

Designing Hands-On Teaming Activities: Exploring Sustainability Tradeoffs for Courses with Large Enrollments*

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In this paper, the authors explore sustainability issues that exist in the development of hands-on activities for classes with large enrollments. Specifically, the authors study four different team-building activities, all with varying levels of resource commitment, to assess potential tradeoffs between cost, environmental impact, and learning objectives pertaining to design and teaming. Faced with several alternatives and multiple, conflicting objectives, the authors approach this choice from a design context. Specifically, following the identification of activity constraints and objectives, activity alternatives are evaluated against several metrics with post-activity student surveys. Survey data is then translated into an appropriate input for a systematic selection framework, the selection Decision Support Problem. The use of this framework allows the authors to select a teaming activity alternative that offers the best compromise to their multiple design goals.

Keywords: engineering design education; design teaming; first-year design; designing design experiences

1. DESIGNING DESIGN EXPERIENCES: TEAMING ACTIVITIES

1.1 Teaming in design

SINCE THE SHIFT in the mid-1980s toward re-integrating design into engineering curriculum, instructors have worked to better understand what students should learn from design, and how and when students should learn design [1–4]. Increasingly, instructors and researchers are advocating that design curriculum be integrated at the freshman level, with the rationale that ‘design is an experience that must grow with the student’s development’ [2]. Learning objectives for these courses usually include an array of both individual and group abilities taught through project-based and cooperative learning methods.

One challenge in orchestrating an introductory course in engineering design is to create opportunities for students to experience design in ways that help them realize that ‘individual and social perspectives on activity are both fundamentally important’ [5]. In addition to technical skills, collaborative design outcomes cited in the literature include benefits such as improved group decision making, conflict management, learning and valuing multiple perspectives, and ability to contribute technical knowledge to group projects.

As a result of the hands-on, collaborative nature of project-based learning (PBL) and cooperative learning, it has been asserted that design education at the first-year level enhances student interest and retention in engineering (especially among under-represented populations), motivates learning in upper-division courses, and improves performance in capstone design courses [6, 7].

1.2 Designing hands-on activities for large enrollment courses

While expanding the scope of design benefits from capstone to cornerstone may improve students’ collaborative abilities in ‘all aspects of their lives,’ it is important to know that ‘simply putting people in a team does not teach them to work together effectively’ [8]. Real, hands-on projects tend to be more engaging for students, and instructors need to provide structure that helps students navigate the challenges and opportunities of collaboration embedded in a design project.

However, hands-on activities of courses featuring a large enrollment can be difficult to orchestrate. For example, instructors wishing to offer hands-on activities featured in the first-year introductory engineering design course surveyed in this paper must provide sufficient resources to support the 1000+ students enrolled in the course. This large commitment of resources introduces potential long-term financial and environmental burdens

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that call into question the sustainability of such activities.

There exist many different interactive, in-class teaming activities, which feature varying levels of resource commitment in their implementation. Aware of potential tradeoffs between resource commitment and student learning and engagement, the authors approach the development of a teaming activity for a large course as a design problem. As part of a larger goal of 'designing design experiences,' the authors follow a systematic design approach to identify a teaming activity alternative that offers the best compromise to objectives pertaining to design and teaming learning, student engagement, cost, and sustainability. As such, the format of this paper mirrors the phases of design. In Section 2 the design problem is identified by scoping the problem's context and the design objectives and constraints. Four teaming activities are ideated in the conceptual design phase, detailed in Section 3. In Section 4, a systematic selection process is employed in order to rank order the alternatives in the context of their evaluation against multiple selection attributes. Closure is offered in Section 5.

2. DEFINING THE PROBLEM

2.1 Context

The to-be-designed teaming activity will be employed in a first-year introductory engineering course of a large, land-grant, mid-Atlantic university. The two-credit course features an enrollment of over 1000 students who represent all but two (Computer Science and Electrical and Computer Engineering) of the college's engineering departments. The course is structured around two weekly meetings: a large group meeting (50 minutes; ~300 seats) that is orchestrated by faculty instructors and a workshop session (2 hours; ~35 seats) that is monitored by graduate teaching assistants. The class is offered in multiple sections: in the Spring 2009 semester 32 workshop sections and four corresponding sections of large-group meetings were offered. This arrangement enables the instructors to create workshop cohorts for instructional experimentation purposes.

