AC 2012-4045: DESIGN SWAPPING AS A METHOD TO IMPROVE DESIGN DOCUMENTATION

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Design Swapping as a Method to Improve Design Documentation

Design educators are often challenged with motivating students to generate detailed design documentation and provide constructive feedback to peers. However, due to the limited scope of class design projects and lack of real-world industry experience, student understanding of the necessity of clear design communication is often lacking. Strict grading of design documentation and frequent instructor feedback can improve the quality of documentation, but does not help students experientially understand its importance.

The purpose of this study was to investigate the effectiveness of using "design swapping" to improve both the quality of design documentation and the quantity of discussion and feedback among teams during design reviews. Design swapping is the notion of having student teams swap designs shortly after a design review such that they construct another team's design. It simulates real-world engineering by separating design and manufacturing, in addition to preparing students for outsourcing environments.

Context

This study took place in four models of 1-week Rube Goldberg engineering design summer camps for middle and high school students taught in Summer 2010 and Summer 2011. Rube Goldberg machines are chain-reaction devices that complete simple tasks, such as replacing a light bulb, in overly complex ways. Students participated in a rigorous engineering design exercise in which they designed Rube Goldberg machines, participated in design reviews, swapped designs among teams, and finally built another team's design while communicating with the designing team (i.e., the team that conceived the design they built) and the manufacturing team (i.e., the team that built the design they conceived) as required.

In each of the models, students were challenged with learning and applying the Boston Museum of Science Engineering is Elementary® engineering design process[1] to design and build a Rube Goldberg machine to inflate and pop a balloon. In the second model, students were physically co-located in teams at the Arizona State University (ASU) Polytechnic Campus. The machines designed and built in Models 1, 3, and 4 had the added constraint that their parts must connect together across camp sites using mobile phones, resulting in a machine that started at one site, progressed through a number of complex intermediate steps, and culminated by popping a balloon at the final site. In the first model, students in an ASU camp worked in domestic geographically-distributed teams (GDTs) with students at another camp using our curriculum at Purdue University in Indiana. In the third model, students in an ASU camp worked in domestic GDTs with students at another camp using the same curriculum at Morgan State University in Maryland. In the fourth model, ASU students worked in international GDTs with students in camps using the same curriculum at both Purdue University in Indiana and Bishop Anstey High School East/Trinity College East School in Trinidad and Tobago.

Students were required to collaborate using mixed media, including face-to-face conversations, participating in design reviews using professional videoconferencing tools, initiating team-to-team collaborations via Skype videoconferencing, and sharing designs among teams using web-based collaborative word processing tools. Videos of the final product are available at http://www.youtube.com/user/shawnsjordan.

The curriculum evolved from prior work over the past 4 years by Jordan, Pereira, and Adams[2-4] in partnership with the Gifted Education Resource Institute[5] at Purdue University, and was pilot-tested by co-author Dalrymple at ASU in the summer of 2010[6]. It is unique because it combines a strong foundation in the engineering design process[1] with cutting-edge virtual teams research[7] to create a new type of engineering team project-based learning environment for middle and high school students[8]. The instructional style is also inquiry-based[9] and differentiated to challenge learners with diverse levels of ability[10]. To date, this curriculum has been successfully deployed in informal settings with approximately 160 middle and high school students at 3 domestic and 1 international site.

Research Questions

The research questions that guided this study are:

1. How does prior knowledge of an imminent design swap affect the quality of documentation prepared for design reviews?
2. How does design swapping affect the quantity and types of discussion during design reviews?

