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A DUAL-PROCESS ANALYSIS OF DESIGN IDEA GENERATION

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ABSTRACT

A traditional engineering education primarily teaches students to use analytical methods when solving problems, which are effective in most real-world situations. However, heavily analytical approaches often hinder creative output and therefore more intuitive methods have the potential to increase novelty in design. Dual-process theory is an established model in psychology and human decision making that separates fast, intuitive Type 1 processes from slow, analytical Type 2 processes, but to this point has not been applied to engineering design methodology. A exploratory dual-process pilot study of a design experiment using retrospective protocol analysis exposed the difference in novelty of ideas produced by intuitive and analytical thinking. The preliminary results suggest that Type 1 intuitive thinking is correlated with a higher average idea novelty up to a threshold. An equal balance of Type 1 and Type 2 thinking maximized novelty potential. Understanding this relationship and the importance of intuitive thinking in the design process is important to improving the effectiveness of conceptual design thinking and has implications in design education and modeling cognitive design processes.

Keywords: Creativity; Dual-Process; Novelty; Intuitive Thinking

1. INTRODUCTION

In teaching design methodology to students, there is a constant need to balance the practicality and analysis necessitated by engineering with the free and unbridled creativity required for novel design. Most scientific, engineering, and mathematics courses teach students to follow prescribed, analytical approaches to problem solving. However, a quick glance at the great geniuses of history

immediately brings into question the efficacy of this approach for solving very challenging problems that require a creative approach. Einstein famously highlighted the value of “combinatorial play” when seeking insight, which usually consisted of playing through sonatas on his violin [1].

With time, through implicit learning, analytical approaches to problems can become intuitive in the sense that with enough experience, students will have a general idea of the best methods to find a solution. (A good example being which method is best to solve a given partial differential equation.) However, given the nature of engineering design with ill-defined problems, and as students do not know what they will eventually be tasked with in their careers, it is difficult to develop this form of intuition without decades of experience. Hence, students generally approach design in the same analytical method that they approach other tasks like solving equations. However, this way of thinking is not the most effective method for design, as it is easy for students to get limited by what they have previously done, leading to fixation [2]. More creative ideas are all too often discarded because they are risky. Finke wrote, “People are afraid of being creative...[it is] thought to promote disorder and chaos” [3]. Thus, the opportunity is open to expand the way that students approach design tasks.

In our research, we explore the impact of intuitive thinking in design idea generation and investigate the ways in which intuitive thinking can be effectively infused in design education and design methods. Taking a dual-process approach, we consider that design ideas are generated through a process composed of Type 1 (i.e., intuitive) and/or Type 2 (i.e., analytical) thinking and both quality and quantity of design ideas generated may depend on how different types of thinking are applied. As a pilot study of this research, we have conducted a dual-process analysis of design idea generation

based on the protocol data obtained from a collaborative design stimulation experiment.

We first review the relevant theoretical background from existing design methodology and psychology in Section 2. The experimental design and dual-process analysis approach are presented in Section 3 and 4. The results are described in Sections 5 and followed by discussion in Section 6 and future work in Section 7.

2. RELATED WORK

2.1 Existing Cognitive Models

This analysis further builds on Finke’s Geneplore model of creative cognition [3] in conceptual design and the successive Generate-Stimulate-Produce (GSP) model by Jin and Benami [4]. The GSP model consists of design entities, which stimulate cognitive processes, which produce design operations, which generate new design entities. The cycle continues until pre-inventive design entities (undeveloped concepts) mature to knowledge entities (the completed design). Also taking a cognitive approach, Shah et al. developed a way to align experiments [5] occurring in creative cognition research with those occurring in design, which focus on incubation.

Chusilp and Jin’s [6] mental iteration model (Figure 1) found that increased iteration frequency corresponds with increased quality, variety, and quantity of ideas, but has a mixed effect on novelty. However, increased problem redefinition frequency may decrease novelty. This model suggested that the default analytical approach might have suppressed novel ideas.

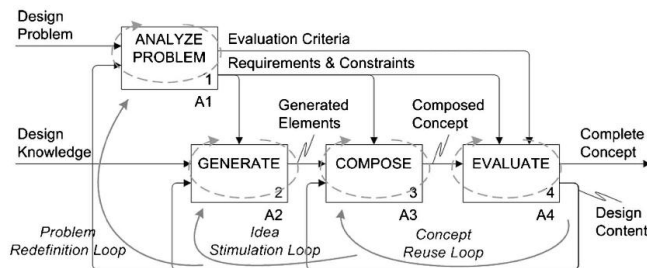


Figure 1: Mental Iteration Model

Sauder’s Collaborative Thinking Stimulation (CTS) model extends the GSP model to include collaboration between designers [7]. Each designer engages in the same individual-processes occurring in the GSP model, but the external interactions such as sharing or questioning concepts with the other designers are also accounted for in the CTS model.

