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STUDENT SYSTEM LEVEL DESIGN ACTIVITIES: AN EMPIRICAL PILOT STUDY ON IMPROVING DESIGN OUTCOMES

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ABSTRACT

Previous studies have indicated that system level design (SLD) has a positive association with the outcome of engineering design projects. However, the causal relationship has not been established. This pilot study will explore the feasibility of implementing a laboratory experiment on design process and attempt to demonstrate a causal relationship between SLD and design outcome quality.

Using outcome data from the pilot student laboratory exercise, a comparison between design processes that used SLD activities and those that did not are made using simple statistical testing methods. The results of this comparison support previous indications that SLD has an effect on outcome quality. The difficulties of constraining students performing SLD activities gave rise to an alternative method of analyzing SLD activities and lead us to conclude that our protocol is insufficient to test design process but is suitable for testing the application of a specific tool.

INTRODUCTION

In prior work, our research group studied student design processes through the use of student design journals. The journals provide a convenient method to collect data on student design processes, data which can be categorized and quantified in order characterize the design processes used. Analysis of the journal data has produced a number of startling results related to design effort at a system level (as opposed to conceptual or detailed level). Analysis reveals that system level design effort has a remarkable correlation to both design quality and productivity. Determining whether this correlation is masking a stronger relationship can not be discovered from the journal data. Further experimentation is required.

Toward that end, we conducted a pilot study with two goals in mind. The first goal was to determine whether we could design an experiment to directly test differences between competing design processes. We were confident that we could design a scientifically valid experiment. The problem was whether we could design a protocol that would constrain the students' design processes in a way that would isolate the variable in question, yet not predispose the creative process to predetermined end result. The second goal was to demonstrate a causal relationship between system level design and design quality.

This paper presents the experimental design and analysis of a pilot study designed to test the correlation between outcome and system level design activities. The article starts by highlighting the importance of system level design and results from prior work. Next, the experimental design and analysis is presented. Subsequent discussion then presents a secondary analysis that evolved from our observations into the difficulties of constraining the design process. The secondary analysis presents a system level design index used to measure the degree to which system-level design issues were addressed. The paper concludes with an interpretation of the results in light of the two goals stated above, along with plans for further experimentation and research.

BACKGROUND

Engineers spend much of their time finding a better way to accomplish a task. The better way might be faster, less expensive, or yield higher quality; but in the most ideal case, it improves all three. Finding a better way is not always easy. Methods are tested, fail in the testing, are refined and tested again, and so on until an elegant solution is found. In hindsight

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the answer always seems simple and the effort required to reach the answer is not often apparent.

The traditional design process of enlightened trial and error can be improved on. Many authors have proposed design methods aimed at improving the effectiveness of the design process. The improvements in the process typically come from eliminating wasted effort by formalizing the methods by which the understanding of the problem requirements are developed, translated to solution space concepts, and embodied in a final solution.

Some authors use what might be considered a top-down approach. Pugh [1], for example, begins his process with the development of a highly refined outline of the problem space. The outline is formalized in a document called a Product Design Specification or PDS. The PDS is then used to provide the criteria against which design decisions are made. The PDS is constantly referenced as a process of controlled convergence is used to narrow down the desired solution space. By completely understanding the product requirements incompatibilities, sloppy interfaces and configuration snafus are prevented. The nuts and bolts of the product are also designed with attention to detail using a Component Design Specification or CDS. Convergence to a single sufficient solution at the detailed level occurs by repeating a highly detailed exploration of the material and technical requirements of the solution space.

Otto and Wood [2] use many of the same tools that Pugh developed for concept selection but their emphasis is placed on idea generation to get an accurate picture of the solution space. One of the tools they use in concept selection is the Pugh Concept Selection Chart which is used to systematically refine the solution space to the final solution. In addition to concept selection, Otto and Wood include a phase of concept embodiment which deals with geometric layout, material composition, and interface compatibility issues. What makes this different from Pugh's treatment of these issues is the level of abstraction. Pugh includes these issues with detailed and technical level while Otto and Wood are using a level that lies somewhere between concept design and detailed technical design.

Similarly, Pahl and Beitz [3] have posited rules and guidelines to embodiment or system design. These rules and guidelines involve "a flexible approach with many iterations and changes of focus". This lack of specificity in the application of system design contrasts with the more rigid adherence to process that typifies design process at conceptual and detailed levels of abstraction. The many interdependencies of system level issues makes rapid convergence of the solution space difficult but perhaps those difficulties can be overcome using some of the tools developed for concept design and development. Applying a formal method to aid in making these decisions at a system level should improve design performance, but it is important to verify this theory through empirical research.

