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INFLUENCE OF GROUP COHESION AND INFORMATION SHARING ON EFFECTIVENESS OF DESIGN REVIEW

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ABSTRACT

Research into group decision-making suggests that, dependent on the information distributed prior to a group discussion, the decision and discussion content can be predicted. While the impact to group decision-making has been studied, its impact on collaborative activities such as design review has not been well investigated. A full factorial design of experiments (3x3, DOE) is conducted to investigate the influence of group cohesion and the awareness of the presence of unshared information among group members on design review effectiveness. The results suggest that awareness may have an effect on locating design issues by representation, functional group domain, and the total amount of design issues located.

1 INTRODUCTION

When designing a product, how is it known that the product will be successful in application? Does the product meet customer defined functions, robustness, and/or quality? Is it done so at a minimum of cost and risk? Answering these questions and others are primary motivations for conducting product design reviews. Design reviews, as typically found in industry, are collaborative activities done to eliminate (or reduce) risk during the various stages of the design process; or, more formally, "a method in which to select and evaluate a given design or solution" [1]. When "product time to market" is compressed, which is often the case to remain competitive, outperform the competition, and establish a hold on the market, mistakes are often made early in a design which can have a large impact on manufacturability, function, quality, and ultimately the cost of a product [2]. It is well known that 70% of the product's total cost is determined in the design stage which consumes only 5% of the total cost [3].

Therefore, design review effectiveness is chosen as a variable we wish to influence because of its impact (especially monetary) during product design. Based on previous research of group decision-making, which is one of the fundamental functions of design review, two variables are identified as having a potential impact on group decision quality [4, 5]: Group Cohesion and Awareness of the presence of unshared information. Group Cohesion is used to evaluate and introduce issues related to group dynamics. Awareness of the presence of unshared information is used to alter the discussion of information sharing activities within the group.

Researchers have found that information common to the members of the group (shared) will be discussed and can have an impact on their decision preference (initial preference) [6]. With that said, only information that is not common to all members (prior to meeting), unshared information, has the power to change the groups initial preference [7]. If unshared information is not presented, a meetings content would be the discussion of information already known. If the ratio of common to unshared information is very large, the likelihood of the unshared information being discussed is low. Thus members of the group tend to focus on their initial preference, rendering the meeting uneventful [4]. Therefore, to maximize the use of the collaborative activity (information sharing), members should not have homogenous prediscussion preferences [4].

More formally, we hypothesize that a high level of awareness by the group members of the presence of unshared information within the group would increase information

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sharing activity and thus raise the effectiveness of the review (improve decision quality [5]). The research in group decision making has tended to focus on simple decision making tasks [6,8]. Design reviews, however, tend to be more complex with many different decisions being addressed simultaneously by individuals from varied backgrounds thus making this research an extension of experiments done in the past.

In addition factors (group cohesion and politics) introduced by those participating in collaborative activities are known as group dynamics. It has been reported that group cohesion can affect information-sharing activities within a group [5]. Research into group dynamics suggests that highly cohesive groups can have a negative impact on group decision-making and thus, possibly, affect design review effectiveness as well [9, 10]. A condition arising from high group cohesion has been classified as "groupthink", in which a highly cohesive group of individuals can lead each other away from rational decision-making and ultimately make decisions that a single individual would never choose [9].

Given that design review activities are collaborative decision-making processes, we wish to improve their effectiveness as they ultimately make a large impact on product design. Presented in this paper is the motivation, methodology, and results of an experiment to investigate design review effectiveness. The paper begins with a background on the fundamentals of design review, the impact of information sharing on group decision-making, the issues of problem representation during design review, and group dynamics. This is followed by the procedure, data, and results of an experiment aimed at improving design review effectiveness. Discussions conclude the paper.

2 LITERATURE REVIEW

A review of relevant literature discussing design review, information sharing, problem representation and group dynamics are is provided to give a foundation to explain the motivation for the experiment presented.

2.1 Design Review

As stated in the introduction, design reviews are, "a method in which to select and evaluate a given design or solution" [1]. In product design, the design review plays a large role in ensuring that the product being developed meets all the requirements of the parties involved in the product's design, as this is the primary objective of the review. They are used to identify conformance to specific requirements, diagnose problems and failure modes, and perform continuous improvement operations [11]. Other operations of a design review can include inspecting and evaluating a design, and discovering problems that would otherwise have not been apparent had a review not been conducted [11]. The objectives of the review may include inspecting a design for cost, manufacturability, or robustness.

Traditionally, design includes several iterative and corrective steps throughout process (Figure 1). These steps alternate between synthesis (Solution Search and Information Collection), analysis (Evaluation and Optimization), and decision-making (Error Identification and Optimization), providing feed back to the engineering designer about the direction that the design is taking [12]. Complications may arise as many of these actions are performed concurrently, some steps are repeated after additional information is generated, or modifications of one design aspect may influence other aspects. Essentially, design reviews are evaluation tools that provide some guidance in subsequent design synthesis. Considering this traditional design process cycle, the design review most appropriately may be found in the evaluation and decision making steps.