Collaborative stimulation influences generative cognitive processes through two mechanisms: *design entity initiated* and *question initiated*. The specific types of design entity initiated stimulation are *prompting*, where a collaborator’s idea reminds a designer of an idea from memory, and *seeding*, where a designer builds on a collaborator’s idea. The specific types of question initiated stimulation are *correcting*, when a designer alters or improves their idea based on a collaborator’s question,

and *clarifying*, where the process of a designer explaining an idea to a collaborator helps the designer to improve their idea [7].

The foregoing models do not explicitly differentiate between conscious and unconscious processes, which offer very different contributions to the idea generation and design processes. For example, in his evolutionary model of creativity, Simonton discusses the amount of unconscious work that contributes to an idea being generated, arising out of trial and error and natural selection [8].

Creative cognition’s unique approach of considering specific processes has led to a number of insights for the development of methodologies. It has been found that more ambiguous and less mature concepts provide the best stimulation [3, 4]. A better understanding has been developed of key components of ideation methods like *provocative stimuli*, or exposing subjects to unrelated pictures or sounds, influence quality, quantity, novelty and variety [9]. Extending creative cognition to dual-process theory will provide additional insights into the design process.

2.2 Dual-Process Theory

In psychology, the dual-process model classifies thought processes into “Type 1” and “Type 2” [10, 11]. Type 1 processes are fast, impulsive, and intuitive, and are effective at using heuristics to make quick, though sometimes inaccurate, judgments. Conversely, Type 2 processes are slow, analytical, and methodical, and take over when they detect a mistake may be made. For example, Type 1 processes are active when you answer simple questions like “What is 2 x 4?” or when you read the conspicuous emotion on a colleague’s face. Type 2 processes arise when someone asks you “What is 24 x 27?” For this question, the answer is obtainable, but for most it would take a short pause of thinking and serial processing [12, 13].

It is important to clarify that Type 1 and Type 2 processes are not analogous to left/right brain thinking, and should not be thought of as independent computer processors in the brain. To this point, psychologists have avoided categorizing individuals as Type 1 or Type 2 dominant. Rather, Type 1 and Type 2 describe collections of autonomous and conscious processes, respectively, that are both commonly used. The “Type 1/Type 2” terminology coined by Stanovich [10] supersedes the earlier, popularized terms “System 1” and “System 2” [13] to avoid this ambiguity.

The early Geneplore model of idea generation [3] alludes to a dual-process model at the very least, if not a tripartite model or more. The generation of preinventive structures can be thought of as a Type 1 fast process that freely and autonomously generates ideas, and then the exploration and interpretation of those ideas can be a Type 2 process. The synergy of these two processes, as formalized by the GSP [4] and Mental Iteration [6] models is key to the success of the design process.

Type 1 and Type 2 processes have been alluded to in current design literature, although these have not been formally identified. As an example, fixation occurs when the new

concepts a designer creates are limited or ‘stuck in a rut’ because of prior observed solutions [2] or premature commitment to a concept [14]. Fixation has been observed when providing example solutions to both novice and expert designers [15, 16]. Fixation results out of overactive Type 2 processes that attempt transformation of ideas with limited inputs. Additionally, an approach to reducing fixation has been to provide the designer with examples that have a low commonality between them [17] that give the opportunity for Type 1 processes to offer new options and information through unexpected associations.

2.3 Triggers of Type 1 and Type 2 Thinking

Motivation, ability, and experience are strong contributing factors to how a problem will be approached. Not surprisingly, intrinsically motivated people, because they find a task personally rewarding and enjoyable, generally produce more creative results [18]. Conversely, people that are extrinsically motivated, such as by a deadline or tangible reward, do not show the same levels of creativity [19]. While deadlines are unavoidable in most academic and professional settings, there is value in reframing one’s mind to ignore a deadline while executing a design task to take advantage of intrinsic motivation.

Type 2 processes are effortful, which is why motivation is a significant factor. When one is physically or mentally depleted, there is a tendency for Type 1 processes to take precedence over Type 2 processes, which in the wrong circumstances can cause serious errors in judgment [20]. On the other hand, experience can allow one to make better decisions with intuitive thinking than analytical thinking in a favorable environment, for example in lie detection of individuals [21]. Much expert skill is implicitly learned through subtle cues, and experienced designers are able to intuitively take advantage of these shortcuts. Simon offered a famous summary of this, “Intuition is nothing more and nothing less than recognition” [22].

In addition, a low *feeling of rightness* when first presented with a problem is associated with an increase in Type 2 analysis [23]. Type 2 processes fire up when the brain senses that there is a mistake about to be made. In a design setting, students believing that a particular idea automatically generated is too outlandish will prematurely discard that idea. Even though the idea itself may be impractical, it could serve as a provocative stimulus.