In addition to homework, quizzes, and exams, students' understanding of course content is assessed through a semester-long group-based design project. The design project not only provides an opportunity for students to engage in engineering design, it also serves as an opportunity for students to synthesize the distinct course content modules (graphics, programming, and design methodology). The teaming activity is presented to the students in the first workshop meeting of the semester and thus serves as a starting point for student design teams. Prior to the teaming activity, students are introduced to teaming concepts via an overview and implementation of the Myers-Briggs personality inventory and

a discussion of Tuckman's Forming–Storming–Norming–Performing model of group development.

2.2 Activity objectives

The primary learning objective of the collaborative activities is for students to understand that teamwork is an important part of the design process. Within this primary objective are several objectives to be considered in the design of the activity, generally categorized into teaming, design, engagement and retention, and sustainability objectives.

Teaming, engagement, and retention objectives: The learning goals for our activities parallel the benefits claimed in the literature of the last 20 years. Specifically, the authors have identified teaming objectives that target both individual and group abilities, and engagement objectives that promote factors that could contribute to retention of populations underrepresented in engineering. The teaming objectives to be considered in the design of the activity are as follows:

- Students experience challenges of group-decision making.
- Students experience need for conflict management.
- Students identify value of multiple perspectives in group decision making.
- Students identify benefits of teamwork.
- Students make social connections with group members.
- Students feel as if they are a better team player as a result of the activity.

These teaming objectives parallel reports in the literature that support the constructivist view of learning as a social, situated activity that can be taught through PBL and cooperative learning [7]. Group decision-making, or group processing, is a major component of cooperative learning [9] that involves problem-solving and information gathering [8]. As Shwom et al. point out, 'a culture of design is by definition a culture of communication' that emphasizes interaction that can otherwise be missing in engineering schools [10]. Through interactive processes, students gain experience in conflict management by collaborating with people who have different learning and work styles [11, 7]. Also, students learn both social and technical knowledge by working with multiple perspectives. Many reports cite the advantages of 'integrative' approaches that combine different perspectives in the group populations and the project assignment [7, 9, 11–15]. The emphasis is on negotiation and construction of shared meanings that can result in more adaptive cognition [2, 16], convergent conceptual change [17], and better connections across disciplines [18]. Ideally, this promotion of the social construction of knowledge leads to an increase in how students value collaborative design, which has been reported as an

outcome even when students are initially doubtful of the importance of teaming [4, 8, 9, 19]. While the social aspect of interpersonal skills is highlighted in teaming objectives [7–9, 20], design collaborations can also be structured to promote individual accountability, embodied by abilities of being a good team player, contributing technical expertise to a group project, and engaging in self-regulated learning [9, 14, 21].

Toward retention objectives, this combination of ‘positive interdependence’ [9] and individual accountability can help build inclusive learning environments in which all students can participate and achieve a sense of belonging. Dym [7] cites over ten successful retention efforts achieved through cooperative learning. In addition to cooperative learning in design as a potential ‘feminist pedagogy’ [22], teamwork and problem-solving have been linked to creativity and logic [15]. Retention can be improved by increasing opportunities for interaction, communication and hands-on projects, all of which support inclusive learning communities [7, 12, 19, 23].

Furthermore, many students enjoy collaborative design more than isolated, individual learning, which could theoretically lead to more engagement in engineering; a characteristic of experts is that they ‘love the activity’ versus novices, who just do the activity [8]. Finally, teamwork experiences can have an impact on individuals’ [21] and groups’ [24] beliefs in their own efficacy as problem-solvers, which can in turn influence whether or not they continue in engineering after their freshman year. Thus, retention and engagement objectives for the teaming activity are expressed as:

- Students see themselves as part of a team.
- Students participate in a cooperative learning experience.
- Each student in the team participates in the activity.
- Students enjoy the activity.
- Students look forward to participating within their team.