Methods

Design-based research is a methodological framework for investigating how, when, and why educational innovations work in practice[11]. It allows researchers to "simultaneously pursue the goals of developing effective learning environments and using such environments as naturalistic laboratories to study learning and teaching"[12]. Within this framework, 4 models of a Rube Goldbergineering curriculum were iteratively designed and implemented. Fundamentally, all models shared the same learning objectives, content material and pedagogical approaches, but varied in terms of the implementation setting and structure. Some of the specific variations were: number, demographic distribution, and cultural and educational background of the students; methods of recruitment; mechanisms for financially supporting students' participation; number of students, location and proximity of partnering sites; nature of the team interaction students experienced; and the use of and dependency on online communication tools and technologies. This mix of deliberate and situational modifications allowed us to evaluate, within authentic settings, the learning affordance of the Rube Goldberg instructional intervention, and connect process of enactment to outcomes of interest. Qualitative methods were employed in the data collection process to capture the richness and often complex nature of the students' experiences within the naturalistic setting. Table 1 shows the various data collection and analysis methods that were employed to address each research question.

Table 1: Research Questions, Analysis Methods, and Data Sources

Questions	**Analysis Methods**	**Data Sources**
RQ1: How does prior knowledge of an imminent design swap affect the quality of documentation prepared for design reviews?	• Quantitative analysis (descriptive statistics)[13]; independent samples *t* test, one-way analysis of variance	Design sketches
RQ2: How does design swapping affect the quantity and types of discussion during design reviews?	• Discourse analysis[14] • Quantitative analysis (descriptive statistics)[13]	Design review videos

Data Collection and Analysis

Table 2 details the four models of summer camps analyzed in this study. Model 1 was a control group, having no design swapping among teams. In Model 2, teams were notified immediately after the design review that they would be swapping designs with another team at the same site. In Models 3 and 4, teams were notified approximately 15 minutes before the design review that they would be swapping designs with other teams in the same or different country.

Table 2: Model Characteristics and Participants

Model	Date	Site	Teams	Enrollment	Swapping Notification
1	Summer 2010	ASU	5	18	No design swap (control)
		Purdue	4	8	
2	Summer 2011	ASU	5	16	After design review
3	Summer 2011	ASU	5	17	After design review
		Morgan State	5	20	
4	Summer 2011	ASU	5	18	Just prior to design review
		Purdue	5	19	
		Trinidad & Tobago	5	20	
		Totals	**39 teams**	**136**	

Design sketches were a primary form of documentation that teams used to communicate their designs to others. An example design sketch is shown in Figure 1. To address RQ1 (see Table 1), the quality of design sketches used during the design reviews in all camps was judged by using a 10-point rubric and 3-point scale from “None” to “Most”. Rubric factors included inclusion of Team # and Name, and Task/Module Name, Step Realism/Recognizability, Step Scale, Step Sequence Labels, Component Labels, Step Descriptions, Step Modifications, Functional Indicators, and Neatness. The rubric was developed through a group process of looking at a sample of design sketches and identifying the key factors that differentiated excellent sketches from poor ones. The full rubric is provided in the Appendix.

An Independent samples *t* test was used to investigate whether the average quality scores for the *design swap* and *no design swap* group teachers differed significantly. An independent samples *t* test was used because the two groups were unrelated. In order to compare the quality scores for the no design swap, design swap with notification after design review, and design swap with notification just prior to design review, we conducted a one-way analysis of variance (ANOVA) because we wanted to compare the average scores for three independent groups[15]. Following the ANOVA, we conducted the Dunnett’s post hoc test to investigate differences between each of the groups. This test was used because equal variances were not assumed for the three groups.

To address RQ2 (see Table 1), videos of design reviews from Models 1 and 2 were analyzed. Student questions were counted, and a coding scheme used to analyze question content. The coding scheme was developed by independent open coding of several sample videos by 4 coders, followed by a comparison of open codes and co-development of a comprehensive coding scheme. The coding scheme categorized questions in the following categories (and subcategories): Understanding (Science Concepts, Functional Clarification), Problem Identification (Feasibility, Connection, Reliability), Redesign (Problem Solving, Design Alternatives), Past Experience, and Questions (Instructor, Student). The full coding scheme is provided in the Appendix.