2.4 The Dual Pathway to Creativity Model

Rietzschel et al. propose a creative idea generation model that mirrors a dual-process approach [24]. They identify two pathways to creative stimulation: cognitive flexibility and persistence. The flexibility pathway is described as “achieving creative insights, problem solutions, or ideas through the use of broad and inclusive cognitive categories. [...] It is important that people do not rely on habitual thinking and fixed task strategies.” Conversely, the persistence pathway is the “systemic and effortful exploration of possibilities...through a systemic exploration of problem space and through incremental

search processes.” Both pathways can produce creative ideas, but the persistence pathway requires more time to process all of the predictable results before getting to ideas that have not been previously proposed. A typical engineering student would likely have a hard time not relying on the “fixed task strategies” to take advantage of the flexibility pathway.

3. EXPERIMENTAL APPROACH

3.1 Hypothesis

The metrics of novelty, variety, quantity, and quality measuring ideation effectiveness are thought to be related to the creativity of a design concept [25, 26]. While these are all well-established metrics, in order to quantify the impact of the dual-process model, it was decided to focus on novelty. Variety and quantity were not selected as they focus on sets of ideas, rather than rating individual ideas [26]. For simplicity in this pilot study, it was decided to avoid quality as it is qualitative. To establish a trajectory for this research, a hypothesis was formed.

H1: The novelty of ideas produced by Type 1 processes will be greater than that of Type 2 processes.

The basis for this hypothesis is that while the default approach to engineering problems is analytical, approaches to improving creativity, such as brainstorming, divergent thinking, and Synectics [27] are generally targeted at withholding evaluation and encouraging intuitive Type 1 processes. Encouraging Type 1 thinking should allow for more creative, less evaluated ideas that, while they may not necessarily be polished final products, spark more unexpected and creative associations between ideas. Of course, having an exclusively Type 1 approach to a problem is impractical and infeasible, so a healthy balance must be struck between quick, intuitive thinking and slow, evaluative thinking.

3.2 Retrospective Protocol Analysis

Two different methods, concurrent and retrospective, were tested to reveal internal thoughts during the collaborative design task. Retrospective approach was most effective, as concurrently thinking aloud and interacting with a team proved to be too much for one designer to process. This allowed for the observation of both private and shared thoughts. In addition, Simonton argues concurrent think aloud methods can interfere with unconscious processes that may benefit creative and divergent thinking [8]. Also, retrospective protocols have been found to have similar accuracy to concurrent protocols [28]. Subjects self-reported that they were able to remember 90% or greater of their thoughts in a design process lasting under thirty minutes. But, as there is no certain way to determine exactly how much information is missing, it is hard to quantify how large an issue memory recall may be. In general, protocol analysis also presents the issue that not all thoughts may be verbalized [29]. However, this method is the

best the design available to researchers to explore cognitive interactions.

3.3 Subjects

Subjects for this experiment consisted of ten senior and master's students in mechanical engineering at the University of Southern California, who were divided into five groups of two. The team assignment was random, except for one team. All students were in engineering design classes and had group projects in those classes. Therefore, they were familiar with participating in collaborative design and had been taught basic engineering design methodologies. However, the participants were novice designers as all had less than a year of industry work experience. The subjects were compensated by being entered in a drawing for an iPod Nano and gave consent when arriving at the study. The study was reviewed and approved by the institutional review board.

3.4 Procedure

When first arriving at the study, participants were given individual training in verbalizing their thoughts. The training started with verbalizing a simple process, and continued to become more difficult until the subject was verbalizing their performance during a practice design problem.

After training, the designers were put in a group and provided with pencil, paper, and the design problem statement (given in the appendix) that asked them to develop a device that would securely store skateboards to prevent students from stacking them up against classroom walls. The designers were then video recorded as they collaboratively worked through the design problem. They were given as much time as they needed to complete the problem, as time constraints could interfere with the natural design process.

Immediately after the subjects completed the design problem, they were asked to retrospectively verbalize their thoughts from the design process. This was done while watching a video of the design problem, providing verbal and visual cues. The retrospective verbalizations were recorded in an audio file for later transcription.

4. ANALYSIS

4.1 Protocol Analysis

The classification of Type 1 and Type 2 processes was accomplished by almost fully building on the preceding analysis' collaborative stimulation protocol coding.

The design entities, cognitive processes and collaborative stimulation were first identified. The data from each experiment consisted of two audio files and a video file. A coding scheme was employed (Table 1) to analyze the data, identifying design entities, cognitive processes, and collaborative stimulation. The coding scheme was checked using inter-coder reliability, and an agreement of 85% was found.

A design entity was identified as a potential or partial solution having a form, function, and/or behavior. Any time a form, function, or behavior was mentioned in the transcript, it

was classified as a design entity. Sometimes, sketches accompanied design entities, making them easier to identify.

