic, social, and/or environmental impacts. To bring about social justice and sustainability through engineering solutions, values and ethics must be at the forefront of current engineering curricula. A socio-technical project-based learning model is implemented in this course [12] with contextualized design problems. Various sustainability-themed activities are assigned to engage students throughout the course. The lab activities in the course include an introduction to sustainability terminology with contextualized design problems and sustainability ideation. In the team projects (4 to 5 members per team) the humanitarian design problem is defined contextually with the following aspects (i) Listening to community – "design-for-community" vs "design-for-Industry" (ii) Technology to transform society vs society transform technology (iii) In addition to technical constraints, teams consider in the design (a) who suffers and who benefits and (b) how the designs increase opportunities and resources, reduce imposed risks and harms and enhance human capabilities [12].

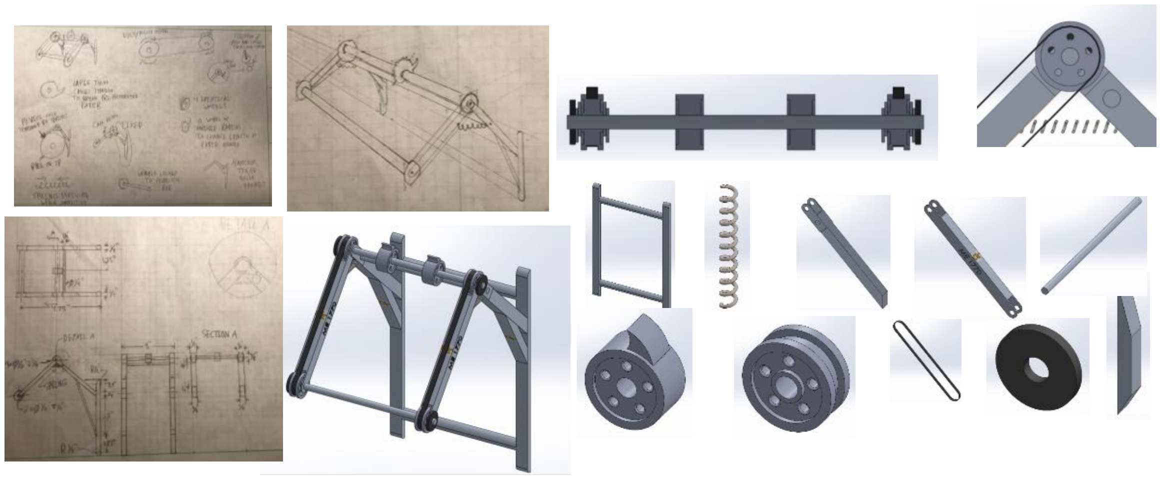

Figure 1: External representation designs-for-sustainability: Making the implicit information explicit (Sketching and CAD models)

Figure 2: External representation designs-for-sustainability: Making the implicit information explicit (Sketching, CAD models and 3D printed parts and assembly)

In individual projects, students work on product designs with external representations promoting sustainable resource-use to motivate people to make decisions and commit to behaviors that sustain resources. In the project-description, students are asked to take the lead on designing creative and unique appliances that promote sustainable use of resources for Home & office use of our university community. Students are supposed to use creative ideation and sustainability design concepts introduced in the lectures and prepare a preliminary set of visualization sketches describing the sustainability design with external representation. After feedback and approval from the instructor, develop CAD models, working drawings and 3D print the parts. Figure 1 and 2 shows examples of student work on external representation designs. Students design project shown in Figure 1 (the toilet paper dispenser design) with external representations promotes sustainable usage by making the implicit information explicit to the user by forcing the break-off of toilet paper once a set length of toilet paper has been pulled from the roll. Students design project shown in Figure 2 (Light design) with external representation promotes the sustainable usage of electricity by motivating the user with reduced cognitive load. A post-activity reflection analysis is performed with students answering following open-ended questions at the end of the project:

- Discuss at least three ways your product design promotes sustainability usage of resources.
- What is your understanding of the relationship among environmental, social and economic systems?
- Think about your design project and discuss how the 3Ps (1) Social sustainability (People) (2) Environmental sustainability (Planet) and (3) Economic sustainability (Profit) are reflected in your project design.
- What did you learn by creating this product? Describe how your engineering discipline can make communities more sustainable. Be specific.

<u>Learning outcomes and assessment</u>

A brief introduction to ongoing assessment, associated instruments and preliminary results is presented here.

Table 2. : Student Learning Objectives (SLOs) and Assessment Instruments

Assessment Instruments	SLOs
Pre and post surveys (word cloud analysis)	Students will be able to identify relationships among ecological, social and economic systems (SLO 1).
Rubrics for grading pre and post surveys, post-activity reflections and student design projects using SLOs	Students will be able to evaluate how decisions impact the sustainability of communities (SLO 3).
Open-coding and comparison of Post-activity reflection on sustainability intervention in design projects (thematic analysis)	Students will be able to describe how they can use their discipline to make communities more sustainable (SLO 4).

Table 2 summarizes identified student learning objectives (SLOs) and assessment instruments currently being used. The assessment instruments include, surveys at the beginning and at the end of the semester, thematic analysis of post-activity reflection responses and grading student post-activity reflection responses using appropriate rubrics.

