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SUPPORTING TEAM INNOVATION WITH DESIGN THINKING COGNITIVE STRATEGIES

Lisa M. Casper
Michigan Technological University, lcasper@mtu.edu

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SUPPORTING TEAM INNOVATION WITH DESIGN THINKING COGNITIVE STRATEGIES

By

Lisa M. Casper

A THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Applied Cognitive Science and Human Factors

MICHIGAN TECHNOLOGICAL UNIVERSITY

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This thesis has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Applied Cognitive Science and Human Factors.

Department of Cognitive and Learning Sciences

Thesis Advisor: *Dr. Elizabeth Veinott*

Committee Member: *Dr. Erich Petushek*

Committee Member: *Dr. Mary Raber*

Department Chair: *Dr. Kelly Steelman*

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Abstract

Innovation is a 21st-century skill needed to design new systems, solve challenging problems, and develop novel solutions. Design Thinking (DT) is a tool used to support team innovation. In this experiment, 145 students (47 teams) used one of two DT methods during a semester-long project to come up with an innovative solution to one of the UNESCO 17 sustainable development goals. The key experimental manipulation was during the DT Ideate phase where teams brainstormed potential solutions. Teams either used a baseline DT Ideate strategy or an expanded one with additional prompts during a 10-minute period. Results indicated that teams using the expanded DT Ideate strategy generated 57% more solutions than those in the baseline DT condition. The solutions were content analyzed for innovativeness and the final proposed solutions were rated by other teams. Implications for implementing design thinking are discussed.

1 Introduction

According to the *2020 World Economic Forum Future of Jobs Report*, by 2025 innovation and creativity will be among the most sought skills by employers (Zahidi et al., 2020). Universities' reputations are built by graduates who can innovate on the job. Design Thinking (DT) (Liedtka, 2018) and open-source community makerspaces (Doughterty, 2012; Kajamaa, & Kumpulainen, 2020) are educational strategies to develop and foster these skills. Applied in a project-based learning context, such as a capstone course or project, DT has the potential to shift an engineer's skills beyond theoretical to being applied (Dym, et al., 2005). DT is commonly believed to foster team innovation (Liedtka, 2018; Razzouk & Shute, 2012). The Stanford Hasso Plattner Institute of Design or d.school uses DT as a tool to teach team innovation, breaking the stereotype of the lone-genius inventor (Brown, 2008). Empirical studies involving DT have been conducted (Cagan, et al., 2013), but this is an emerging area of study, and it is unclear which cognitive strategies support team innovation during DT. Theories of DT, and cognitive models that identify effective strategies and why they work and are missing (Ely, 2023). This thesis focuses on identifying which cognitive strategies support team innovation. It will also provide results for the first controlled experiment of the complete DT process.

1.1 Design Thinking Defined

DT is a team activity that uses a human-centered design process centered around delivering value-added, user-friendly ideas (Brown, 2008; Kelley & Kelley, 2015; Kelley & Littman, 2016). Its five phases are: Empathize, Define, Ideate, Prototype and Test (Gibbons, 2016; Hasso Plattner, 2016). (See Figure 1.) The goal of DT is to better understand a problem to develop useful, impactful, and novel solutions throughout the five-phase process (Brown, 2008).