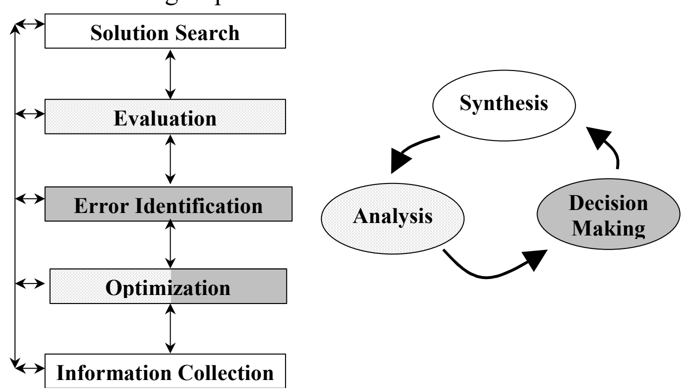

Figure 1: Iterative and Corrective Steps in Embodiment Design (adopted from [12])

Design reviews are generally conducted in multidisciplinary teams of stakeholders with design tools that are used for evaluation. They are conducted at various times during the design process such as after the conceptual design and embodiment stages [13]. A common tool used in design reviews is a checklist [1]. This tool allows the participants of the review to systematically follow the checklist and check for conformance between the design and the customer derived product design specification (PDS). The PDS is a document, which records the primary design function, design constraints, and design criteria. A strong conformance suggests that the design is sufficient to proceed in the design process to eventually becoming a manufactured product. Other types of tools used in design review can evaluate a design for assembly, manufacture, strength, and/or conformance to customer requirements. Other design review methods exist that allow the selection of several designs generated during initial concept generation phases of the design process. These methods can exist as matrices that allow the systematic ranking of designs based on conformances to prescribed requirements, such as those generated in a PDS [2].

Design reviews can require the input from experts in all aspects of a product's design. The experts can exist as the customer, development team, manufacturing team, suppliers, and other functional groups associated with taking a product to market. Synchronous collaborative input from several functional groups is able to develop a more accurate view of the design artifact. This is due to the larger information and expertise base, influence of superior decision making from interacting groups, and the checking of errors and rejections of flawed suggestions [14].

It is necessary for product team members with the appropriate expertise to be present during design reviews. Pugh suggests identifying the members of these processes by listing the characteristics of the design and identifying the resources needed for the characteristics to be discussed [15]. An example would be if a new product is being reviewed for conformance to customer desired function, areas such as ergonomics and legislation need not be considered during the review. By utilizing this method suggested by Pugh, parties with the appropriate expertise could be correctly identified for the review, assuming that one knows which parties carry which expertise.

Many tools exist to aid the participants of a design review in obtaining their objective. The tools created typically serve for one of two distinct functions: evaluating new concepts and auditing a current design such as redesign of a current product [16]. Evaluation and design selection tools are used to identify and rate the most appropriate design solution created during the novel design or idea generation processes. As mentioned earlier a matrix that enables a systematic rating of designs based on conformances to prescribed requirements is an example of an evaluation tool [2].

Audit tools are used to quantify, verify, initiate, and justify changes in a design. An audit tool such as the previously mentioned design review checklist allows the participants of the review to systematically check for conformance between the design and the PDS. Other types of audit tools, typically classified as “design for X” tools, seek to identify and verify conformance to certain objectives such as design for automated assembly, customer, manufacture, injection molding, robot assembly, manual assembly, and robustness [17]. These audit design review tools identify and justify changes before a design advances to the manufacturing phase. However, it is often the case that when multiple DFX tools are used in conjunction they can have an inverse relationship and therefore improvements in one area may have a detrimental impact on another. It is important in the application of the tools to prioritize them in importance to your particular application. Developing these trade-offs for design decisions is an important issue, but is considered out of scope for this investigation.

2.2 Information Sharing

It is design review effectiveness that we wish to study in the course of this experiment where information sharing has been selected as a variable that perhaps can have a positive effect [5]. It is necessary to look at some of the fundamental operations of design review and their associated parent-child relationships with information sharing. During this exercise we want to alter those variables that possibly affect design review effectiveness. Therefore, identifying those variables begins with a theoretical decomposition of what occurs during design review.

We argue that information sharing is a root issue in influencing design review effectiveness. Design review effectiveness is dependent upon the design review method or tool that is used. Some examples of design review tools might include Failure Mode Effects Analysis (FMEA), design review checklists, or design for X tools (DFX). Most design reviews are conducted in a collaborative environment, where the cognitive activities involved in collaboration must be examined. The collaboration focuses on group decision making. Research suggests that a key aspect of the collaborative cognitive activities is information sharing. Therefore, information sharing is likely an influencing factor of design review effectiveness.

It has been suggested that in order to influence the quality of the group decision, information that is unique to each member of the group must be discussed and pooled [4]. Otherwise groups have a tendency only to discuss information that is common, thus negating the purpose of the meeting [6].

In addition researchers have found that the awareness of the presence of unshared information has had a positive impact on information sharing thereby affecting decision making [5], design review tool output, and ultimately design review effectiveness (working Figure 2 from inside to outside).

In order to foster better group decision-making, groups should not have uniform pre-discussion preferences, where their bias is based on information received prior to the meeting of the group [4]. Having a non-homogenous distribution of information can possibly alter the presence of group initial preference and aid in information sharing activities (due to the awareness of the presence of unshared information), thus providing more informed decision making activities.