Importance of System Level Design

Common categories of design can be identified when studying design process. These categories can be broken into three areas relating to the level at which design work occurs (Conceptual, System, Detail) and four categories pertaining to the activities done at those design levels (Problem Definition, Engineering Analysis, Idea Generation, and Design Refinement) [4]. Of the three levels of design, system-level appears to be the least understood. We define system level design as: the exploration of and decisions about what the components and subsystems are and what their function will be; how the different pieces will be arranged, including location, orientation, and grouping; and how the pieces will connect or interface with other pieces, the user, and the environment in which the product with function.

The consensus within design literature is that conceptual and detailed design is necessary, well-defined, and can be successfully implemented according to a prescribed standard or protocol. However, system level design, encompassing elements from embodiment design, system architecture, preliminary design, and modularity, does not lend itself to the prescribed standards that work for conceptual and detailed design.

The limitation of embodiment design, as described by Otto & Wood and Pugh, is the purely iterative method for achieving system level design. Iterative design processes are capable of producing high quality results but typically perform poorly against productivity standards. Since standard methods for conceptual and detailed design do not rely solely on iterative design processes; can system level design be formulated to increase productivity through a less iterative process?

In prior work we have characterized student mechanical engineering design processes according to the amount of effort expended at concept, system, and detailed levels of design [4]. We have modeled the data in several ways to determine whether a correlation exists between these process characteristics and design project outcomes. In Jain's analysis [5], the proportion of project time spent at system-level design associated significantly with measures of design quality and client satisfaction. Wilkening and Sobek's [6] analysis found that raw number of person hours spent in system-level work associated positively with design quality but not with client satisfaction. Costa and Sobek's [7] analysis found strong association between system-level effort and design team productivity. Thus a theme that seems to emerge from these results is that design activity that occurs at a system level, called system level design (SLD), correlates strongly to both design team productivity and outcome quality. However, correlation does not necessarily imply causality.

In order to test the hypothesis of a causal relationship between SLD and outcome quality, a laboratory experiment was designed. The goal of the laboratory experiment was to compare student design processes that make use of system level design with those that do not. According to the indicators from the previous studies, the students using system level design would score higher on the quality of their outcomes than those

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who did not use system level design. Whether or not such a laboratory experiment was feasible was another important question.

EXPERIMENTAL DESIGN

The two goals of this experiment were to demonstrate a causal relationship between system level design and quality outcome by comparing student design processes, and to test the feasibility of laboratory experimentation on design processes. Our hypothesis is that if a causal relationship exists, we would expect to see teams using system level design activities to score higher across all measures of quality. An important aspect of this question that relates to our second goal is the ability of the experimenter to effectively direct and constrain the design process in order to constrain the team's activities without impeding their creativity.

Providing the resources required for creativity and ingenuity in the design process while maintaining a structured environment that allowed for accurate scientific results required a constrained design problem. Time limitations dictated that each group must have a fixed time during which they create their solution. The problem developed is somewhat similar to other Lego design problems, e.g. the "Bodiometer Design Exercise" [8]. Here Lego^{TM} Technics are used to transport a golf ball between locations on a variable-terrain course to a target. The problem statement given the teams was:

> Move a golf ball from a stand still in the starting area so that it comes to rest on the target ring as close to center as possible using only the materials provided. The only energy that can be applied to the ball must be stored in the materials.
>
> Points will be awarded based upon the final resting location of the golf ball in relation to the target area. The objective is to score the most points possible while using a minimum number of parts.

This exercise is a design-build problem in which the participants are given a limited amount of time during which they must design, build a prototype, and implement their design. During their implementation a score is assigned based upon the accuracy of their design and the number of component parts used.

The students completed the exercise in teams of two. Teams were randomly assigned to the experimental group or the control group. Both groups followed the same protocol except that the experimental group is asked to complete activities designed to emphasize SLD. Both groups were restricted to a total design-build process time of 75 minutes. An additional 15 minutes was allocated for a familiarization exercise to introduce the participants to some of the functionality of the Legos. While both groups only had 75 minutes of design-build time, the allocation of that time differed between the experimental group and the control group. The time allocated to the experimental group for design was extended by 10 minutes to allow time for the system level design activities required. In order to maintain an equality of times between the experimental and control groups, 10 minutes was removed from the build time of the experimental group (see Appendix for Table 1). Our prior work suggests that work done on system level issues would allow for a more efficient convergence to a solution, thereby requiring less time for building the prototype.