Design objectives: It is desired that the teaming activity be situated in the context of an engineering design problem as is reflected in the activity’s primary objective for students to understand the importance of teaming in design. As such, objectives are identified that reflect on important elements of an engineering design task:

- The task resembles an engineering system.
- All participants are novice to the task.
- Presence of multiple, conflicting objectives.
- Presence of constraints and/or limited resources.
- Multiple solutions are possible (multiple alternatives must be assessed).
- An opportunity for creative solutions exists.

Sustainability objectives: As described in Section 1.2, the instructional team has identified objectives

regarding the sustainability of the to-be-designed activity:

- Maximize use of reusable, recyclable resources that are derived from sustainable sources.
- Minimize cost of the activity.

2.3 Constraints

In addition to the above objectives, the instructional team identified the following constraints:

- The activity must be able to be completed in one hour.
- The activity must be able to be moderated by a teaching assistant (TA). As such, any expert knowledge must be able to be conveyed to the TA within the one-hour weekly TA training meeting.
- The activity must feature opportunities for all members of the team (5–6 students) to be involved.
- The activity must cost less than \$1,200 to implement over a period of six semesters.
- The activity must not be disruptive to students in surrounding classrooms.
- The activity must be safe.

The design task set before the instructional team is to design a teaming activity that offers the best compromise to multiple, conflicting objectives relating to engagement, sustainability, and teaming and design learning objectives, while taking into account resource constraints.

3. CONCEPTUAL DESIGN: TEAMING ACTIVITY ALTERNATIVES

Following the identification of the design objectives and constraints, the authors ideated four different alternatives for the teaming activity. Three of the activities are centered on a hands-on design-build competition, while the fourth is oriented around discussion and negotiation. As such, each alternative features a different level of resource commitment.

Balloon tower: In this activity, student teams are tasked with constructing a tower using 15 balloons and 12 in. of tape. Their goal is to build the tallest tower possible. In addition to the constraints placed on building material resources, the towers must be freestanding (i.e., cannot be attached to the floor or other structures; e.g., ceiling, desk, chair, etc.). After the towers are constructed, they are measured; the team that has constructed the tallest tower is declared the winner.

Paper tower: In this activity, student teams are provided 10 sheets of standard 8" × 11" copy paper and 18 in. of tape. Using these materials, the students are instructed to build a freestanding tower (Fig. 1a). The activity presents two design objectives to the teams: (i) to build the tallest tower



Fig. 1. Tower-building teaming activities; (a) Paper tower, (b) TinkerToy™ Tower

and (ii) to build a tower that can withstand the teaching assistant's efforts to blow the tower over. After construction, the teaching assistant attempts to blow over each team's tower; towers that are still standing are then measured to determine their height.

TinkerToy™ tower: This teaming activity alternative is similar to the balloon tower exercise in that the singular design goal is to construct the largest freestanding tower possible (Fig. 1b). In this activity, student teams are each given a standard kit (~100 pieces) of TinkerToys™ (a common children's construction toy) with which to build their towers.

Survival scenario: This teaming activity is unlike the other alternatives in that it does not feature a hands-on building component and instead is completely oriented around discussion. In this activity, students are presented with a fictitious scenario in which their team is stranded in a snowy, desolate area following a plane crash. The teams are presented with a list of twelve items that have been salvaged from the plane wreckage for purposes of survival (e.g., a compass, a small axe, a sheet of canvas, a ball of steel wool, etc.). Students are tasked with rank ordering the items to identify those that are most critical to survival in the harsh climate. Once students have created their individual lists, they then work with their team to create a unified list. Each team's list is compared with a list created by a survival expert; the team whose list shares the most in common with the expert's list is declared the 'winner.'