However, just as important as information sharing is how that information is presented and interpreted by members of the design review team. Perhaps information remains unshared because a particular member was unable to interpret it. This leads to issues of design representation.

2.3 Design Representation

How design information is represented to members conducting a collaborative design review can be important as interpretations of data could be affected thus limiting or improving the effectiveness of design review. In a study conducted to determine the influence of design representation on the effectiveness of idea generation, it was identified that graphical representation provided greater benefits for engineering idea generation [18].

Sketches allow for faster processing of information compared to information represented in a textual form. Other benefits in representing the design problem in a graphical sense are they aid in the understanding of the idea, the idea is more concisely represented, and graphical solutions are easier to evaluate. The role of sketching in design was also discussed in which sketching accounts for 67% of all that is drawn over the course of design [18].

Similar findings in regards to visual representation were had in the development of an idea-generation tool called "C-Sketch" [19]. It was noted that in the protocol studies that sketches accounted for 72% of the marks made on paper during the design process [2]. This is again due to the conciseness and simplicity of data representation over written sequential statements [19]. Visual representation also offers the ability of better relationship recognition based on the placement of information in the sketch. The spatial placement that sketches provide is an advantage over sequential statements as the information is conveyed to the reader in a serial format and if the information is sorted in a group of sentences the relationships are lost [19]. Thus, one would expect that a higher percentage of problems represented visually (both graphical and symbolic) would be found during design review over problems represented by text or numeric characters.

2.4 Group Dynamics

Two factors that can negatively affect group collaborative decision-making are high levels of group cohesion and group politics [9, 10]. The combination of high levels of group cohesion and considerable pressure to reach a decision has been classified as "groupthink" and appeared as a concept in the early 1970's, [9]. An example of the impact of groupthink is the 1986 space shuttle Challenger disaster due to brittle failure of O-rings at below freezing launch temperatures [9]. NASA officials allowed a launch despite strong evidence that serious safety concerns were present.

When a group has members that are highly cohesive (lack of conflict, strong personal relationships), eight symptoms can result, describing the conditions of groupthink [9]: an illusion of invulnerability (groups are led to believe they are incapable of error and they avoid obvious danger signs), rationalization of poor decisions, belief in a group morality (proving safe rather than unsafe), negative stereotyping of outsiders, pressure on dissenters, pressure to conform, illusion of unanimity, and mind guarding. Suggested corrective actions for avoiding groupthink include impartial leadership (treating all subordinates in the same manner), using outside experts to challenge the decisions of the group, and the use of policy forming groups to regulate the larger group.

As a result of the Challenger catastrophe NASA now requires sign-off by up to twenty individuals certifying launch readiness of individual components. The theory is that breaking responsibility into subgroups will allow for a more free expression those with dissenting opinions without the presence and pressure of the entire group. Essentially, this is a design review with a single decision or launch or not.

Group political factors can also play a negative role in the group decision-making process. Group members may feel suppressed due to the presence of a particularly assertive or outspoken group member; therefore, limiting the amount of unshared information sharing for a well-informed decision. Superior group members can influence other members of the group given the power of authority instilled in that particular member. Groups may also decide on extreme points of view (a point of view that perhaps no individual would support on his or her own) if an appreciable element of risk is involved [9].

Group initial preferences can also carry powerful social implications with respect to group dynamics. The quantity of similar preferences can have a social influence on the other members of the group, as majorities can often sway others to their position [20]. These social pressures can come from heuristics of fairness in which the majority wins therefore affecting a possible decision due to the influence of the majority [20].

3 USER STUDY

This investigation is conducted via a controlled user study. The user study research method allows researchers to identify specific variables of interest and observe the impact on the result of varying that factor. These variables are used in a research method called design of experiments to assess specific influences in a controlled environment that simulates portions of real situations. This is in contrast to protocol studies, which are used to observe processes or procedures. This study did result in statistically significant results in addition to qualitative observations. Popular user study methods include surveys, focus groups, interviews, observation, and diary methods [21].

The effects of group cohesion and the awareness of unshared information on design review effectiveness are investigated. In order to determine the presence of any significant results a full factoral design of experiments approach for experimentation is employed. This classical approach is more intensive than other DOE methods such as Plackett-Burman, Fractional Factorial, and Taguchi Orthogonal Array but it offers the highest accuracy for statistical significance since it separates main effects from interaction effects [22]. The design of experiments employed in this study uses two variables (group cohesion and awareness of unshared information) each with three levels of variation (low, mid, high). This requires nine experiments. In order to obtain statistical significance, each experiment is planned to be repeated a minimum of three times (actual replications varied due to participant absenteeism). Using 150 sophomore level mechanical engineering students in groups of four from an introductory design course, a total of 34 experiments were performed.

Each design team member receives varying amounts of information based on that design teams' specified level of awareness (Factor 2). The members of each team are also chosen based on the level of group cohesion required (Factor 1). The design artifact for review is a self-propelled lawn mower mechanism where the design content is found in four packets of information. The packets correspond with the functional groups: development, manufacturing, purchasing, and document control. The types of documents found in each of the functional group packets are illustrated in Table 1. On the day of the exercise a single document is generated by each team that is used to evaluate the effectiveness of the design review.