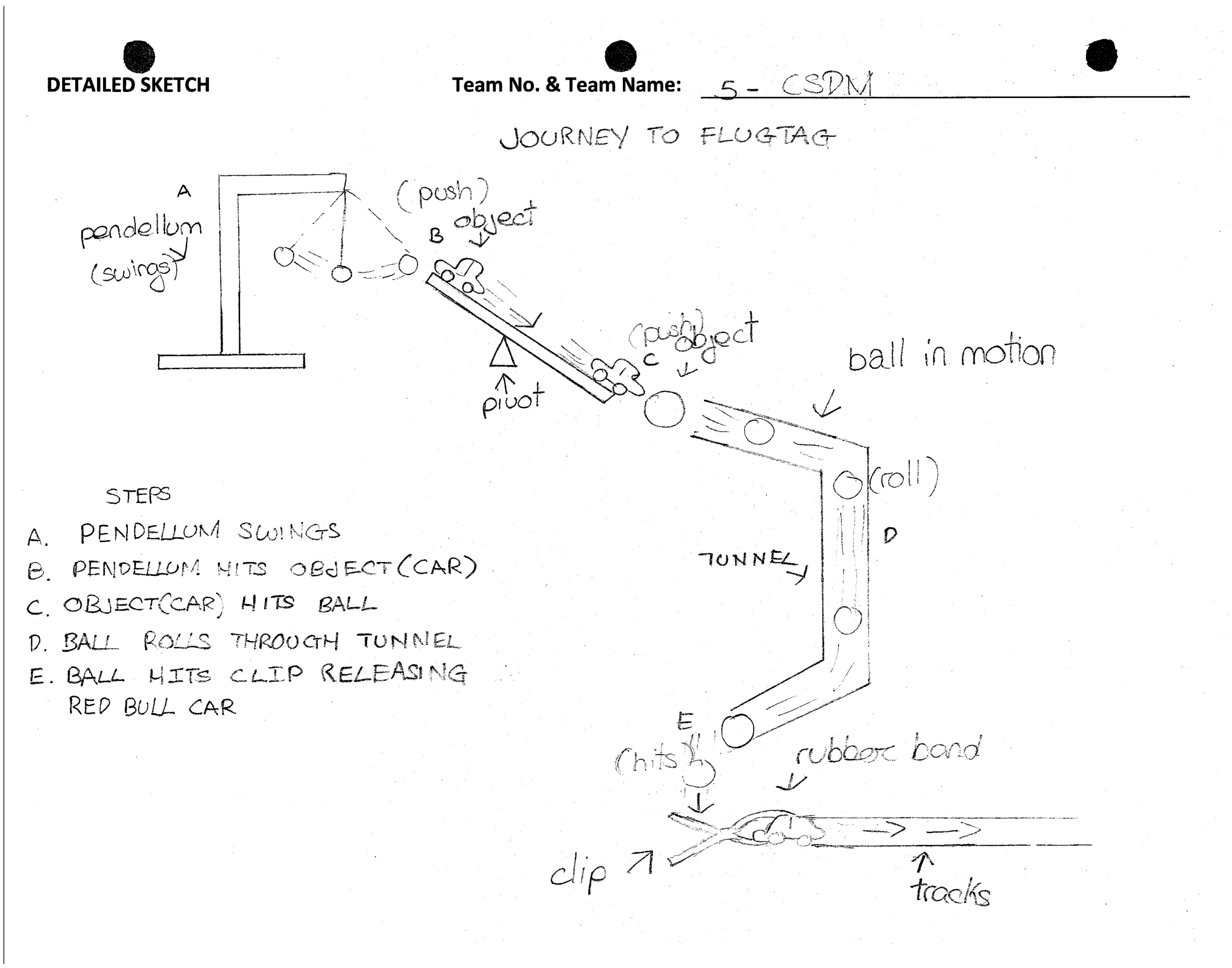

Figure 1: Example Design Sketch from Model 4

Results

RQ1: How does prior knowledge of an imminent design swap affect the quality of documentation prepared for design reviews?