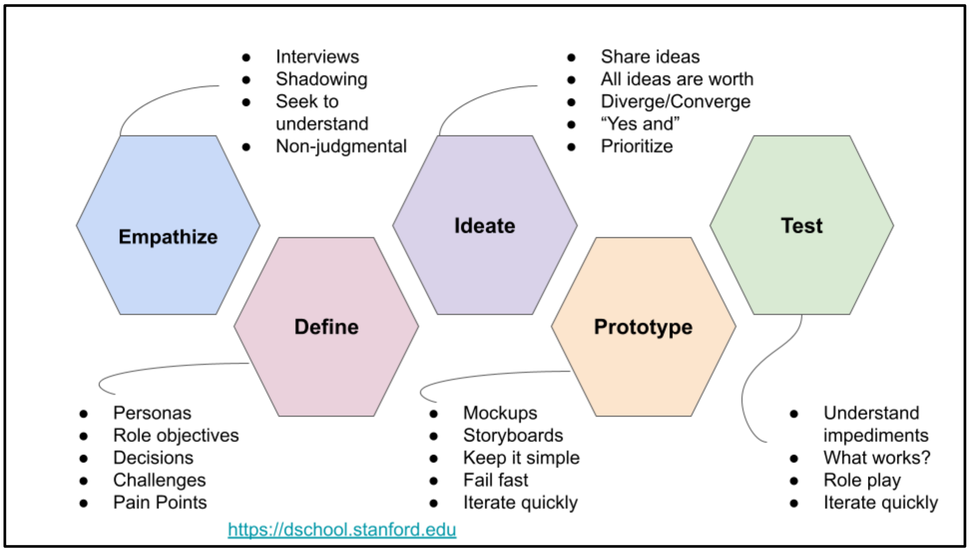

Figure 1. Design Thinking phases. Adapted from *An Introduction to DT Process Guide*, Hasso Plattner Institute of Design at Stanford.

DT phases start by understanding the user to define the problem, move to generating ideas for new solutions, then to prototyping solutions and finally testing solutions. In the Empathy phase, teams gather information, conduct qualitative interviews, and research the end-user experience to support the next phase which is to define the problem. Using the information gathered from the Empathy and Define phases, teams then generate solutions to the problem by ideating, and then developing prototypes. The Ideate phase focuses on taking the new perspectives developed in the prior DT stages and brainstorming to open a range of novel solutions, while withholding criticism or critiquing of the ideas. Prompts can be provided in the Ideate phase to encourage quantity and wild ideas. After brainstorming, teams analyze their ideas and converge on a solution. They cluster common ideas, note themes, and vote for their top ideas. Next, they visually represent their solution with a Prototype and playtest the solution (Gibbons, 2016; Hasso Plattner, 2016). Gerber and Carroll (2012) describe the importance of failure during the prototyping and playtesting process. Failure is part of the learning process that informs the next iteration of prototype design. Lastly, during the Test phase, teams present their prototype to their stakeholders, gather feedback, and make iterative changes moving towards a working prototype and implementation of the design solution (Pande & Bharathi, 2020). Team innovation could result from several different phases, but a key one is the Ideate phase.

We seek to understand the relationship between perspective shifting and innovation during DT Ideate. There is evidence that perspective shifting occurs during the Empathy, and Test phases when design teams strive to better understand the end-user's perspective and to frame the problem differently (Pande & Bharathi, 2020). Brainstorming, an Ideate activity, generates multiple perspectives, however this is different from perspective shifting (Klein et al., 2006; Honebein, 1996; Kaufman, 1996) as the former is about iterative generation of ideas and the latter is about the range of ideas. During the Ideate phase, improv strategies and problem constraints may facilitate perspective shifting and divergent thinking to develop innovative team solutions (Brown, 2008; Gerber, 2007; Gibbert, et. al., 2007; Moreau & Dahl 2005;). To what extent perspective shifting is occurring during the Ideate phase and leading to novel solutions may be dependent on the prompts added during brainstorming, such as problem constraints and "Yes and."

1.2 Theoretical Foundations for Team Innovation: Team Cognition and Social Constructivism

Before reviewing DT and team innovation research, it is important to briefly describe team innovation literature and then the theoretical foundation of team innovation and DT which includes team cognition and social constructivism. Several team cognition theories exist (Clark & Brennan, 1991; Cooke, et al., 2012). (See Table 1.)

Table 1. Review of team cognition theories.

No.	Contributors	Team Cognition Theory	Summary
1	Cooke et al., 2012	Interactive Theory of Team Cognition	The knowledge distributed across teams is more than the sum of individual contributions. Tenets of team cognition are: 1) It is an activity. 2) It should be measured at the team level. 3) Team cognition is tied to the context.
2	Clark & Brennan, 1991	Common Ground	A team's shared beliefs and mental models are collaboratively developed and mutually negotiated.
3	Vygotsky & Cole, 2018	Social Constructivism	A student's knowledge is constructed through their interaction with teachers and other students.

Common Ground, the Interactive Theory of Team Cognition, and Social Constructivism provide insight into some of the cognitive processes at work during DT.

They also provide a frame of reference for us to design an experiment and interpret our results. Team cognition theories suggest that team innovation needs to be measured at the team level.