Table 1: Document Type and Contents

	Development	Manufacturing	Purchasing	Document Control
Bill of Materials (BOM)				X
Component Drawings				X
PDS	X			
Process Flow		X		
Assembly Drawings		X		X
Component Costs			X	
Release Report	X			
Foreign Content			X	

3.1 Participants

The participants of the design review experiment are selected from a sophomore level mechanical engineering design course. Their expertise in design is limited, as the material taught in class is their first exposure to elements of the engineering design process. Therefore, an additional goal of the experiment is to further develop the students understanding of the design and design review process. Since the participants of the exercise have not previously performed a design review, they are provided via a training session on design review. The training is used to ensure they would all be capable of conducting a design review, thus putting all participants on a common level of expertise with respect to conducting a design review. Further, this training session, across five course sections, is conducted by the same person in an attempt to create a common frame of reference. In this manner, we have attempted to ensure a uniform understanding of design reviews in the participant pool.

The design review training includes the following topics: what a design review is, how they are conducted, when they are conducted, why they are conducted. The classes then conduct a practice design review in evaluating and identifying problems with a children's toy in order to solidify what was taught during the lecture. The children's' toy is the design of a block type toy. An illustration of the toy can be seen in **Error! Reference source not found.**. The design review tool used in this exercise is the same tool (checklist) that is used during the experiment. The design review checklist included criterion: function, working principle, layout/form design, safety, ergonomics, production, assembly, and cost. Each criterion is associated with a question, such as: "Is the stipulated function fulfilled?".

The participants in this exercise are all mechanical engineering students. We recognize that this homogeneous group is not ideal in a design review setting. We argue that it is acceptable in this exercise as the problem was designed to require no outside resources or technical knowledge beyond the material taught in the participant's design class. Therefore there are limitations to the conclusions that may be made given that the body of participants are all engineering students (which may not be representative of all design review groups). Based on the results of this exercise further evaluation should be conducted using groups of various backgrounds.

3.2 Evaluation Measures

Measuring design review effectiveness can be interpreted in many different ways. One could evaluate the state of participant being after the design review (how he or she felt). One could also look at the total number of problems identified and/or the level of difficulty of problems identified. One could evaluate the amount of information sharing during the review. For objective purposes, the count of problems identified is employed here as this would allow a consistent approach in measuring the output of all the groups.

In order to have an objective approach to the measurement of design review effectiveness and to provide useful information to a wide audience in regards to how design reviews should be conducted in the future, four main areas are investigated. These four areas included: representation type, implicit/explicit nature, functional group, or quantity identified.

Problem representation was broken into four main groups:

- Text: problems represented by strings of text, such as manufacturing procedures, or design features
- Graphical: problems represented by pictorial representation, such as assembly or part drawings
- Numeric: problems represented by numeric characters such as part numbers, quantities, or specifications
- Symbolic: represented by means of symbols, such as figures generated in sketches.

Design Review Checklist

Instructions: Consider the criteria below, and record all design inadequacies found during the design review. Problems may be identified which do not fit these categories, and some categories may have no design problems. Use additional paper if necessary.

Criterion	**Check**
Function	Is the stipulated function fulfilled? *Colors are not noted on the drawing so the end product may not meet this part of the intent. Some blocks can fit into multiple holes.*
Working Principle	Does the chosen working principle produce the desired effects and advantages? *Not exactly a "working principle" problem, but the hinges are not well defined on the drawing. Fixation and details of the hinge design are not given.*
Layout/ Form Design	Do the chosen overall layout, component shapes, materials and dimensions provide: • adequate durability (strength)? *Acceptable* • acceptable wear with the stipulated service life and load conditions? *Acceptable*
Safety	Has operator safety been considered? *No – Material (hardness) is unsafe; sharp corners are unsafe, small block are unsafe*
Ergonomics	Have unnecessary human stress and injurious factors been avoided? *Stress is not an issue – see above for injurious factors.*
Production	Is the information specified in the drawings [MSOffice1]sufficient and accurate for manufacturing the part? *No – hinge location is not completely defined; the star block is not completely defined; the small house block is not completely defined; the holes are defined by the block dimensions, but should be slightly larger;*
Assembly	Can the assembly process be performed simply and in the correct order? *N/A*
Cost	Have the stipulated cost constraints been observed? *N/A*

Figure 2: Calibration Exercise Key

Problems being labeled as implicit or explicit are determined as whether the problem in the design was explicitly stated, such as a conflicted part count, or if students had to interpret the information in a particular document to determine if a problem existed, such as the non-existence of shields over moving parts. Functional group problems are used indicate if groups tended to focus on a particular functional groups output (design, manufacturing, purchasing, or document coordination) during the exercise.

Quantity is measured to capture the total amount of problems discovered, this measure is not complete as quantity does not necessarily mean quality in regards to difficulty, hence the presence of implicit/explicit measures.

The list of problems and their appropriate classification are found in the next section. Problem definition for the exercise is completed by the classification of the problems and approval by a panel of individuals familiar with the problem and the design process.

3.3 Design Review Problem

The goal is to develop a problem that could not be completed in the time allotted. If all the groups identified all of the problems in the allotted time there would be no opportunity for variation in the response variables. Further, the problem must be at a level of difficulty that is in alignment with material taught in the students' class, thus reducing pre-existing expertise. Finally, the problem should not require any resources outside of the academic level of the participants. Thus, the problem is created with the student's capabilities in mind.