4. SYSTEMATIC SELECTION OF ALTERNATIVES

4.1 Selection decision support problem

With four alternatives ideated, the instructional team must identify the activity that offers the best compromise to the identified design objectives.

This selection decision is made difficult by the presence of multiple, conflicting selection attributes that feature varying levels of importance, varying scales, and both science-based 'hard' engineering information and experience-based 'soft' information. Mistree and coauthors propose the selection Decision Support Problem (DSP), a systematic framework for making selection decisions that facilitates the ranking of alternatives based on multiple attributes of varying importance [25]. The order indicates not only the rank but also by how much one alternative is preferred to another. The word formulation of the DSP representing selection is stated as follows:

- Given:* A set of concepts.
Identify: The principal attributes influencing selection.
 The relative importance of each attribute.
Rate: The alternatives with respect to each attribute.
Rank: The feasible alternatives in order of preference based on the attributes and their relative importance.

Other Multi Criteria Decision Making (MCDM) techniques such as a weighted Pugh Matrix or the Analytic Hierarchy Process (AHP) [26] could also be used for the purposes of making a selection amongst the activity alternatives. It should be noted that all MCDM techniques have fundamental shortcomings; one should treat them as 'attention directing tools' and carefully reflect on the results of any selection decision [27].

4.2 Selection attributes

Selection attributes are generated by reflecting on the objectives and constraints outlined in Section 2. The attributes are organized into five generalized categories: teaming, design, sustainability, engagement and retention, and general attributes. The individual attributes are presented in Table 1 along with the acronyms that will be used in the selection DSP.

Table 1. Teaming activity selection attributes

| | Specific attribute | Acronym | Evaluation metric |
|------------------------|--|-----------|--|
| Teaming | Challenges of group-decision making are present. | GRPDEC | 'My team had to resolve conflicts during this activity.' |
| | Need for conflict management. | CONFLICT | 'My team is better prepared to handle conflict as a result of this activity.' |
| | Value of multiple perspectives. | MULTPRSP | 'Having input from multiple perspectives helped our team achieve a better result than I could have achieved alone.' |
| | Value of teamwork. | TEAMWORK | 'My understanding of the value of teamwork has improved as a result of this activity.' |
| | Social connections are made. | SOCIAL | 'I know my teammates better as a result of this activity.' |
| | Student perceives themselves as 'team players'. | TEAMPLYR | 'I am a better team player as a result of this activity.' |
| Design | Participants have equivalent prior experience. | NOVICE | 'I have experience with building structures with this material' (tower-building); 'I have done this specific activity before' (survival scenario). |
| | Multiple conflicting objectives. | MULTOBJ | Pairwise comparison; preference is for presence of multiple objectives. |
| | Presence of constraints. | CONSTR | Pairwise comparison; preference is for presence of multiple constraints. |
| | Solution space is open. | MULTSOLN | Pairwise comparison; preference is for multiple potential solutions. |
| | Clear engineering context. | ENGRCNTXT | 'This activity was clearly related to engineering design.' |
| | Opportunity for innovation. | INNOVATE | 'This activity challenged me.' |
| Sustainability | Use of sustainable resources. | SUSTAIN | Pairwise comparison; Preference is for the use of materials derived from sustainable resources. |
| | Use of reusable materials. | REUSE | Ordinal scale; 1 = use of non-reusable items; 10 = all items are reusable. |
| | Use of recyclable materials. | RECYC | Ordinal scale; 1 = use of non-recyclable items; 10 = all items are recyclable. |
| | Cost of implementation. | COST | Ratio scale; Max = \$200; Min = \$0 . |
| Engagement & retention | Cooperative learning experience. | COOPXP | 'My team is better prepared for our design project as a result of this activity.' |
| | Team participation. | PPATE | 'Everyone in the team participates in the activity.' |
| | Student enjoyment. | ENJOY | 'I enjoyed this activity.' |
| | Student is part of team. | TEAM | 'I feel like I am a part of the team.' |
| | Student is excited about team. | RTNTION | 'I am excited about working with this team this semester.' |
| General | Safety. | SAFE | Ordinal scale; 1 = dangerous, 10 = safe for all users. |
| | Potential for disruption. | DISRUPT | Ordinal scale; 1 = very disruptive, 10 = not disruptive. |

4.3 Evaluation of the alternatives

As discussed in Section 2.1, workshop sections provide an opportunity for instructional experimentation. Each teaming activity alternative was implemented in eight of the 32 class workshops, thus providing opportunities for their individual evaluation. The metrics for the evaluation of each attribute are presented in Table 1.