In order to compare the quality scores for sketches in the control group (no design swap and notification of design swap after the design review) to the scores for sketches of the other groups (notification of design swap just prior to design review), we conducted an independent samples *t* test. Average quality scores for the two groups and results of the *t* test are shown in Table 3.

Table 3: Comparison of Average Quality Scores for the No Design Swap and Notification of Design Swap After Design Review (Group 1) and Notification of Design Swap Just Prior to Design Review (Group 2) Groups

	Group 1 (*n*=24)		**Group 2 (*n*=15)**					
	Mean	**SD**	**Mean**	**SD**	**Mean Diff.**	***t*(37)**	***p***	**Cohen's *d***
Overall Quality	72.53	8.45	84.20	13.17	11.67	3.38	.002	1.06

Note. SD = Standard Deviation

The average quality score for the notified of design swap sketches was 11.67 higher than the average quality score for the not notified of design swap or no design swap sketches. This difference was significantly higher (t= 3.38, df=37 p=.002, d= 1.06). An effect size of 1.06 indicated that the quality scores for the Group 2 sketches were on average 1.06 standard deviations greater than the scores for the Group 1 sketches. The higher scores could be due to the Notification of Design Swap taking place prior to the design reviews, which was used with Group 2. Separating based on year and offering, we also compared the quality scores for sketches of no design swap teams in 2010 (Group A), 2011 who were not notified in advance of the swap (Group B), and 2011 who were notified in advance of the design swap (Group C). Table 4 includes the average quality scores and standard deviation for the sketches of the three groups.

Table 4: Comparison of Average Quality Scores for No Design Swap (Group A), Design Swap with Notification After Design Review (Group B), and Design Swap with Notification Just Prior to Design Review (Group C)

	Group A (*n*=9)		**Group B (*n*=15)**		**Group C (*n*=15)**	
	Mean	SD	Mean	SD	Mean	SD
Overall Quality	67.49	4.05	75.55	9.05	84.20	13.17

Note. SD = Standard Deviation

Average quality scores for Groups B and C were higher than the scores for Group A. We conducted a one-way analysis of variance to investigate if means for the three groups were significantly different from one another. Results indicated that the mean quality scores for the three groups were significantly different from one another (F= 7.882, df= 2, p= .001). To investigate if there were significant differences among the three separate groups, we conducted Dunnett post hoc tests, which indicated that average quality scores for Group C (design swap just prior to design review) were significantly higher than the average quality scores for Groups A (p= .001) and Group B (p= .047). There was no significant difference between the average quality scores of Groups A and B (p= .114). These results could indicate that using design swapping may have had positive effects on the quality of the sketches students produced, since the average quality scores for Group C were significantly higher than the scores for the other two groups.

RQ2: How does design swapping affect the quantity and types of discussion during design reviews?

In order to compare the quantity of questions asked in a design review by the control group (2010, no design swap) to the quantity of questions asked in a design review in an experimental group (2011, design swap), we compared the average number of questions asked by the students about each design (see Table 5).

Table 5: Student Questions in Design Review

	Group 1 (No swap) (*n*=7)		**Group 2 (Swap notification after DR) (*n*=5)**	
	Mean	SD	Mean	SD
Questions Per Design	1	1.15	4.2	2.77

As shown in Table 5, the mean number of student questions in design reviews across all teams was 1 in Group 1 (2010) and 4.2 in Group 2 (2011). This suggests Group 2 asked significantly more questions than Group 1, but perhaps not because of the design swapping since Group 2 did not know about the design swap prior to the design review.

In order to compare the types of student discussion in a design review by the control group (2010, no design swap) to the types of student discussion in a design review in an experimental group (2011, design swap), we compared the average number of different types of discussion by the students about each design (see Table 6).