As mentioned previously, the issued design problem is a self-propelled lawn mower mechanism for a walk behind type mower. The design incorporates a belt driven power train to take power from the mower's engine and applies it to a set of drive wheels. In this design exercise the mechanism itself is the only item detailed. Other features of a lawn mower, such as the blade, wheels, engine, handle, and controls, are not included. This is explained to the students that the company for which they are working provides only the self-propelled mechanism; the end customer assembles the rest of the components.

Issued materials includes the output typical for a design in a detailed stage as it approaches serial production. The materials are divided into outputs from four functional groups such that there is the possibility of each member receiving a different packet (per requirements of the DOE). The packets distributed to the students are substantial in size (5-30pages); therefore, the students are unable to review the packages during the review and are forced to study them prior to running the experiment. A design review checklist, such as the one used during the practice exercise, is given to each group to provide a consistent methodology for identifying the problems in the given design.

3.4 Controls

To understand the impact of the two variables (group cohesion and information sharing) in the exercise other variables are attempted to be controlled (Table 2). Other variables not controlled, nor studied, include personality effects, gender effects, and expertise. These additional variables may need to be investigated in the future to determine that they are not influencing factors. However, this is an initial investigation to identify whether either of the two identified variables has an influence on design review effectiveness.

Table 2: Exercise Controls

Variable	Method of Control
Design problem	Presenting an identical design to each team, by informing the morning participants that they are prohibited from discussing the exercise with the afternoon participants
Duration of the design review	Limiting the design review to 35 minutes, regulated by observers
Team size	Organizing teams into groups of uniform size (4)
Communication Resources	All teams had the same modes of communication available (all students spoke the same language, nor had any handicaps in regards to sight, speech, or hearing)
Technical Resources	Providing a design problem that requires no books or other resources for an effective review. Included literature in design report provided all necessary information to participants.
Methodology	Providing a checklist to promote a consistent methodology
Experience	Exposing students to the concept of design reviews with a lesson and practice problem in an undergraduate mechanical engineering design course
Team administration style	Groups would individually dictate how they would govern themselves in regards to the design review output

3.5 Procedure

In order to obtain the required levels (Table 3) of each of the two factors (cohesion and awareness to the presence of unshared information), group formulation and the distribution of information prior to the exercise was designed before conducting the experiment.

Table 3: Planned Experiments

	Cohesion	awareness	
Experiment #	Factor 1	Factor 2	replications
1	low	low	4
2	low	mid	4
3	low	high	4
4	mid	low	3
5	mid	mid	4
6	mid	high	4
7	high	low	3
8	high	mid	4
9	high	high	4
		total	34

To vary the level of group cohesion groups are built based on previous relationships with one another. All participants of the exercise are placed into design teams at the beginning of the semester for a team design project whose duration spanned the entire semester. This design review exercise is conducted at the end of the semester, allowing the flexibility of using these design teams in controlling the group cohesiveness variable. Therefore, the three levels of group cohesion being low, mid, and high were constructed as follows:

- Low: all group members are from different design teams
- Mid:
  - Mid-1: group members are chosen so that two members are on the same class design team and two members are randomly selected such that these two members are not on any class design teams with other members
  - Mid-2: two group members are from the same class design team and two group members are from another design team.
- High: all group members are the same as their design team

Factor 2, awareness of the presence of unshared information is altered by the distribution of materials prior to the experiment (materials are distributed two days prior in order to maintain that each group member became an expert in his or her packet of information). The levels of awareness are constructed as follows:

- Low: All functional group packets are distributed to each group member
- Mid: each group member receives two functional group packets, there were two variations
  - Mid-1: Two pairs of group members receive the same pair of documents (each document is duplicated and common with one other individual)
  - Mid-2: Each document is duplicated but the pairs are such that each document is common with at least three persons of the group
- High: Each group member receives a single functional groups' output

These levels assume that groups sharing all of the same information will have no awareness of the presence of unshared information (since it is all shared) and as the distribution of information decreases, the awareness increases (more information becomes unshared). Thus, high awareness is associated as high information sharing (unshared information sharing) and low awareness as low information sharing (sharing of unshared information).

On the day of the experiment, students are split into their pre-assigned groups, the instructions of the assignment are explained, and the groups are distributed among different locations to offer private working conditions. In addition a single packet that includes only one copy of each functional groups output is distributed. The students have 35 minutes to conduct the exercise and a single design review checklist is generated for each group.

Each group of participants is given the following instructions:

- Consider the criteria below and the product design specification relative to the given design.
- On **this checklist**, **record** all design inadequacies found during the design review. Problems may be identified which do not fit these categories, and some categories may have no design problems. Record on the back if necessary.
- Each team should collaborate to **compile a single list**. The leader/recorder should submit the completed checklist at the end of the review, using additional paper if necessary.
- You will have 35 minutes to conduct the review. Timekeeping is your team's responsibility, but you will be notified when 35 minutes have passed and work must stop. A leader/recorder has been assigned, but any other roles you choose to use may be decided within your team.

Upon completion of the exercise all of their work is collected and a post experiment survey is distributed. This survey is used to obtain feedback for future experiments as well as understand how the participants feel about the design review. This survey and results are not included here.