As can be observed, several different types of scales are used to handle different points of measurements. COST is the only physically measurable attribute, and is thus evaluated on a ratio scale. The evaluations of attributes REUSE, RECYC, SAFE, and DISRUPT are based upon the qualitative observation of the designer and are rated on an ordinal scale. Three attributes, MULTOBJ, CONSTR, and MULTSOLN, are

evaluated using a pairwise comparison approach wherein the alternatives' evaluations are completed via a direct pairwise comparison based on the designers' qualitative observations.

As the majority of the attributes are predicated on student perspective, they are evaluated through a statistical analysis of student survey responses. The survey, taken on-line immediately following the activity implementation, consisted of several five-level Likert items (5 = 'Strongly Agree,' 4 = 'Agree,' 3 = 'Undecided,' 2 = 'Disagree,' and 1 = 'Strongly Disagree'). The Likert statements are presented in Table 1 next to their corresponding selection attributes.

Statistical analysis was used in concert with a pairwise comparison approach in order to convert the raw survey data into a meaningful basis for

Table 2. Pairwise comparison of SOCIAL attribute

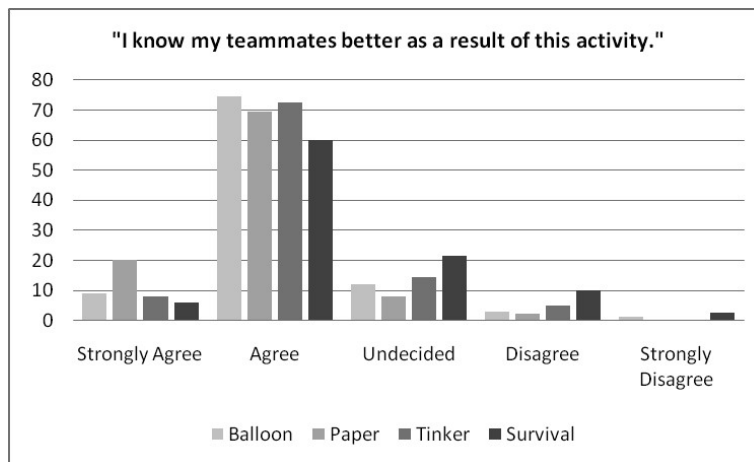
| Attributes | Balloon | Paper | Tinker | Survival | Dummy |
|-------------|---------|-------|--------|----------|-------|
| Balloon | | 1 | 0.5 | 0 | 0 |
| Paper | 0 | | 0 | 0 | 0 |
| Tinker | 0.5 | 1 | | 0 | 0 |
| Survival | 1 | 1 | 1 | | 0 |
| Dummy | 1 | 1 | 1 | 1 | |
| Sum | 2.5 | 4 | 2.5 | 1 | 0 |
| Rank | 2 | 1 | 2 | 4 | 5 |

evaluation. First, each data set was tested for normality using Anderson-Darling statistics assuming a significance level of 0.05. *P* values for all data sets were well below this level ($p < 0.005$), indicating the data did not follow a normal distribution; thus, a non-parametric test was chosen. Data from each survey question were analyzed using a Kruskal-Wallis test to determine if there were significant differences in the medians of any activity, with a significance level of 0.01. If significant results were determined, a Kruskal-Wallis Multiple Comparison method (Fig. 2) was used to determine which specific activities were significant. The multiple comparison family error rate