Each design team was responsible for turning in a set of deliverables. The deliverables required were sketches of concepts considered, the criteria used to make the final selection, and the final concept selected for prototyping. Once the concept was selected the team prototyped that selection.

The teams that participated in the exercise were composed of Mechanical Engineering students enrolled in ME 403 Mechanical Engineering Design I. This course is structured as a design project experience emphasizing use of a formal design process, presentations, and documentation. The course also includes coverage of industry machining and welding practices. Each team was comprised of 2 members. There were 7 teams in the control protocol (no SLD emphasis) and 8 teams in the experimental protocol (with SLD emphasis). Table 2 summarizes the participant demographics.

Table 2 – ME 403 Participant Demographics

	Number of Participants	Average Age	Average GPA
Male	30	22	2.82
Female	2	21	3.2
Cumulative	32	22	2.84

The exercise was implemented as according to the script attached in Appendix B. The script was followed rigorously. No significant deviations from the planned protocol occurred. However some of the groups did not need the full 5 minutes for reading the problem statement and examining the set-up. At any time the groups could ask for clarification on any rules or the problem but typically they would only ask during the speech when called upon for questions. The phase began at the end of the scripted segment with the verbal announcement of time remaining and a written time on a white board in clear view of the students. The time on the board would be updated at 5 minute intervals. A verbal warning of 5 minutes and a reminder of the deliverables required at the end of the period was always given to accompany the written time remaining on the board. With 2 minutes remaining, a final verbal warning was issued and when time expired all activity was brought to a halt. All but two of the groups completed the prototype build session before time had expired, which indicates that sufficient time was allocated for the design problem assigned.

During the final test the accuracy score was gathered using the final resting location of the ball. This was judged based upon the ball's contact point with the surface of the target. If the design precluded the ball's contact with the target a judgment was made based upon the ball's center of mass projection down onto the target. Once the final test began no pieces could be added to or removed from the design. After the completion of the three accuracy runs two counts were made of the pieces

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used in the design. These counts were conducted under the supervision of both team members and the experimenter.

RESULTS

The outcome variable was constructed for analysis by normalizing the accuracy score and the piece count score and then averaging them together. The accuracy score was normalized on a 0 to 1 scale with 1 being the best score possible. The piece count score was normalized on a 0 to 1 scale with 0 being the best score. Then that score was subtracted from 1 to rescale it so that 1 was the best score. Normalized accuracy and normalized piece count could then be averaged since they were on the same scale. This new composite score is then used as a response variable in a 2 factor ANOVA. We chose a 10% level of significance due to the interaction with human subjects.

The first set of tests performed on the data was to test for adequacy of the normality assumption and whether any outliers existed. A normal probability plot was used to check adequacy assumptions on the accuracy scores, the piece count score, and the composite score. No values were found to be outliers and the lowest R^2 value was 0.96 on the regression test.

The second test was on the equal variability assumption. In order to test this assumption a two-sample F-test for variances was used. The p-value for the test on the composite score was 0.3976 so it was concluded that the variability between the control and experimental protocol was equal. This means that the response variable was appropriate for testing the means for equality. This test was also performed on the accuracy score and the piece count score. It was concluded that both accuracy and piece count scores also had equal variability and could be tested for equality of means.

The equality of the means was tested using both the standard two-sample t-test and the ANOVA test for means. These tests were performed on both the accuracy and piece count scores in addition to the composite score. The composite t-test resulted in a p-value of 0.2675 and the composite ANOVA in a p-value of 0.3540. These p-values force the conclusion that no difference in scores exists between the two protocols tested. The accuracy and piece count p-values were 0.5591 and 0.2834 respectively. See Table 3.

Table 3 – t and F-test results summary

	Accuracy	Piece count	Composite
Control Mean	0.511	0.305	0.452
Experimental Mean	0.635	0.473	0.563
p-value t-test	0.559	0.283	0.354
p-value F-test	0.246	0.474	0.397

Since the experimental data showed no difference, it appears on the surface that system level design activity had no impact on the outcome of the exercise. However, a closer look at the deliverables collected during the exercise and the observations recorded by the experimenter revealed that some of the teams in the control group, with a protocol that did not emphasize system level design activities, actually did system level design or considered system level issues. Conversely, a number of teams in the experimental protocol failed to adequately complete or even attempt the system level design activities as specified by the protocol.