Table 6: Average amount of different types of discussion in each design review

	Group 1 (No swap) (*n*=6)		**Group 2 (Swap notification after DR) (*n*=4)**	
	Mean	SD	Mean	SD
Understanding > Science Concepts	0.33	0.52	0.75	0.96
Understanding > Functional Clarification	0.83	0.75	3.25	1.71
Problem Identification > Feasibility	0.83	0.98	2.50	0.58
Problem Identification > Connection	0.17	0.41	1.25	1.50
Problem Identification > Reliability	0.67	0.82	1.75	0.96
Redesign > Problem Solving	0.33	0.52	0.50	1.00
Redesign > Design Alternatives	0.33	0.52	0.50	0.58
Reference Past Experience	0.17	0.41	0.50	0.58

As shown in Table 6, all 8 coded types of discussion occurred during design reviews in both Group 1 and Group 2. The mean number of discussions of each type was somewhat to significantly higher in Group 2 (2011) compared with Group 1 (2010). This mirrors the previous result that Group 2 asked more questions than Group 1. Looking at the specific types of discussion, Group 2 had significantly more discussions to understand how the machine functions and to challenge the feasibility of designs during the design review. Since Group 2 did not know about the design swap prior to the design review, this improvement in discussion may not be attributable to the design swap.

Conclusions and Implications for Undergraduate Engineering Education

Results indicate that the quality of design artifacts was superior when students knew prior to the design review that they would be building another team's design. The average quality score for the sketches made by the teams that knew they would swap designs prior to the design review was 11.67 quality pointshigher than the average quality score for the teams that did not swap designs or did not know they would swap designs at a later time. When separating groups by middle and high school, the average quality score for the sketches made by teams of primarily high school students that knew they would swap designs prior to the design review was 16.71 higher than the average quality score for the teams that did not swap designs. One explanation for this could be that the middle school group excluded in this comparison was made up of many gifted students.

Therefore, prior knowledge that designs will be swapped can improve the quality of design documentation generated by students. One possible reason for this could be the swap introduces an audience beyond the team, in a similar way that having a real client can motivate students to communicate their designs more effectively. *Since real clients are often not feasible or accessible for undergraduate design projects, the idea of design swapping can provide a surrogate client in the absence of a real client.*

The quantity of discourse increased significantly between the group that did no design swapping when compared with a group that did, though this difference may not be attributable to the design swapping and requires further study. Similarly, the type of discourse in the group that did swap designs was heavily skewed toward functional clarification to gain understanding of designs and identifying problems to challenge the feasibility of designs, though this increased discourse may not be attributable to the design swapping and requires further study.

The results of this study with middle and high school students brings about the future research question: will our undergraduates produce higher-quality design documentation and participate more in design reviews if challenged with swapping designs? These results can help to inform design process structure for faculty teaching design to undergraduates or secondary students, in addition to those wishing to simulate the separation of design and manufacturing engineering in the undergraduate curriculum.

Appendix

Table 7: Design Sketch Rubric

Factors	***None***	***Some***	***Most***
Team # and Name	Neither team # nor team name	Team # or team name	Both team # and team name
Task/Module Name	Does not exist	N/A	Exists
Step Realism/Recognizability	None of the step sketches are realistic or recognizable	Some of the step sketches are realistic and recognizable	Most of the step sketches are realistic and recognizable
Step Scale	None of the steps are drawn to scale	Some of the steps are drawn to scale	Most of the steps are drawn to scale
Step Sequence Labels (A, B, C...; 1, 2, 3...)	None of the step sequence was labeled	Some of the step sequence was labeled	Most of the step sequence was labeled
Component Labels (e.g., ball, dominoes, car)	No components were labeled with text	Some components were labeled with text	Most components were labeled with text
Step Descriptions	No steps described in text form	Some steps described in text form	Most steps described in text form
Step Modifications (DR2 only)	No modifications to the original design were described	Some modifications to the original design were described	Most modifications to the original design were described
Functional Indicators (e.g., arrows)	No steps had functional indicators to show motion	Some steps had functional indicators to show motion	Most steps had functional indicators to show motion
Neatness (e.g., line quality, edges, readability, smudges)	None of the design is sketched neatly	Some of the design is sketched neatly	Most of the design is sketched neatly