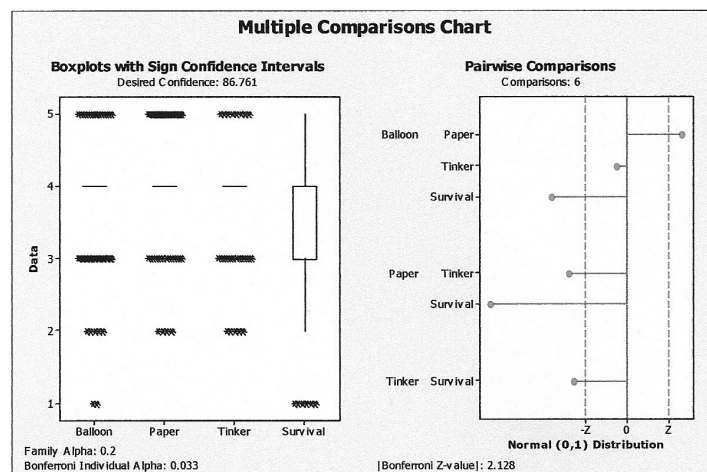
was established at 0.2, with a Bonferrini individual error rate of 0.033 for each pairwise comparison.

From the Multiple Comparison method, one can identify preference between alternatives where there is a statistical significance in the difference in their performance. From this information, one can create a composite scale centered on direct comparison of alternatives (Table 2). In this method, each alternative is compared quantitatively (1 for a significant positive difference, 0 for a significant negative difference, and 1/2 for equal or non-significant difference). A dummy attribute is introduced so that the least important alternative exerts some influence on the overall evaluation. The points are then totalled; the attribute that receives the highest score is the most preferred alternative. This method of comparison is preferred over simple ranking methods since it reflects the quantitative difference in preference.

The evaluation of the SOCIAL attribute is presented as an example in Fig. 2. Survey response data is presented in Fig. 2a. The pairwise comparison plot (Fig. 2b) shows that significant differences are found when comparing the Paper Tower (a positive difference) and the Survival Scenario (a



(a)



(b)

Fig. 2. Evaluation of SOCIAL attribute; (a) bar chart of survey responses, (b) pairwise comparisons of statistical significance.

Table 3. Evaluation of teaming learning attributes

| | Balloon | Paper | Tinker | Survival |
|----------|---------|-------|--------|----------|
| GRPDEC | 2.5 | 2.5 | 2.5 | 2.5 |
| CONFLICT | 2 | 4 | 2 | 2 |
| MULTPRSP | 2.5 | 3 | 2.5 | 2 |
| TEAMWORK | 3 | 3 | 2.5 | 1.5 |
| SOCIAL | 2.5 | 4 | 2.5 | 1 |
| TEAMPLYR | 3 | 3 | 3 | 1 |

negative difference) with any of the other activities. These differences are then related in the pairwise comparison of the alternatives (Table 2). It is concluded that, with respect to the SOCIAL attribute, the Paper Tower activity is the most preferred alternative, while the Survival Scenario activity is the least preferred alternative.

Teaming learning attributes: The evaluation of the teaming learning attributes is presented in Table 3. Generally, responses from students involved in the Paper Tower activity showed positive significant differences from all other alternatives across all teaming attributes. The opposite is generally true for the Survival Scenario. Assuming an equal preference for all attributes in this category, the order of preference (most preferred to least preferred) is found to be Paper Tower, Balloon Tower, Tinker Tower and Survival Scenario.

Significant differences aside, the majority of responses for all alternatives was generally positive across all attributes. For example, nearly 50% of students in each activity responded 'Agree' or 'Strongly Agree' to the CONFLICT Likert item regarding feelings of preparedness for future team conflict as a result of the activity. Additionally, students involved in each activity agreed that it provided them an opportunity to get to know their teammates better (at least 60% of students responded 'Agree' in each activity for the SOCIAL attribute).