This means the exercise failed to sufficiently affect or limit the design process with regards to system level design. The results indicate that we were not able to design an experiment to test differences in design process. Some students did system-level design even when not prompted to do so, while other students did not attempt system level design even when prompted. This came as a surprise since previous studies had indicated that very few students performed SLD naturally. Since SLD had not been explicitly taught to the students, we were not expecting the control group to perform SLD. Of even greater surprise was the failure of experimental groups to perform SLD even with prompting.

Post-analysis - System Level Design Index

Since system level design activities were not limited to the experimental groups, a new classification system was designed to measure the degree to which groups performed design work at system level. One measure of SLD effort is the number of system level issues that each group addressed during the design phase of the protocol. This could be further refined to include system level design work done only on the concept selected for prototyping. Thus, two measures of system level design effort have been created and might provide a measure of correlation between system level design and outcome.

In order for system level effort to be recorded, it is first necessary to identify all system level issues that the groups addressed during the design phase. The documentation collected from the students and the experimenter's notes were combed, and four different problem solution concepts were identified. They were a dragging device, a rolling device, a sliding device, and a carrying device. For each of these concepts, four to six system level issues were identified. While some of these issues were shared by all of the concepts, e.g. "Activating the device in such a way that starting the ball in motion will interface smoothly with other aspects of the concept," some of the issues were found in only one concept, e.g., for the sliding concept, "Was the clearance requirement of the ball/device interface considered?". These issues are consistent with our definition of system level design, and are typically not considered conceptual or detailed level development. For example a group may generate an idea for an activation device and a separate idea for transitioning from the starting area to the target. The interface between the two separate ideas can pose its own problems that are separate from the overall concept. If the system level issue is not addressed in the design phase it must be dealt with in during the build phase, which often results in iteration.

Once the criteria for system level design issues had been established, each group was analyzed. The analysis was done on system level design activity for the selected concept only, and on system level design activity for any concept. A numeric score, the system level design index (SLDI), was calculated for each group based on the number of system level design issues addressed in course of design. The SLDI, then, is a measure of the degree to which the teams pursued system level design. Three linear regressions then compared the SLDI with the composite score, the accuracy score, and the piece count score.

The resulting R^2 values, Table 4, offer interesting insight into the association between system level design and design outcome. The variance explained by the SLDI on the selected concept is good for the cases of the composite score and the accuracy score. In both these cases the p-value for the coefficient indicated a significant result. The piece count score falls outside of the significant p-value level of significance (LOS = 0.10). The variance explained by the SLDI on all concepts reveals mixed results. The strong R^2 in accuracy is contrasted by the poor R^2 on the piece count element. R^2 value for the composite score is weaker than the accuracy score but still suggestive. The p-values for the composite score and the piece count score do not indicate a significant result.

Table 4 – Descriptive Stats from the Linear Regression Analysis on SLDI

	SLDI on selected concept		
	Composite Score	**Accuracy Score**	**Piece Count Score**
Intercept	-0.393 *	-0.713 ***	-0.073
Slope	1.239 ***	1.819 ***	0.659
R^2	0.589	0.720	0.166
n	15	15	15
	SLDI on all concepts		
	Composite Score	**Accuracy Score**	**Piece Count Score**
Intercept	0.047	-0.346	0.441
Slope	0.062	0.131 ***	-0.007
R^2	0.170	0.428	0.002
n	15	15	15

*** p-value < 0.01

** p-value < 0.05

* p-value < 0.10

System Level Design Index Results

These R^2 values do not indicate a causal relationship between SLDI and outcome. However, the results are suggestive of correlation and support the need for further study. The primary question raised is why is there such a disparity between the R^2 values of the selected concepts and all concepts. In every case, there is a significant difference between the two measures of system level design effort.

One explanation for why the accuracy score may have improved with increased system level design effort from the selected concept to all concepts is that for the selected concept only the issues specifically needed for creating solutions to areas with system level issues are included in the index. This means that rejected ideas or ideas adopted from other conceptual consideration are neglected in the analysis. Thus a team that came up with one concept may be indexed no differently than a team that fully explored 3 concepts and narrowed down to their 'best' choice. When all concepts are included in this index, the team with 3 fully explored concepts does have a stronger correlation to higher quality outcomes when comparing composite score and accuracy score. However, the reverse is true for the piece count score.