Team innovation, a goal of DT, has at its foundation team cognition and social constructivism. Team innovation is a special type of team cognition. Team cognition theory focuses on the process of sharing emergent knowledge (Grand et al., 2016), whereas social constructivism focuses on the way teams construct new knowledge (Cooke, et al., 2012; Hirtle, 1996; Vygotsky & Cole, 2018). During team innovation, the total contribution is more than the total of individual contributions (Cooke et al, 2012).

1.2.1 Perspective Shifting as a Key Cognitive Strategy in DT

We believe that the effectiveness of ideation is related to perspective shifting. Perspective shifting (Damnik, et al., 2017; Mezirow, 1978) is a key constructivist cognitive strategy in DT that is leveraged in several different phases of DT which help designers to see challenges, problems, and solutions through new paradigms. Teams may shift to be user centered (empathy), or to solve a different part of the problem, or to encourage innovative solutions (Moreau & Dahl, 2005; Gerber, 2007). A Swedish DT study exploring the effects of perspective shift supports this (Calgren et al., 2014).

Perspective shifting can occur at the individual level and the team level (Klein, et al, 2006). Consequently, it is a motivation for cultivating diverse teams as diverse team members from different disciplines contribute their own framing lens. Diverse teams support perspective shift (Drach-Zahavy & Somech, 2001).

Perspective shifting and generating multiple perspectives are two constructivist experiential learning cognitive strategies to support divergent thinking (Klein et al., 2006;

Honebein, 1996; Savery & Duffy, 1995). While DT ideation or brainstorming occurs from the generation of multiple perspectives, perspective shifting is not specifically identified as a factor that supports it. Strategies that support perspective shifting during ideation should be tested further in the literature.

1.2.2 DT Ideate Strategies

Team brainstorming is a key part of the DT Ideate process. Through team ideation one builds off the ideas of others (Kohn et al., 2011). Understanding cognitive strategies to spur creativity has the potential to improve innovative outcomes during DT.

Brainstorming in DT sometimes includes new prompts or activities to support teams to generate innovative ideas (Brown, 2008). For example, the DT facilitator may add something like, “Come up with a solution that relates to science fiction.” Problem constraints can be defined as materials available or the framing/restriction of a problem. The “Yes and” improv prompt encourages individuals to build off each other’s ideas by saying “Yes and” and then adding their ideas. Both problem constraints (Gibbert, et al., 2007; Moreau and Dahl, 2005) and “Yes and” improv (Gerber, 2007; 2009) have been researched to varying degrees. For example, Moreau and Dahl (2005) found that controlling for time and problem constraints affected an increase in creativity. In addition, individuals given a task with fewer resources will look for new ways to complete it (Gibbert et al., 2007). Theater improvisation strategies are thought to improve team collaboration (Gerber, 2007), but no experiments have tested the added value yet. Gerber (2007, 2009) described how improv strategies support design and the ways that improv aligns with the goals of design and DT and cites elements of the process as creative collaboration, fostering innovation through being obvious, supporting spontaneity, and learning through error, (Gerber, 2007).

While there are a few DT phases where one might measure team innovation, the most direct would be the Ideate phase. No research to date has experimentally and quantitatively measured team innovation in DT that I found, although innovation or creativity has been studied in the brainstorming literature more generally and outside of DT (Anderson et al., 2014; c.f., Kohn et al., 2011; Parnes & Meadow, 1959). This is a first experiment to examine how many ideas, how innovative the ideas are, and the range of ideas generated during two different versions of a DT condition (DT-Baseline vs. DT-Expanded).

1.3 Creativity and Innovation Defined

Creativity and innovation definitions are entwined throughout the literature (De Dreu et al., 2011). For this thesis, here we applied the following framework. Innovation can be defined as a clear change in a process, product, or service that moves away from the normal (Anderson et al., 2014). Innovation is the act of developing something different and unique by breaking away from the current collection of knowledge. It is a process in which new knowledge is constructed (Moreau and Dahl, 2005). Creativity itself is considered out-of-the-box thinking (Peek, 2023). Creativity is often thought of as a prerequisite for innovation, but it is considered different from it (Kohn, et al., 2010) and improved by an efficient associative memory which connects different elements stored in long-term semantic memory (Kahneman, 2011). Team innovation is often measured as creativity is measured with the number of ideas generated, the conceptual diversity of those ideas, and the originality of those ideas (Kohn et al., 2011).