Design learning attributes: The results of evaluating each alternative against the design learning attributes is presented in Table 4. Generally, the balloon and paper tower-building activities were preferred over the TinkerToy™ Tower and Survival Scenario activities with respect to design learning attributes. Student responses suggest that students did not prefer the Survival Scenario activity due to their inability to identify its relation to the engineering discipline.

Table 4. Evaluation of design learning attributes

| | Balloon | Paper | Tinker | Survival |
|-----------|---------|-------|--------|----------|
| NOVICE | 4 | 1 | 2 | 3 |
| MULTOBJ | 1 | 3 | 1 | 4 |
| CONSTR | 3 | 3 | 3 | 1 |
| MULTSOLN | 3 | 3 | 3 | 1 |
| ENGRCNTXT | 2.5 | 4 | 2.5 | 1 |
| INNOVATE | 3.5 | 3.5 | 1.5 | 1.5 |

Table 5. Evaluation of sustainability attributes

| | Balloon | Paper | Tinker | Survival |
|---------|---------|-------|--------|----------|
| SUSTAIN | 1 | 2 | 3 | 4 |
| REUSE | 1 | 1 | 8 | 10 |
| RECYC | 1 | 7 | 1 | 10 |
| COST | \$125 | \$20 | \$75 | \$0 |

Interestingly, in the evaluation of the NOVICE attribute, it is observed that a higher percentage of students reported inexperience with building structures with TinkerToys™ (18% of students responded 'Strongly Disagree' and 21% responded 'Disagree') than with paper (4.5% of students responded 'Strongly Disagree' and 17.5% responded 'Disagree'). This difference was found to be statistically significant and suggests that TinkerToys™ are not as ubiquitous as was previously assumed.

Sustainability attributes: The results of evaluating the alternatives with respect to sustainability attributes (Section 4.2) are presented in Table 5. From the perspective of general sustainability objectives, the Survival Scenario activity is ideal as its implementation does not require any resources. As such, when compared to the other activities, it is the most preferred for the SUSTAIN attribute, and receives the highest possible scores on the ordinal scales for the REUSE and RECYC attributes. The Balloon Tower activity is the least preferred for all sustainability objectives as latex balloons are not a sustainable resource, cannot be easily reused between implementations (and thus supplies must be repurchased), and cannot be recycled after disposal.

Engagement and retention attributes: The evaluation of the engagement and retention attributes is presented in Table 6. Generally it is observed that the Paper Tower activity is consistently preferred over other alternatives and the Survival Scenario is deemed inferior.

Statistical significance aside, it should be noted that response to the Likert items of this group of attributes was generally positive. For example over 60% of each activity's students responded 'Agree' or better to the RETNTN Likert item, 'I am excited about working with this team this semester.' Additionally, although the Survival Scenario showed significantly negative responses in the Likert item for the ENJOY attribute ('I enjoyed this activity') when compared to the other alter-

Table 6. Evaluation of engagement and retention attributes

| | Balloon | Paper | Tinker | Survival |
|--------|---------|-------|--------|----------|
| COOPXP | 2.5 | 4 | 2 | 1.5 |
| PPATE | 2.5 | 3 | 2.5 | 2 |
| ENJOY | 3 | 3 | 3 | 1 |
| RETNTN | 3 | 3 | 2.5 | 1.5 |
| TEAM | 3 | 3 | 2.5 | 1.5 |

Table 7. Evaluation of general attributes

| | Balloon | Paper | Tinker | Survival |
|---------|---------|-------|--------|----------|
| SAFE | 6 | 10 | 10 | 10 |
| DISRUPT | 5 | 9 | 9 | 10 |

natives, the responses were generally positive: 14% of respondents responded ‘Strongly Agree’ and 48.9% responded ‘Agree.’ Interestingly, results from a related survey statement, ‘I generally prefer hands-on activities compared to discussion-based activities,’ received a statistically significant fewer number of positive responses from those students involved in the Survival Scenario.