After the design entities were identified, the cognitive processes occurring in the transcript were identified. Generative cognitive processes consisted of *memory retrieval*, when an experience or design entity which existed in the past is remembered, *association*, when connections are drawn between two design entities, *transformation*, when a design entity is altered or changed, *problem analysis*, when the design problem is explored in more detail, and *solution analysis*, when the fitness of a design solution is compared to the problem. Then the collaborative stimulation processes were identified by examining how cognitive processes came about, and if they could be attributed to a collaborative stimulation.

Table 1: Collaborative Stimulation Coding Scheme

Name	Abbr.	Coding Notation	Transcript Example
Design Entities			
DE			
Function	F	F(make hole)	Makes hole in wood
Structure	S	S(car)	attached to a car
Behavior	B	B(moves)	Moves up and down
Thought Processes			
TP			
Memory Retrieval	MR	MR(DE(X))	I think a solution would be (lists a preexisting solution)
Transformation	TF	TF(DE(X), expanded)	If X was expanded
Association	AS	AS(DE(X), DE(Y))	Idea X is like Idea Y
Problem Analysis	PA	PA(X)	Do we really need to accommodate X?
Solution Analysis	SA	SA(X)	I don't think X would fit.
Collaborative Stimulation			
CS			
Prompting	Pr	Pr(DE(X),MR(Y))	X reminded me of Y
Seeding	Se	Se(DE(X),CP(DE(X));DE(X*))	X you proposed can be modified to create X*
Correcting	Co	Co(DE(X), CP(S(X), DE(X*)))	X can be modified to create X*, which solves the issue you brought up
Clarifying	Cl	Cl(DE(X), CP(X);DE(X*)) or Cl(DE(X), CP(Y);DE(X*))	X works like this, but it can be changed to X* or X works like Y, which changes it to X*

4.2 Dual-Process Analysis

In applying the dual-process model to the collaborative stimulation approach, the classification of processes and statements coincided with the hallmarks of fast, intuitive Type 1 thinking and slow, logical Type 2 thinking. Memory retrieval, association, prompting, and correcting were categorized as Type 1, as these processes often happen quickly and without much logical, conscious mental computation. Problem analysis, solution analysis, seeding, and clarifying were categorized as Type 2, as these processes often require slower, serial, logical thinking. Transformation was categorized as given in the context of the code cell and could be categorized as

either Type 1 or Type 2. Code segment that were ambiguous or irrelevant were omitted. Occasionally, depending on the context or subjects' retrospective comments, there would be a compelling case to break from the rule and categorize a Type 1 process as Type 2 or vice versa. This analysis was completed blindly before comparing the novelty of the individual ideas.

Table 2: Division of Processes

Type 1	Type 1 or 2	Type 2
Memory Retrieval	Transformation	Problem Analysis
Association		Solution Analysis
Prompting		Clarifying
Correcting		Seeding

4.3 Novelty Analysis

While not a complete measure of ideation effectiveness, novelty is an important and serves as a good proxy as it is both quantitative and can measure each design entity individually, not only the entire set of design entities produced. To quantify novelty, an approach derived from Shah, Smith, and Vargas-Hernandez [26] was used.

First, each new concept (or design entity) had to be identified in order to quantify its novelty. A new design entity was identified by examining all the design entities found through the coding scheme and determining when each design entity was created. These design entities were put into a list with a time stamp of their occurrence and it was noted the number of times other groups had identified the same design entity.

After each design entity was identified, they were then categorized into a series of hierarchy levels: functions, physical principles, working principles, embodiment, and details. Functions are extracted from the problem statement and are the concept requirements. All the possible functions from the problem statement were first identified, and the rest of the hierarchy was then grouped under each function. Physical principles are verbs that fulfill a function. Working principles are nouns that are able to implement the physical principle, usually through structures. Embodiment is how the structure is constructed. Details consist of many minute aspects, such as materials or aesthetics.

The novelty of ideas was evaluated relative to four previously defined functional principles: Clean to Environment, Stabilize Skateboard, Identify Skateboard, and Safety. For the sake of the dual-process analysis, in the event that a particular idea contributed to several functional principles the idea would be split and treated as multiple ideas, as the novelty could be different for each function the concept fulfilled.

The total novelty of a design entity, N , is measured by comparing the maximum number of times a design entity can be repeated (or the number of teams) to the number of times it was invented by each team (Equation 1).

$$N = \frac{\#Teams - \#DE}{\#Teams} \times 10 \times p \quad (\text{Equation 1})$$

In the equation, the number of times a design entity occurs is subtracted by the maximum number of times a design entity can be repeated (equivalent to the number of teams in the experiment), and then divided by the same. Note that Equation 1 is slightly modified from Shah's metrics as the authors were interested in the novelty of each design entity and not total novelty over the entire process. Therefore, novelty is not aggregated at each hierarchy level. Also, novelty is not given in terms of ideas and their repetition within categories, but rather the repetition of specific ideas, as it is hard to place design entities into meaningful categories being so specific. Next is a normalization factor of 10, used to prevent small decimal results. Finally, p is the weighting factor for each level of the hierarchy. A weighting factor was necessary as novelty in broad working principles is more influential than novelty in small details [26]. Physical principles have a weight of 10, working principles a weight of 6, embodiments a weight of 3, and details a weight of 1. Note that while only pair of subjects was analyzed in depth to highlight Type 1 and Type 2 thinking, the calculated novelty reflected the novelty of their ideas relative to the rest of the study participants.