Innovativeness has been operationalized as the range and originality of the generated ideas in previous research (Putman et.al 2009; Moreau and Dahl 2005).

1.4 Team Innovation

Team innovation studies identify the psychological behaviors that overlap with DT, a tool to support team innovation. A meta-analysis spanning thirty years, one hundred and four studies and N=50,096 looked at the moderating effects of variables on team innovation (Hülsheger et al., 2009). Subjective innovation data included independent ratings of innovative outcomes, peer ratings, and subject matter experts. Objective innovation data was operationalized by the number of contributions, number of patents, and number of new products. Process variables correlated with innovative outcomes and most relevant to the design of our DT study, had the strongest correlation effect (Hülsheger et al., 2009). (See Table 2.)

Process variables were more strongly correlated with team innovation factors than individual innovation factors. These process variables are hypothesized to have stronger innovative outcomes (Hülsheger et al., 2009). However, as can be seen in Table 2, these process variables are described at a high level (e.g., task orientation, team vision) and it is still not clear how team innovation can be implemented. DT provides some suggestions in the phases. In the current experiment, we focus on identifying and measuring process variables in specific DT stages, such as quantifying the shifting in thinking that happens by the end of the Ideate phase and its impact on the ultimate design.

Table 2. Team process variables correlated with innovative outcomes (Hülsheger et al., 2009).

Team Process Variables	**Correlation in**
External Communication	ρ = 0.475
Internal Communication	ρ = 0.358
Team Vision	ρ = 0.493
Organizational Support	ρ = 0.470
Task Orientation	ρ = 0.415
Task Cohesion	ρ = 0.307
Goal Interdependence	ρ = 0.276

Note. In this context, ρ*(rho), used with meta-analyses refers to the linear correlation coefficient of a population, values are statistically significant,* $p < .05$.

1.5 Team Innovation Measures

The Hülsheger et al., (2009) meta-analysis did not include a review of the measures used to any of the aspects of team innovation from Table 2 (Anderson et al., 2014; Drach-Zahavy , & Somech, 2001; Hülsheger et al., 2009). In my review, team innovation is typically measured by a) the number of ideas or solutions generated (Hülsheger et al., 2009; Kohn et al., 2011), b) qualitative analysis of the novelty or innovativeness of those ideas or possible solutions generated (Hülsheger et al., 2009; Kohn et al., 2011), c) subjective ratings of the experience or team innovation (Hülsheger et al., 2009; Kohn et al., 2011) and d) external evaluation of the quality of ideas or the final outcome (Hülsheger et al., 2009).

1.6 Design Thinking Research

Cagan et. al, (2013) conducted a survey of 25 years of DT research and found gaps in the literature. One of these gaps was identifying the cognitive framework involved in DT. Another was the lack of DT theories. A reason suggested for gaps in the research was that analysis is tedious due to large volumes of data. It was suggested that future research would benefit from automated collection and analysis to move research forward more rapidly. In addition to Cagan's DT survey, three additional case studies were reviewed. Observation, reflection, and semi-structured interviews were used to operationalize innovation. In the Fu et al, (2023) study, a Q-sort rank ordering procedure was used to evaluate practitioners', such as designers' and product managers', perspectives on the DT process. In another, by Mosley et al., (2018) practitioners ran two, 2-hr DT workshops, one in Australia and Netherlands, and compared facilitators' reflections on the experience. In a third study, a diabetes app was developed, and semi-structured interviews were conducted to understand the user experience during the test phase (Petersen & Hempler, 2017). We didn't find a controlled experiment comparing two DT conditions, or quantified results. Empirical research includes mostly case studies without team measures and no controlled experiments quantifying innovation or controlling to a baseline condition.

While there may be gaps in the DT thinking literature, elements of the DT process have been employed in human-computer interaction and engineering design processes since the 1960's (Fu et al., 2022; Dym et al., 2005; Razzouk, & Shute, 2012). Of the findings reviewed, Dym et al, (2005) concluded that experts are breadth focused while novices are depth focused. Experts prioritize solution elements while novices treat elements equally. This insight points to the importance of finding cognitive strategies to shift perspectives for students engaged in the DT process. DT researcher, Jeanne Liedtka (2018), a DT business professor deconstructs the DT process and demonstrates its alignment with management best practices. To drive team innovation, the cognitive mechanisms that support DT team innovation need to be measured.