General attributes: The evaluation of those attributes derived from the design constraints is presented in Table 7. Generally, the activities were deemed to be safe and non-disruptive. However, the Balloon Tower activity received lower evaluations on the attributes’ ordinal scales due to the possibility of latex allergies the concern that the sounds of popping balloons would be a distraction to surrounding classes.

4.3 Evaluation of the merit function

The final step in the selection DSP is the evaluation of the merit function values of each alternative (MF_i). The merit function is based on the alternatives’ attribute ratings and the relative importance of each attribute. Specifically, MF_i is calculated using Equation 1, where m is the number of alternatives, n is the number of attributes, I_j is the relative importance of the j^{th} attribute, and R_{ij} is the normalized rating of alternative i for the attribute j . The attribute ratings are normalized since the various attributes use scales that are neither uniform nor have similar upper and lower bounds.

$$MF_i = \sum_{j=1}^n I_j R_{ij} \quad (i = 1, \dots, m) \quad (1)$$

While a designer could perform a pairwise comparison amongst the numerous individual attributes to determine their relative importance, it is assumed that each attribute carries equal preference within its generalized category. Three different scenarios for the relative importance of these attribute categories are presented in Table 8. Scenario 0 reflects the unacceptable case of no preference for the sustainability attribute; it is included to explore the effect of the sustainability

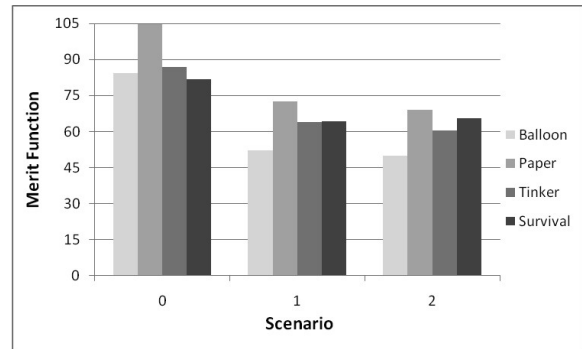


Fig. 3. Merit function values for three preference scenarios

attribute. Scenario 1 represents an equal preference for all attributes. Scenario 2 represents an accurate view of the instructional team’s preference: a strong preference for teaming, design and sustainability attributes.

The merit function values for each alternative and for each preference scenario are presented in Fig. 3. As can be observed, the preference for the Survival exercise is heavily dependent on the amount of weighting given to the sustainability attribute. The Balloon Tower, the most resource intensive alternative, was the least preferred alternative in scenarios in which the sustainability was given weighting. The Paper Tower activity is preferred over the other alternatives for all scenarios. In the case of Scenario 2, a reflection of the instructors’ stated preferences, the Paper Tower activity is preferred over the Survival exercise (by a 5% margin).

5. CLOSURE

Recognizing the potential tradeoffs in resource commitment and learning objectives for hands-on activities for courses with large enrollment, the authors approach the development of a teaming activity for a first-year introductory engineering design course as a design problem. The authors first establish the context for the activity and then identify design objectives and constraints (Section 2). Four alternatives for the teaming activity, all with varying levels of resource commitment, were then generated in a conceptual design phase (Section 3). Finally, a systematic selection procedure is employed to select amongst the activity alternatives based upon their evaluation against several attributes concerning sustainability, engagement and retention, and teaming and design learning (Section 4).

Table 8. Attribute preference scenarios

| Scenario | Teaming | Design | Sustainability | Engagement & Retention | General |
|----------|---------|--------|----------------|------------------------|---------|
| 0 | 25% | 25% | 0% | 25% | 25% |
| 1 | 20% | 20% | 20% | 20% | 20% |
| 2 | 25% | 25% | 30% | 10% | 10% |

While this analysis assisted the authors in identifying the teaming activity that offers the best compromise to the multiple design objectives of those alternatives evaluated, it is not the specific result of the selection that is of merit; the result reported in this paper is appropriate for the authors' unique context and preferences. Instead, the authors hope that the general approach to designing a design experience through systematic

selection, and the associated objectives, selection attributes, and evaluation metrics and techniques identified therein are of benefit to the community.

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