4.4 Dual-Process Idea Association

In the protocol coding, each idea was isolated and associated with a single code segment and point in time, but most ideas were developed through a series of thoughts. In this kind of analysis it was difficult to determine with high credence which specific thoughts verbalized by the subjects contributed to each idea. As such, three different analyses were completed to associate the thought processes that went into the generation of each individual idea, each with its own strengths and weaknesses: individual analysis, standard aggregated analysis, and time aggregated analysis.

4.4.1 Individual Analysis

Ideas were identified in the transcript and associated with each designer individually. For each designer, the thought processes leading to some idea C were considered to be in the time between the preceding idea B and idea C. This method was best to isolate the thoughts of each individual subject, which is the primary focus of this research. However, due to the nature of the communication between the subjects, this would sometimes cause large gaps between ideas, as an idea could arise out of a long discussion.

4.4.2 Standard Aggregation

As the original purpose of the study was an analysis of collaborative stimulation, there was a systemic issue with analyzing each designer in isolation. Therefore for the second analysis method, ideas and thinking were aggregated for both designers, and the same method as above was applied. The thinking leading to some idea C was considered to be the time between the preceding idea B and idea C. However, considering the ideas for *both* designers sometimes decreased the number of code segments associated with each idea. This also increased the number of ideas that arose consecutively, meaning that only one code segment could be applied to it.

4.4.3 Timed Aggregation

To the aggregated data, the thinking that led to an idea was uniformly assumed to consist of the five preceding code segments before each idea, representing approximately 20-30 seconds of thought processes. The thought processes of both subjects were considered together in the same grouping for each idea. The logic behind this process was to capture the thought processes behind successive ideas that in previous analyses would only have one associated code segment. Timed aggregation allowed for a better understanding of how thought processes generally evolved over the course of the design task.

4.4.4 Percent of Type 1 Thinking (PTT)

After the thought processes and ideas were associated, the principal method of thinking was reflected by the *percent of Type 1 thinking* (Equation 2).

$$PTT = \frac{\text{Type 1 Count}}{\text{Type 1} + \text{Type 2 Counts}} \times 100 \quad (\text{Equation 2})$$

The Type 1 and Type 2 counts are the numbers of code segments associated with each idea that included statements by the designers that reflected Type 1 or Type 2 thinking. This percentage will be referred to as the PTT.

4.5 Example Analysis

To demonstrate how the data was analyzed, consider the related sections of collaborative dialog and individual retrospective transcripts below, where two designers were discussing a wall mounted skateboard rack. This is a small section of the dialog. The numbers in the collaborative dialog transcript indicate which designer was speaking.

Collaborative Dialog Transcript: (1) Okay. Have you seen Parkside?... (2) Yeah... (1) They have those racks... (2) Yeah... (1) Well, assuming like if they have those racks plus a locking device that you can just use like a padlock... (2) Well, who with a skateboard carry around a pad

lock? (2) What if it was ID card swipeable [sic]? (2) Every USC student is going to have an ID card...

Images of the way the skateboard is locked are shown in Figure 2. The locking mechanism (ID card reader or padlock) would be located at the front of the arm where the arrow points.

The transcripts were then divided into segments, and after all of the transcripts had been segmented, they were coded for collaborative stimulation and dual-process thinking.



Figure 2: Skateboard locking arm and lock locations

5. RESULTS

5.1 General Results

For this pilot study, the transcript from one pair of designers was thoroughly analyzed for Type 1 and Type 2 thinking. The session lasted approximately 22 minutes. The novelty scores in each analysis were compared to the average PTT for the entire design session. The average total novelty is compared to PTT for each analysis method in Figure 3. The ideas were then categorized based on their PTT, and the average was taken of each category, for each analysis method. This separated the ideas into Type 1 dominant ideas (PTT greater than 65%), balanced ideas (PTT between 65% and 35%), and Type 2 dominant ideas (PTT less than 35%). This categorization allowed for greater resolution as to the impact of Type 1 and Type 2 thinking on design characteristics. These results are summarized in Table 4 and Figure 4.