Table 8: Design Review Coding Scheme

Code	***Description***	***Examples***
Understanding > Science Concepts	• What science concepts apply? • How do science concepts apply?	• “How much force does it take?” • “Will the ball fly in another direction?”
Understanding > Functional Clarification	• How does it work? • Where does it work? • When does it work?	• “Will the cups be fixed or point up?” • “How is the connection going to take place?”
Problem Identification > Feasibility	• Can it work?	• “Going up the stairs may be challenging” • “In my experience, a pulley system won’t work”
Problem Identification > Connection	• Can it connect?	• “If a pin needs to pull out, how will it work? It needs a special track.”
Problem Identification > Reliability	• Can it work consistently?	• “How will you make the ball stay on the ramp?” • “Does the ball have an exact spot?” • “How easy will it be to test this module?”
Redesign > Problem Solving	• How can the problem be solved with minor changes?	• “Could a track be used to keep the ball on the ramp?”
Redesign > Design Alternatives	• How can the step be completely redesigned?	• “Could you use a reverse pulley instead?”
Past Experience	• What past experience is referenced as justification?	• “In my experience, a pulley system won’t work”
Questions > Instructor	• Is the coded statement a specific question from the instructor?	• Who/what/when/where/why/how?
Questions > Student	• Is the coded statement a specific question from a student?	• Who/what/when/where/why/how?

References

1. Cunningham, C.M. and K. Hester (2007). *Engineering is elementary: An engineering and technology curriculum for children*. In proceedings of the American Society for Engineering Education Annual Conference & Exposition, Honolulu, HI.
2. Jordan, S. and R. Adams (2008). *...A good imagination and a pile of junk*. In proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition, Pittsburgh, PA.
3. Jordan, S. and N. Pereira (2008). *Design twice, build once: teaching engineering design in the classroom*. In proceedings of the National Center for Engineering and Technology Education (NCETE) Conference on Research in Engineering and Technology Education, St. Paul, MN.
4. Jordan, S. and N. Pereira (2009). *Teaching engineering design to middle school students with Rube Goldberg*. In proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition, Austin, TX.
5. Feldhusen, J. and A.R. Wyman (1980). Super Saturday: design and implementation of Purdue's special program for gifted children. *Gifted Child Quarterly*, 24(1), 15-21.
6. Ringle, H. (2010, July 20). Gilbert students go Rube Goldberg with engineering design class machine. *The Arizona Republic*.
7. Jordan, S.S. (2010). *Success in virtual cross-disciplinary engineering design teams in industry*. (Doctoral dissertation). ProQuest Dissertations & Theses database. (Accession Order No. 3453124)
8. Blumenfeld, P.C., et al. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational psychologist*, 26(3-4), 369-398.
9. White, B.Y. and J.R. Frederiksen (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and instruction*, 16(1), 3-118.
10. Tomlinson, C.A. (2001). *How to differentiate instruction in mixed-ability classrooms* (2nd ed.): Association for Supervision & Curriculum Development.
11. The Design-Based Research Collective (2003). Design-Based Research: an emerging paradigm for educational inquiry. *Educational Researcher*, 5-8.
12. Sandoval, W.A. and P. Bell (2004). Design-based research methods for studying learning in context: Introduction. *Educational Psychologist*, 39(4), 199-201.
13. Cohen, L., L. Manion, and K. Morrison (2011). *Research methods in education* (7th ed.). London ; New York: Routledge.
14. Brown, G. and G. Yule (1983). *Discourse analysis*: Cambridge University Press.
15. Moore, D.S., G.P. McCabe, and B.A. Craig (2012). *Introduction to the practice of statistics* (7th ed.). New York: W.H. Freeman.