3.6 Data collection

The completed design review checklist is used for data analysis. Since the participants will not state the design problem as it is explicitly listed in the problem key it is necessary when reading the results to correlate the wordings of the students and the description of the problems in the key. The same panel that was used for the problem identification then approves these correlations.

An example of these wordings is illustrated (taken from a group's output): "All of the moving parts are exposed". This statement correlates with the following problem: "4-C, no shields present over mechanism", thus giving this individual group credit for identifying the problem 4-C. An example of a typical group's output can be seen in Figure 3.

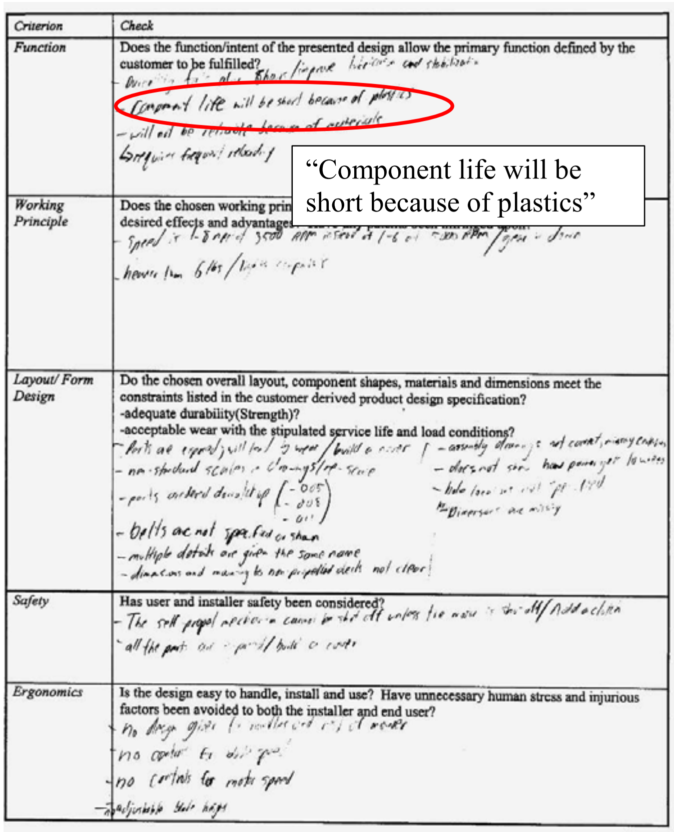

Figure 3: Student Design Review Output

4 RESULTS

While the planned experiments were developed to include four replications per test, the actual experiments conducted ranged from two to six replications. This was due primarily to participant absence on the day of the exercise. Table 4 describes the experiments and replications that were actually done.

Table 4: Experiments Conducted

	Cohesion	Awareness	
Experiment #	Factor 1	Factor 2	replications
1a, 1b	low	low	2
2a, 2b, 2c, 2d	low	mid	4
3a, 3b, 3c, 3d	low	high	4
4a, 4b, 4c, 4d, 4e, 4f	mid	low	6
5a, 5b, 5c, 5d, 5e	mid	mid	5
6a, 6b, 6c, 6d	mid	high	4
7a, 7b	high	low	2
8a, 8b, 8c	high	mid	3
9a, 9b, 9c, 9d	high	high	4
		total	34

The classification of each of the problems in the design can be found in Table 5. The representation type is identified as numeric (N), graphic (G), text (T), or symbolic (S). The reasoning type is identified as implicit (I) or explicit (E). The error and document locations are identified as Bill of Materials (BOM) (B), drawings (D), PDS (S), design release (R), purchasing (P), manufacturing (M), or design (A). The code is a composite of the document, representation, and reasoning.

Table 5: Design Problem Classification

Code	Error Location	Error
BNE	B-D	quantity of 2 for deck
BNE	B-D	5 thrust bearings are shown
BNE	B-D	6002LM0008 quantity should be 2 not 5
BNI	B	weight would be ok if thrust bearings and bushings were correct in count
BNE	B-S	non-deck weight is too high (would be ok if # of thrust bearings and bushings were correct)
RGI	D	6002LM0001 missing hole locations for drive plate through hole and thrust bearing holes
RTE	D	6002LF0012-2 ftlbs should be in NM
RNI	D	6002LF0012-3 11.86+/-10 is too great
RTI	D	6002LM0002 incorrect material - plastic
RTI	D	6002LM0004 incorrect material - plastic
RTI	D	6002LM0012 surface is polished
RNI	D	6002LM0012 shaft diameter is too big
RGE	D	6002LM0011 material thickness is not given
RGI	D	6002LM0011bearing hole location not shown
RTI	D	6002LM0006 no material given
DTE	R-S	failed durability test
DSI	R-S	speed not adjustable on the fly
RGI	R-S	no shields are present over mechanism
DTE	R-S	engine RPM too low, max speed too high
DSE	R-S	cannot disengage or adjust mechanism unless mower is shut down
DNI	R-S	insufficient ground clearance between r6 and r wheel
DTE	R-S	no patent search was conducted
DTI	R-S	maintenance intensive
RGI	R-S	no belt tensioners incorporated
DSI	R-S	unable to steer mower
PNE	P-S	28.6% of component content is foreign
PNE	P-S	5 thrust bearings and 6 bushings are shown in component cost breakdown
PNE	P-S	supplier tooling is too high
PNI	P-S	customer price higher than PDS requirement due to 5-b
PNE	P-S	no adder for labor or manufacturing equipment in customer price
PNI	P-S	identifying price is ok if 5b were corrected
MNE	M-S	tooling too expensive
MTI	M-S	special processing required with drilling and load cell
MTE	M-S	more than hand tools are required to assemble
MNI	M-D	tightening torque process #8 too high, should be 12