If teams addressing more system level design issues across a wider range of concepts scored better than teams that focused on system level design issues for fewer concepts, why would the piece count scores for those same groups be that much worse? The answer to this question might lie in the nature of the design requirements. The requirements of maximum accuracy and minimum component part usage are in most cases conflicting requirements. Each team must address how to prioritize these requirements. The problem statement doesn't explicitly state that equal weight would be given to both the accuracy score and the piece count score. In light of this ambiguity, it is possible that teams chose to prioritize these requirements differently.

Many of the teams that chose between multiple developed concepts seem to have prioritized the accuracy more so than the piece count requirement. This is supported by comments by the teams in the criteria section. These teams base their decision on the expected accuracy of their solution and make no mention of the piece count requirement. While some of the teams didn't mention the component piece count requirement, every team mentioned the accuracy requirement! This leads to some suspicion as to the appropriateness of the prior analysis since the problem statement did not clearly direct the students as to the intended distribution of the requirements. This has a strong impact on the data obtained since there is no way of knowing the full impact on the teams during their design process.

These results are difficult to relate to the previous results regarding design iteration. Because the groups seemed to focus exclusively on quality, as measured by accuracy, rather than the productivity, as measured by piece count, the results show a positive correlation between system level design and quality but no correlation between system level design and productivity. This failure to demonstrate correlation between productivity and system level design is the result of method of experimental implementation. Since the original experimental design did not sufficiently constraint the variables to obtain an accurate productivity result, we turned to SLDI to provide insight into our research objective. From SLDI we learned a method of providing measurability to system level design activities in an experiment and we provided additional supporting evidence to the relationship between SLD and outcome.

CONCLUSION

The first goal of this pilot study was to determine whether it is possible to design a laboratory experiment to test design process. We found that the experimental protocol we designed was insufficient in constraining the design activities of the students. We observed control groups actively pursuing SLD without prompting and experimental groups failing to emphasize SLD even with prompting. The inability to impact the design process choices of the students in a controlled manner without stifling the design process lead us to conclude that controlled experiments to test the design process elements are extremely difficult. Based upon those same observations

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and our experiences with the SLDI analysis, we feel that a laboratory experiment is an ideal environment to test the effect of a specific tool on the design process.

Analytically the results of this study are moderately good for the second goal of the pilot study, to determine if a causal relationship existed between system level design and outcome quality. No causal relationship was found between system level design activity and outcome measures. The expected correlation between the two was difficult to recover from the experimental design as it was implemented. It is important to note that the failures of the experimental design lead to the development of an alternative analysis method (SLDI). The analysis based on SLDI lead to further support of SLD having a strong positive association with the quality of outcomes. The results from the system level design index are promising and have introduced a new method of studying system level design. We believe that the failures and successes of this pilot study provide an important basis for future work on system level design issues.

Our immediate plans are to test whether system level design can be used in design process to improve design quality through the use of a specific tool. This tool was constructed using the lessons of this pilot study and was adapted from a morphological design tool coupled with a functional decomposition analysis. This kind of tool is usually used in conceptual development activities to aid in concept selection and idea generation. However, this tool is suitable for adaptation to system level design evaluation.

The next step is to implement the redesigned experiment to test the effectiveness of the proposed morphological tool in effecting outcome quality, rather than the correlation of the broader system level design concept itself. This experiment, ongoing at the time of submission of this paper, should demonstrate the effectiveness of a specific system level design tool on the quality of outcomes on student designs.

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Appendix A: Table of Group Protocol

Table 1 - Group Protocol Overview

Phase	**Control**			**Experimental**	
	Activities	**Time**		**Activities**	**Time**
Familiarization	Handle the parts Guided assembly work	15 min.		Handle the parts Guided assembly work	15 min.
Problem Statement	Read about and look at set-up	5 min.		Read about and look at set-up	5 min.
Design	*No handling of parts!* 1. Generate ideas 2. Sketch at least 3 promising ideas 3. Select best idea for prototype *Deliverable*: 3+ sketches, winner, & criteria	20 min.		*No handling of parts!* 1. Generate ideas 2. Sketch at least 3 promising ideas 3. System-level work on alt's 4. Select best idea for prototype *Deliverable*: 3+ sketches, winner, & criteria	30 min.
Prototype & Test	Build and test selected idea	40 min.		Build and test selected idea	30 min.
Demo	Three trials	10 min.		Three trials	10 min.
	TOTAL TIME	**90 min.**		**TOTAL TIME**	**90 min.**

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Appendix B: Experimenter's Script

Experimenter's Script

Purpose Speech – given at the beginning as an introduction to what this is

Good morning/afternoon/evening, my name is Joshua Ruder and I've been working with Dr. Sobek's research group in an attempt to get a better understanding of Student Design Processes. We have some interesting initial results and have been looking at ways of applying these finding into the class room. This lab exercise is a key step to doing this.