Figure 3 shows an example of pre and post survey analysis results on student responses in Fall 2018. The experimental section had 40 students: 19 students participated in pre-survey and 16 students responded to post-survey.

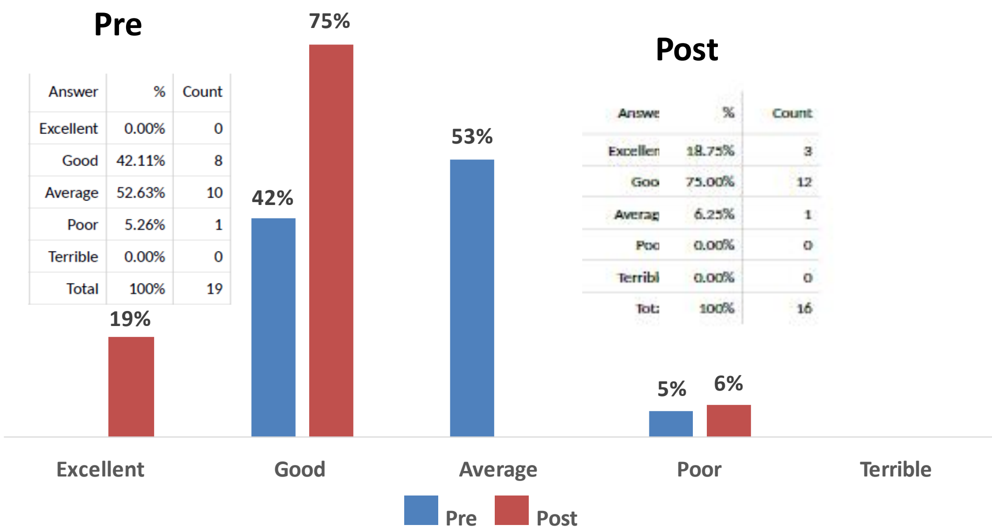

Figure 3. Pre and post-survey response analysis (Rate your understanding of the relationship between ecological, social and economic systems, SLO1)

Table 3. Individual project (Spring 2018): Post activity reflection results

Theme	Frequency
design-innovate-solve	45
skill-experience-creative-learned	33
challenged-appreciated-impact	26
active-apply-think-improve-focus	24
social-environment-community-context-human	22
value-attitude	21
help-allowed-understand	16
ideation methods	9

Table 3 shows post-activity reflection analysis results in external representation design projects using open coding constant comparison codes analyzed for major themes. The frequency of eight major themes in 67 comments is analyzed.

Various rubrics with sustainability-system-thinking and discipline skill-based measures are currently evaluated in individual projects on external representation design-for-environmental sustainability. The sustainability system-thinking skills include (i) dynamic relationships among ecological, social, and economic factors of sustainability and (ii) influence of context and evaluate how design decisions influences the sustainability of communities.

References:

1. Elrod, D., & Stewart, M.D. (2002). "Assessing student work in engineering graphics visualization course". Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.
2. G. Wiggins and J. McTighe, "Understanding by design. Alexandria, VA: ASCD," in *Assessment for Learning Conference*, Ljubljana, June, 1998.
3. Pucha, R.V and Utschig, T.T (2012) "Learning-Centered Instruction of Engineering Graphics for Freshman Engineering Students," Journal of STEM Education: Innovations and Research, vol. 13, p. 24.
4. A. W. Combs, "Fostering maximum development of the individual," *Issues in secondary education*, pp. 65-87, 1976
5. S. J. Brown, A. Collins, and P. Duguid, " Situated Cognition and the Culture of Learning", Educational Researcher, Vol. 18, No. 1, pp. 32-42, 1989.
6. J. Choi, and M. Hannafin, "Situated cognition and learning environments: roles, structures, and implications for design", *Journal of Educational Technology Research and Development*, 43 (2) pp. 53 – 69, 1995
7. R. P. Khotimah and M. Masduki, "Improving teaching quality and problem solving ability through contextual teaching and learning in differential equations: a lesson study approach*", Journal of Research and Advances in Mathematics Education*, Vol. 1, No. 1, pp.1-13, 2016.
8. G. A. Kiker, T. S. Bridges, A. Varghese, T. P. Seager and I. Linkov, "Application of multicriteria decision analysis in environmental decision making", *Integr Environ Assess Manag*, 1: 95-108, 2005.
9. R. P. Bagozzi, U. M. Dholakia, and S. Basuroy, "How Effortful Decisions Get Enacted: The Motivating Role of Decision Processes, Desires, and Anticipate Emotions", *J. Behav. Dec. Making*, 16: 273–295, 2003
10. S. Chandrasekharan, and M. Tovey, "Sum, quorum, tether: Design principles underlying external representations that promote sustainability", *Pragmatics & Cognition*, 20(3): p. 447-482, 2012
11. J. Lucena, "Bridging Sustainable Community Development and Social Justice", In: Christensen S., Didier C., Jamison A., Meganck M., Mitcham C., Newberry B. (eds) *International Perspectives on Engineering Education. Philosophy of Engineering and Technology*, vol 20. Springer, Cham, 2015
12. Pucha, RV., Thurman, CJ; Yow,R; Meeds, CR; and Hirsch, J (2018). Engagement in Practice: Socio-technical Project-based Learning Model in a Freshman Engineering Design Course. ASEE Annual Conference & Exposition.