While researchers have conducted empirical studies (cf. Cagan et al., 2013 for review), they were mainly case studies (Fu et al., 2023; Mosely et al., 2018; Petersen & Hempler, 2017), while controlled experiments involving DT are missing. Therefore, this thesis will contribute to this body of research by conducting an experiment using DT in a team setting on a real-world problem and focusing on the phase where the novel solutions are initially generated (Ideate phase).

While DT experiments are limited, research on elements of the DT Ideate process exist, such as the extensive research on brainstorming strategies (cf, Kohn, et al., 2011; Parnes & Meadow 1959; Putman & Paulus, 2009). For example, Parnes and Meadow's (1959) seminal brainstorming experiment provided evidence that guided brainstorming, the baseline strategy used in the DT Ideate stage, stimulates creativity, and resulted in more ideas and more unique ideas when students were challenged to come up with all possible uses for a wire coat hanger. Brainstorming, problem constraints, and improv strategies have been studied in separately as mentioned above (Kohn et al., 2011; Parnes & Meadow, 1959; Putman & Paulus, 2009; Moreau & Dahl, 2005; Gerber, 2009), but have not been experimentally tested often in DT context (Ely, 2023).

This thesis project involves an experiment that evaluates the overall effect of these DT prompt strategies to shift teams' perspective and increase their innovation and creativity. Based on the literature review, no such experiment has been performed. This thesis makes several contributions to the literature. It is conducting the first controlled experiment of the complete DT process and tests strategies to support innovation.

Therefore, the first controlled experiment should be one that compares a baseline DT (i.e., DT-Baseline) approach during the Ideate phase to one that includes additional prompts (DT-Expanded) while controlling for time on task. To quantify and evaluate team innovation, the experiment will focus on the output of the Ideate phase and the final proposed solution at the end of the Prototype phase. While there are several prompts to choose from, two common ones used in DT were chosen: adding a problem constraint, and a “Yes and” improv prompt. Both strategies are designed to shift teams' perspectives on a problem to allow them to generate more innovative solutions. The problem constraint does this by focusing the mind which is more likely to accept an unusual idea when focus is narrow (Gibbert et al., 2007). The “Yes and” prompt does it by having teams playfully and collaboratively riff on ideas with no critiquing. We test that in a semester-long project involving each stage of DT where student teams spent a semester developing solutions to a real-world problem.

2 Research Questions and Hypotheses

This research addresses the following questions: Does adding perspective shifting prompts to DT lead to more ideas or more original ideas? How does this activity affect an individual's perception of their own innovativeness? Do teams generate more novel final solutions as a result. Based on the literature, we have the following hypotheses.

H1: Compared to teams in the DT-Baseline condition, DT teams that use problem constraints and an improv activity (DT-Expanded) will generate more ideas overall.

***H2**:* Compared to teams in the DT-Baseline condition, teams that use DT with problem constraints and an improv activity (DT-Expanded) will generate more innovative ideas.

If the prompts are shifting people's perspectives to new design solutions, one would expect these teams to generate more innovative ideas than DT-Baseline teams. This hypothesis was evaluated by content coding of the ideas generated.

H3: Compared to teams in the DT-Baseline condition, DT-Expanded teams will rate the number of ideas generated as higher and rate their ideas as more innovative.

H4: Compared to teams in the DT-Baseline condition, DT-Expanded teams' final solutions will be rated by both their own team and another evaluating team as more innovative.

If DT-Expanded teams develop more innovative final solutions as predicted in H2 and H3, then they should rate their final solutions as more innovative than DT-Baseline teams, and other teams should rate DT-Expanded final solutions as more innovative than DT-Baseline teams.

3 Method

3.1 Participants

Participants included 145 Michigan Technological University students enrolled in an *Introduction to Psychology* course working in teams of two to four who were working on a semester-long DT project. Students completed an IRB opt-in consent form in accordance with the IRB. All 145 undergraduate college students opted in. No other demographic data were collected. Participants did not receive compensation or credit for the participation. Team data were dropped if the team size was too small (less than two) during the Ideate phase when the empirical data collection occurred. This resulted in two teams being dropped in the control condition (DT-Baseline), and one team in the experimental condition (DT-Expanded). There were 23 teams of two to four for the control condition and 24 teams for the experimental condition. There were 47 teams total.