We hope you come away with some more hands-on experience with the design process, while at the same time seeing how emphasizing different aspects of the process can lead to different outcomes. Today we'll be looking at just one process but when we report the results in class you'll be able to see the results of different process after everyone has had a chance to run through the exercise.

Do you have any questions before we get started?

Guided Assembly Instructions (verbal) – given at the start of the familiarization stage

To give you an overview of what you'll be doing today let me say that we'll start by giving you a design problem. You'll design a solution, prototype, and test it. Materials will be provided to you now for a brief familiarization and again when you build your prototype. However while you are designing your solution you won't have access to the materials.

To familiarize your group with the materials, take 15 minutes and play with the parts. During that time I'll ask you to build two modules. The first module will be a wheeled frame capable of rolling a short distance (think car frame). The second module will be an adjustable armature that can be "locked" into place. After you have completed that, please use the remaining time to experiment on your own. Any questions?

Problem Statement – handed out

> "Move a golf ball from a stand still in the starting area so that it comes to rest on the target ring as close to center as possible using only the materials provided. The only energy that can be applied to the ball must be stored in the materials.
>
> Points will be awarded based upon the final resting location of the golf ball in relation to the target area. The objective is to score the most points possible in 3 runs while using a minimum number of parts."

Now that you've read the statement lets take a closer look at the course. As you can see the starting area is a raised landing overlooking the target area. You'll have to start the ball from rest, navigate the drop, and bring the ball to rest in the target area. There is no time limit on this process. However, remember that only energy that can be stored in the materials can be applied to the ball.

Are there any questions?

Design Introduction (A control) – given at the beginning of the design stage

This first step will be the design stage. Here you will be designing your device but won't have access to handle the materials. During the next 20 minutes you should generate as many ideas as you can. Then sketch at least 3 of the best ideas you come up with. From these 3 or more sketches you should select the best choice for prototyping which will be the next step.

At the end of 20 minutes you need to be able to provide the sketches, your winning choice, and the criteria you based your selection on. Any questions?

Design Introduction (B experimental) – given at the beginning of the design stage

This first step will be the design stage. Here you will be designing your device but won't have access to handle the materials. During the next 30 minutes you should generate as many ideas as you can. Then sketch at least 3 of the best ideas you come up with.

Once you have gotten your sketches of the promising solutions done, think about the configuration of each alternative: 1) could you implement the concept with a different configuration? 2) Which interfaces are crucial to the design? What is an alternative way to make these pieces interact? You should ask yourself either 1 or 2 for each conceptual sketch. So for each of these sketches you should develop at least 2 different approaches to accomplish the same concept. For example if you were to design a parachute areas of interfacing might be the straps to hold the person to the pack, the cord to activate the chute, and the lines to attach the chute to the pack. Then maybe an alternative to using a cord to activate the chute is to use a button. Questions?

Once you have studied the configuration issues and possibilities for each solution, let me look them over briefly. Then I'll ask you to select the best option for prototyping, including which alternative would work best.

At the end of 30 minutes you need to be able to provide sketches of the 3 best ideas, documentation of your configuration study, your winning choice, and the criteria you based your selection on. Any questions?

Prototyping Introduction – Given at the beginning of the Prototype and test stage

Now that you have selected your design it is time to build and test a prototype. During the next 40 minutes (30 for experimental) you have free access to the materials and the testing area. At the end of the time you need to have a working prototype for use in the final stage as well as a piece count for the number of pieces you used (be sure to include the rubber band and string if used).

Demonstration Introduction – given at the beginning of final testing

For this next stage you will demonstrate the capability of your prototype. Let me quickly review the scoring rules:

> "Points will be awarded based upon the final resting location of the golf ball in relation to the target area. The objective is to score the most points possible in 3 runs while using a minimum number of parts."

Be aware that while you may reset or rebuild your design after a trial no additions or changes to your design are permitted at this stage. Let me know when you are ready to begin.

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