MNI	M-D	process number 11 distance is incorrect
DSI	D	verification of negative velocity (vector) not indicated in design report
DSI	D	will move upon starting attempt
DTE	D	lack of belt specification
MTI	M	process order incorrect 7 should be before 6
MTE	M	metric/english conflict
RTE	D-P	part number discrepancy for 6002LM0003

In Table 6, a complete listing of all dependent variables found to affect (numbers in bold) or possibly affect (numbers in italics) the response variable and their associated p-values is listed (all variables from **Error! Reference source not found.** were tested). When looking at the p-values, their associated hypothesis test can be seen in the second column. The null and alternative hypotheses tested take on the following format.

Test of interaction (Interaction, Table 6):

Ho: Factors 1 and 2 do not interact when measuring X (see top row to insert appropriate dependent variable)

Ha: Factors 1 and 2 do interact when measuring X

If no interaction is present, then each factor is tested for significance to see if that particular factor impacted the results. Tests of Each Factor (when interaction is not present Factor 1, Factor 2)

Ho: Factor 1 does not affect X

Ha: Factor 1 does affect X

and

Ho: Factor 2 does not affect X

Ha: Factor 2 does affect X

When Factor 1 and 2 are group cohesion and the awareness of the presence of unshared information (respectively).

Table 6: ANOVA Significant Results (P-values)

Legend	Hypotheses Test	Symbolic	Design	% of Total Problems	Text
Does	Interaction	0.867	0.755	0.874	0.472
Possibly	Factor 1	**0.050**	*0.121*	0.753	0.590
does not	Factor 2	**0.022**	**0.020**	*0.233*	*0.189*

Factors 1 and 2 have a statistically significant impact on the percentage of symbolic problems during the design review. Factor 2 and possibly Factor 1 have a statistically significant impact on the percentage of problems located in the design document. Factor 2 possibly has an impact on the percentage of total problems found, and text type problems found. Those p-values in italics above warrant further study to further develop their individual contributions since their statistical significance is weak. There are two distinctions in the results: "does affect" and "possibly affects". These distinctions are based on their respective p-values (probability of test statistic value) and the heuristic associated with reading these values is that when the p-value is less than the level of significance (chance of creating a type 1 error) one defaults to the alternative hypotheses. Values for significance are generally between 0.05 (95%) and 0.10 (90%), however in the case of human subjects and their unknown variability, values of significance as high as 0.2 (80%) have been used in this experiment to suggest possible influence. Therefore, "possibly" is associated with p-values greater than 0.10 and less than 0.23, in which further research is required.

Since both factors are found to be statistically significant Figure 4 suggests that in order to identify symbolic type problems, high group cohesion and low awareness of the presence of unshared information is preferred.

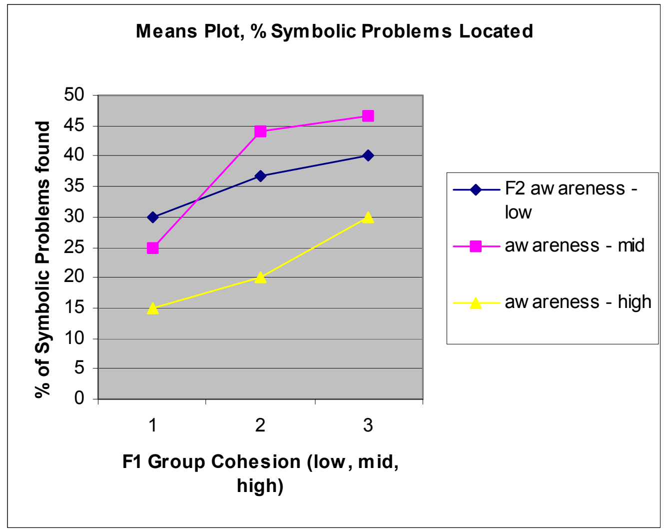

Figure 4: Percentage of Symbolic Problems Identified

When looking at the means plot for the percentage of design document problems located in Figure 5 the same observations for symbolic problem identification are true here as well (low awareness, high cohesion).