Table 3: Example Coding

#	Time	Segmented Dialog	CS Coding	Dual-Process Coding		Ideas	
				Subj. 1	Subj. 2	Subj. 1	Subj. 2
1		Episode 3: Racks and Security System					
2		(1) Okay. Have you seen Parkside?... (2) Yeah... (1) They have those racks... (2) Yeah...	(1) MR(S(Parkside B(has S(racks))))	1	0	S(rack at Parkside)	
3		(1) Well, assuming like if they have those racks plus a locking device that you can just use like a padlock...	(1) TF(S(racks AS(S(lock device B(use S(padlock))))))	1	0	S(rack plus pad lock)	
4		(2) Well, who with a skateboard carry around a padlock?	(2) SA(F(why(S(skateboard user B(carry S(padlock))))))	0	2		S(ID card swipeable)
5	2:06	(2) What if it was ID card swipeable?	(2) Se(TF(S(rack S(ID card B(swipeable)))) (below)	0	2		S(lock device), MR(S(convention center...))
6		(2) Every USC student is going to have an ID card...	(2) SA(S(USC student B(have S(ID card))))	0	2		

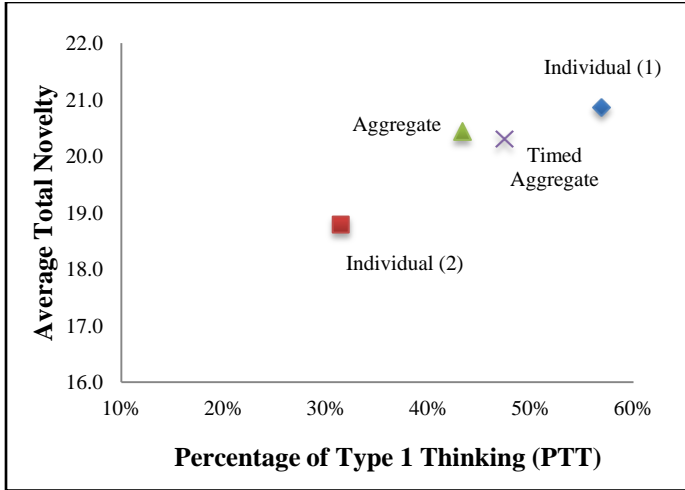


Figure 3: Analysis Comparison

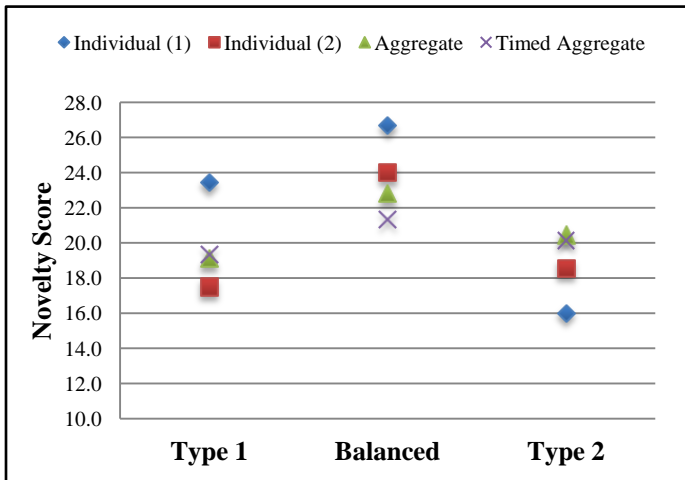


Figure 4: Novelty per Category by Analysis Method

5.2 Thought Process Evolution

The novelty of ideas as associated through the time aggregated method and classified into the above categories was compared over time. This allows for a look at how thought processes evolved as ideas are generated, developed, and refined. For simplicity, the ideas are presented sequentially with their corresponding novelty. The intent of this chart (Figure 5) is to analyze the overall trend of how thought processes change throughout the design task, as the data does not have enough resolution to isolate specific times or instantaneous changes in thought processes.

6. DISCUSSION

6.1 Hypothesis Analysis

As this is only an exploratory pilot study, clearly the sample sizes are not large enough to be statistically significant, which is reflected in the large standard deviations in Table 4. However, the analysis tends toward supporting the proposed hypothesis. Combining the different analysis methods, there is a slight positive correlation between the PTT corresponding to idea generation and the corresponding novelty score (Figure 3). However, as novelty decreases towards very high PPT, there may be a threshold past which Type 1 thinking is no longer beneficial. Comparing Type 1 thinking directly with Type 2 thinking, there does not appear to be a significant difference in novelty.

Between the two individual subjects, Subject 1's PTT is much higher than Subject 2, and Subject 1's total average novelty score is also higher. Subject 2 had a considerably more Type 2 oriented design approach than Subject 1 (31% vs. 57%) and the corresponding novelty is noticeably lower than Subject 1 (18.8 vs. 20.9).