3.2 Experimental Design

The experimental design was a 2 *DT Condition* (DT-Baseline, DT-Expanded) x 2 *Idea Type* (Common, Innovative) mixed-factorial ANOVA on the number of *Ideas Generated*. The *DT Condition* was the between-subjects independent variable and *Idea Type* was a within-subjects independent variable nested within teams. Team was treated as a nested random factor, while *Idea Type* and *DT Condition* were treated as fixed factors. Statistical analyses were conducted in R using Rstudio. The 'lmer' function of the lmer4 library was used to account for the fixed and random effects in the experimental design. A planned post-hoc pairwise comparison with Tukey's Honest Significant Difference was used to identify significant differences between the tested groups.

The dependent variables were the overall number of ideas generated during the 10-minute DT Ideate phase for *H*1, ratings of those ideas for *H*2, and content coding of those ideas. To evaluate the originality of the ideas for *H*2, we used the distribution percentage of those ideas based on the originality or innovativeness of each team's generated ideas coding scheme which is described below. (See Tables 4, 5, and 6.)

The dependent measures were the group mean *Total Ideas*, *Innovative Ideas* and *Common Ideas* generated per team. Effect sizes were calculated using eta squared with an $\eta 2 = 0.01$ indicating a small effect. $\eta 2 = 0.06$ indicates a medium effect. $\eta 2 = 0.14$ indicates a large effect (Cohen, 2007; Draper, 2011).

The independent variable, type of DT activity, we will refer to as *DT-Condition*. The DT-Baseline condition included a 10-minute brainstorming session with no additional prompts. The DT-Expanded condition included a 10-minute brainstorming session with two additional prompts during the ideation phase: problem constraint (Moreau & Dahl, 2005) and “Yes and” theater improv strategy (Gerber, 2007). Table 3 outlines the two experimental conditions.

Table 3. Independent variable description by DT activity.

Conditions	DT Ideate	DT Problem Constraint	DT Collaborate: “Yes and”-improv
Baseline DT (n=23 teams)	X		
Experimental (n=24 teams)	X	X	X

3.3 Task and Measures

The team task was to choose and develop novel solutions for one of the 17 UNESCO sustainable problem challenges provided in Appendix B.

Team innovation was measured several ways. At the end of the Ideate phase, each person was asked three questions about the number of ideas, how innovative the ideas were, and what was innovative (Appendix C.). At the end of the semester and after the DT prototype exercise, teams evaluated their own solution and another team's solution in their class section that included an *Individual Team Evaluation* and *Other Team Evaluation* survey. Individuals completed a team survey using a 9-point Likert rating scale on a scale ranging from 1 (not very) to 9 (very) and rated their final solutions across three dimensions: how innovative, how doable, and how impactful. (See Appendices D & E.).

The questions were:

- Our team/Team X solutions seem innovative
- Our team solution/Team X solutions seem doable
- Our solutions could have a large impact

3.4 DT Team Innovation Coding Schemes

Innovativeness has been operationalized as the range and originality of the generated ideas in previous research (Putman et.al 2009; Moreau and Dahl 2005). Several coding schemes were developed to evaluate *H1* and *H2*.

To evaluate *H2*, we qualitatively analyzed the DT ideas team-generated solutions in terms of three dimensions: originality (Table 5), the target audience for the solution (Table 5), and the strategic function of the idea (Table 6).

Two independent coders rated the originality of each solution (Moreau and Dahl 2005; Kohn et al., 2011). Coders trained on subsets of the data, with about 30 to 40 ideas, until they achieved an inter-rater reliability (IRR) using a Cohen's Kappa of at least .7 (Cohen, 2007). Cohen's Kappa is a percent agreement that controls for chance agreement. The coders achieved the following Inter-rater reliability measures:

- In the originality category, a Cohen's Kappa of 0.82 was achieved after three training rounds, each with about 30 different items from the corpus of data.
- In the target audience category, a Cohen's Kappa of .82 was achieved after two rounds.
- In the strategic function category, a Cohen's Kappa of .7 was achieved after three rounds.