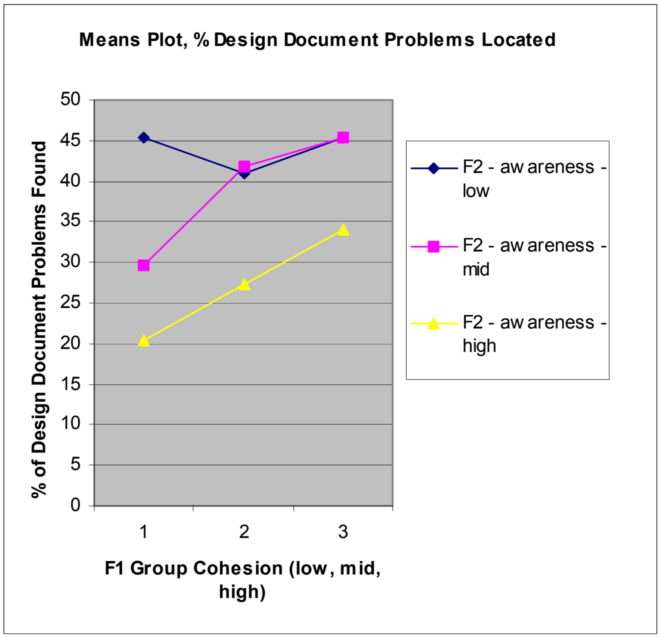

Figure 5: Percentage of Problems Identified within Design Document

The percentage of text type problems located is possibly affected by the level of awareness where a level of low to mid has the highest results (see Figure 6).

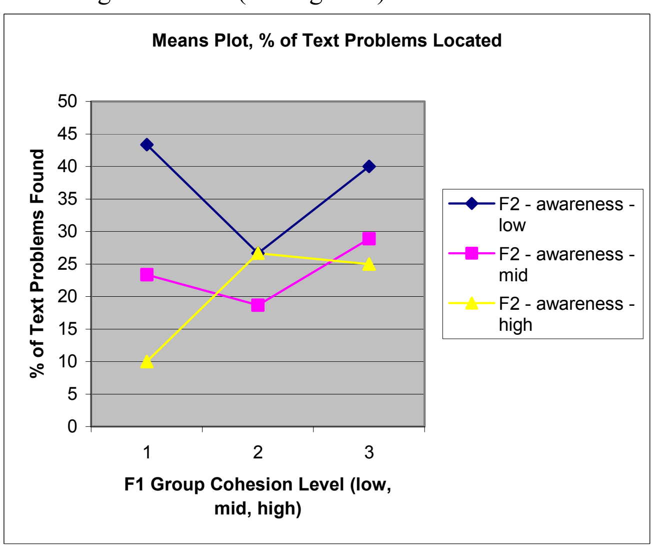

Figure 6: Percentage of Text Problems Identified

In regards to the total number of problems located (Figure 7), there is a possibility that having low to mid awareness increases the quantity of problems found (cohesion is not found to make an impact

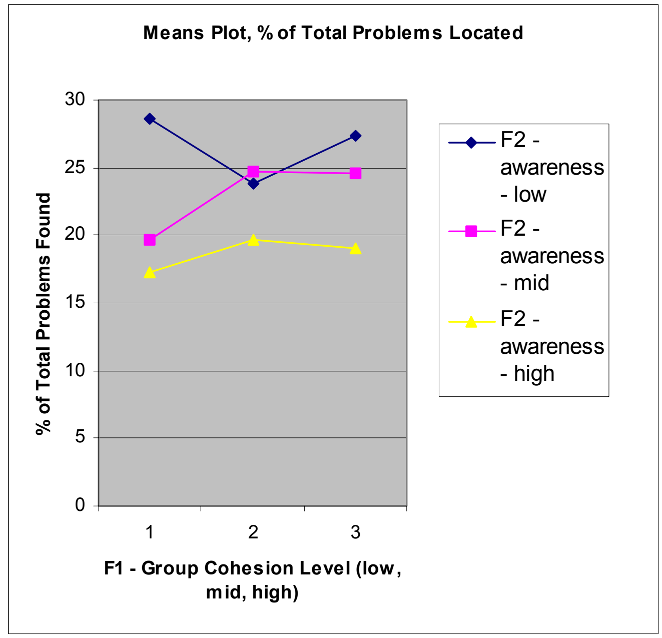

Figure 7: Percentage of Total Problems Identified

5 CONCLUSIONS

Based on the findings in this research one may conclude that design teams should all share the same information prior to the design review. This would correlate to "low awareness" since the presence of unshared information is non-existent. Since group cohesion was only supported in one instance, there seems to be no supported data for a required cohesion level; therefore, this is not a pre-requisite for a successful design review. However, as mentioned in the literature review on group dynamics, one should watch for the warning signs for issues such as Groupthink. As discussed in the literature review, discussion content is generally focused on common information. Therefore, perhaps based on the results from this exercise, all available information should be made available to all members prior to the review such that it becomes "common" or shared and therefore increasing its possibility of discussion. Of course for large-scale projects this could become a burden since each design team member cannot review the output of all functional groups. In the case that a single document that contains vital information is not included, the document will probably not be discussed. The results illustrate that the more the information becomes unshared among members, the less likely problems (whether quantity, representation, or location) will be located based upon that information. Further the results presented do not support the assumption that the awareness of the presence of unshared information fosters information sharing in group activities. Perhaps better performance was seen when all information was shared because the group was not relying on a single individual to disclose his or her information. In theory the strongest member has the ability to contribute to all areas of the design review when all the information is shared.

In summation we have identified a variable that does have an influence on design review effectiveness. It is our goal as researchers to use this understanding to guide the development of new design review tools. We seek to improve design review effectiveness by understanding the factors that are included in the collaborative design activity. We readily recognize that the results from this exercise should not be considered universally applicable (given the problem and participant constraints). However, we feel that this experiment, and subsequent investigations, will provide an excellent place from which to start when developing design review tools and conducting design reviews in the future.

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