Table 4: Summary of Novelty Analysis

		PTT	Average Novelty Score	Novelty by Category		
				Type 1 (PTT ≥ 65%)	Balanced (65% > PTT > 35%)	Type 2 (PTT ≤ 35%)
Individual (Person 1)	Average	57%	20.9	23.4	26.7	16.0
	StDev	44%	13.8	13.1	20.1	12.9
	(n)		(28)	(14)	(3)	(11)
Individual (Person 2)	Average	31%	18.8	17.5	24.0	18.5
	StDev	40%	10.5	10.9	24.0	7.6
	(n)		(33)	(8)	(3)	(22)
Aggregate	Average	43%	20.4	19.1	22.8	20.4
	StDev	42%	12.3	13.5	11.9	11.9
	(n)		(55)	(18)	(10)	(27)
Timed Aggregate	Average	47%	20.3	19.3	21.3	20.2
	StDev	33%	12.4	12.5	12.2	12.8
	(n)		(67)	(24)	(17)	(25)

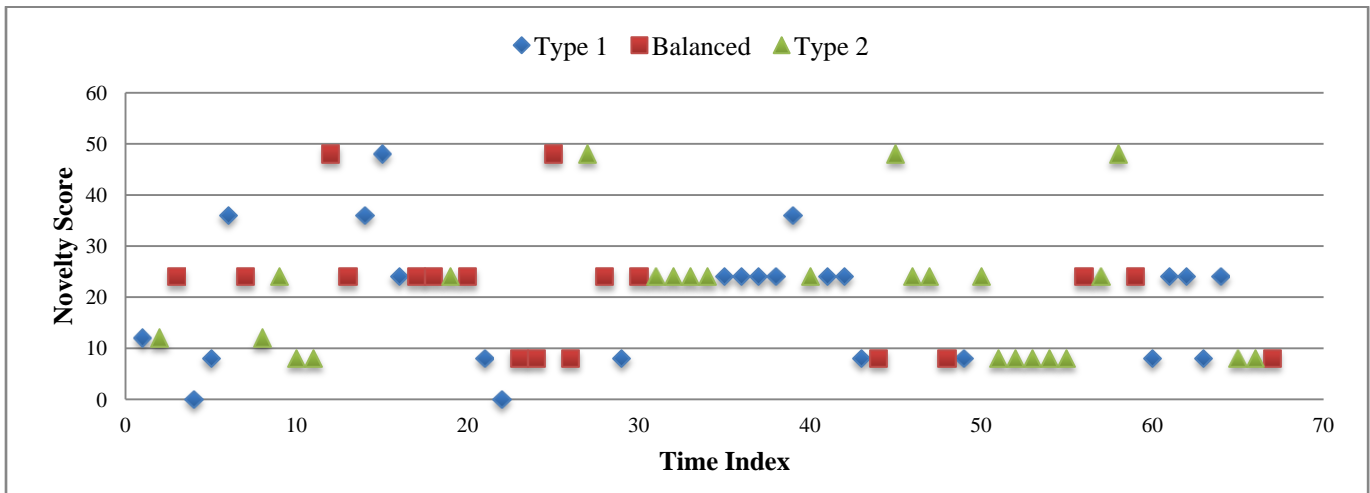


Figure 5: Time Aggregated Novelty vs. Time

6.2 Process Categories

In separating out ideas into three categories by primarily Type 1 thinking, balanced Type 1/Type 2 thinking and primarily Type 2 thinking suggests that the most ideal balance of thought processes in a design task is to balance Type 1 and Type 2 thinking as much as possible, as the average novelty was highest for the balanced category. This trend was seen in all three methods of analysis (Figure 4). However, for the individual analyses, the sample size is far too small to be conclusive. This also coincided with Chusilp’s iteration model, which shows too much problem analysis iteration was associated with lower novelty [6].

For engineering design, as opposed to purely artistic design, the goal is not only for a design to be novel but also to be practical and implementable. There must be analytical and evaluative steps throughout the design process. Without these steps, designers could develop ideas that are impossible to implement or too costly. Students who are exhausted from their studies, while they may depend on low-energy Type 1 processes [20], are unlikely to come up with very novel ideas. The data suggests that the synergy of Type 1 and Type 2 thinking, as expected by previous models [3, 4, 6], generates the most novel ideas. This coincides with the integral use of both divergent and convergent thinking in innovative thinking methodologies [27, 30].

By dividing the time evolution of the Type 1 and Type 2 processes in Figure 5 into three equal sections, the shift in thought processes over the course of the design process is clear. The early conceptual stage of the design process depends more on Type 1 thinking, which generates ideas through memory recall, association, and occasionally transformation. The data also show that many ideas early on arose out of balanced thought processes. Later on in the design process, Type 2 processes became more prominent, and the novelty and frequency of Type 1 and balanced ideas noticeably decreases.

Logically, in the final embodiment phase of the task, there will be more solution analysis, which uses more Type 2 processes. Much of this solution analysis is likely triggered by an unsatisfactory “feeling of rightness,” which has been shown to trigger Type 2 processes [23].

Following the dual pathway to creativity model [24], it could be argued that Type 2 thinking showing lower novelty may be as a result of time constraints that did not allow the subjects to fully explore all potential solutions. The study was likely not long enough, nor the data clear enough, to resolve this effect. The subjects were not time limited, however like most engineering students, they were probably eager to finish the study to begin working on another problem set.

6.3 Implications

Existing conceptual design models do not effectively differentiate between intuitive and analytical processes. However, as stated by Simonton, “intuition just might provide the single most potent resource for creative genius” [8]. The goal of this work is to provide evidence that Type 1 and Type 2 processes can be identified in the design process and are an important factor in idea generation. While the data suggests Type 1 processes may generate more novel ideas than purely Type 2 thinking, it is not that Type 1 processes generate these ideas *in vacuo*. It is through a combination of Type 1 and Type 2 processes that generate novel ideas, reinforcing the importance of both divergent and convergent thinking in ideation. Capturing this was a goal of the third time-aggregated analysis.

It should be clarified that the *intuitive thinking* described in this paper is not *intuition* in the colloquial sense. Designers intuitively associate preinventive structures in their minds, though because of hyperactive Type 2 processes, these ideas may not be allowed to surface, or if they surface, unique ideas may not be fully explored. Intuition is a function of experience, implicit learning, and a suitably favorable environment to

perform in [12, 31]. A simple conceptual design task is a sufficiently benign environment that allows for intuition to be useful, but a full discussion and analysis of expert intuition is outside of the scope of this paper.

We seek only to understand the natural approach students take to design tasks, in hopes of building on this analysis to develop techniques to improve creativity, novelty, and decrease time required for the conceptual design process. If Type 1 thinking promotes higher novelty in design tasks, then it would be beneficial for students to have more opportunities to take advantage of positive qualities of Type 1 processes in design during a university education. We believe allowing more free thinking and a less purely analytical approach will stimulate more random thoughts and associations leading to increasingly novel ideas. It may also help to mitigate the problem of fixation [17]. Methods to encourage uninhibited creativity, such as Synectics have been around for decades, but perhaps due to a lack of theoretical understanding, these methods have not staked their claim in engineering design [27]. A mindset that truly withholds judgment of unique ideas and allows for metaphorical and analogical thinking is still anathema to many engineers. Arts and creative education do a much better job at teaching these skills, and not surprisingly past creative experiences have been shown to increase frequency of collaborative stimulation [32-34]. Combining current engineering education with more opportunities to participate in various creative activities that cultivate Type 1 processes, such as studio and performing arts and divergent thinking exercises like forcing associations between two unrelated objects, is a promising way to cultivate innovative thinking in the next generation of engineering students.

7. SUMMARY & FUTURE WORK

This work applied a dual-process approach to existing engineering design and creative cognition methodologies in order to identify intuitive and analytical thought processes in the various stages of the conceptual design process. While this exploratory pilot study was a relatively small data set, the results are encouraging and highlight the need for future work to fully understand the nature of intuitive processes in design.

The analyses suggested that there may be a correlation, to an undetermined threshold, between the novelty of an idea and the amount of Type 1 thinking that went into its development. In addition, Type 1 and Type 2 processes take precedence at different points in the design process, with earlier stages depending more on Type 1 and balanced processes and later stages depending more on Type 2 processes. There is literature and anecdotal evidence on the value of intuitive and stochastic thinking in creative problem solving [30, 35-37], and our future work will seek to understand the nature of these methods and how they can be mapped onto detail-oriented engineering design.

Our ongoing work will increase the sample size and provide key evidence needed to prove or disprove if Type 1 thinking is associated with higher idea novelty in design tasks.

Present models of conceptual idea generation and design do not place enough emphasis on differentiating intuitive and unconscious processes inherent in any design task. The extent that a university education changes the way that students approach problems (though either Type 1 or Type 2—or a combination of both—thinking) has yet to be determined. Students may lose the ability or the confidence to apply intuitive approaches to problems over the course of an analytical engineering education, in lieu of other creative outlets that encourage a reliance on intuitive thought. We hope that engineering education can take advantage of the creative powers of intuitive thought so that students will have the skill and the confidence to be able to confront the world's rapidly growing technological challenges.

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APPENDIX

Design problem statement: Skateboards are one of the most popular forms of transportation at USC. Unfortunately though, when students come to class, the only current method for skateboard storage is to line them up against the wall. However, this has the potential to mark up the wall and skateboards can fall over in a domino effect if one is accidentally bumped. A larger problem is that in large lecture halls, where there are often 2-3 rows of skateboards stacked up against the back wall. With so many boards, it can be hard to find yours, or even worse, it provides the opportunity for someone to steal one unnoticed. Design a device which will safely and securely hold skateboards while students are in class. This device could either be located in the hallway or outside the building, but not in the classroom due to space constraints.