3.4.1 Originality Coding Scheme.

Two independent coders rated the originality of each solution were adapted from previous innovation research (Moreau and Dahl 2005; Kohn et al., 2011). They used four categories. Novel, divergent, and extended were grouped as innovative ideas. Common were ideas that are not different or widespread. Other ideas were dropped for the analysis.

Table 4. Originality coding scheme.

Originality Code	Definition	Example
Common	A solution widely used in different contexts	Promote charities around campus
Novel	New and unique idea	Build a dome of mirrors to focus energy on one point
Divergent	Applies an existing solution in an unusual way	Sponsor exchange programs to immerse students in a (UN) challenge
Extended	By adding features, attributes, or changing an idea's function.	Use QR codes around campus that direct students to companies that plant trees
Other	Not codable, missing, or didn’t fit into any other category	Beat racism

3.4.2 Descriptive Data Coding Schemes

The ideas were also coded along the dimensions of target audience and the strategic function to look for patterns and trends to provide insight into DT activity outcome differences between the DT-Baseline and DT-Expanded. (See Tables 4 & 5.) Target audiences were simply defined in terms of the focus on improving an individual, a group, or a community behavior, experience, or outcome. Target audience might be interesting and informative if focus shifted between the two DT conditions. For example, if the DT-Expanded teams shifted their target audiences because of different idea-generation activities that would be interesting to explore. For example, if DT-Baseline teams were found to focus on individuals predominantly and DT-Expanded teams shifted to include more group and community efforts.

Table 5. Target audience coding scheme.

Target Audience Code	**Definition**	**Example**
Individual	A solution target to an individual	Create incentives for donating
Group	A solution targeted to a collection of individuals with common factors such as interests, geography, etc.	Lower the cost of tuition so that students can afford to donate
Community	A larger collection of groups who would apply a solution	Offer local jobs

Like the target audience coding, data were also coded for strategic function as innovation might vary in terms of the type of strategic function. Strategic Function might be informative if for example, the DT-Expanded Group shifted to incentivize or service ideas rather than survey or punish.

Table 6. Strategic function coding scheme.

Strategic Function Code	Definition	Example
Inform	A solution designed to educate the target audience.	Provide step-by-step ways to clean certain things.
Service	A solution that provides an act of service to the target audience.	Collect gray water, recycle it.
Survey	A solution that gathers either information, data, or evidence to inform the target audience.	Address concerns of students with disabilities, take a poll.
Incentivize	A solution that positively motivates the target audience to take action.	Grant more extensions.
Punish	A solution that penalizes the target audience and restricts their actions.	Turn off the heating.

3.5 Procedure

Using psychological strategies and the DT process, student teams were challenged to come up with an innovative solution for one of 17 United Nations sustainability goals (https://sdgs.un.org/goals). (See Appendix B.) The DT exercise took the entire semester; however, the experiment was embedded into the single session for the DT Ideate phase class activity and was conducted during two sections of an *Introduction to Psychology* class. Each section completed one of the DT conditions, with the DT-Expanded group happening in the first section and the DT-Baseline in the second section. The same instructor led both sections. This way if the instructor improved their delivery in the second section, that improvement would favor the control or DT-Baseline group. (See Appendix A for Procedure.)

Each team performed a DT Ideate brainstorming task for 10 minutes to generate solutions for their chosen United Nations problem. The ideate phase happened about 6 weeks into the semester after all teams had completed the DT Empathy and Define problem phases. For the Ideate phase the teams in each DT condition completed a set of activities (See Figure 2.). DT-Baseline teams defined a problem, headlined their framing statement, and then brainstormed ideas for 10-minutes total. DT-Baseline teams were instructed to "Generate as many solutions as you can - don't edit, critique," with no further instruction. In contrast, teams in the DT-Expanded condition completed the same steps, and then brainstormed for 10-minutes total, but their brainstorming activities differed. They first brainstormed solutions for four minutes, and then received a resource constraint. They were told to "Brainstorm solutions that could be implemented tomorrow," for the next three minutes. The final three minutes, an improv activity was introduced. DT-Expanded teams were asked to build off any idea on the table while saying "Yes and" aloud.

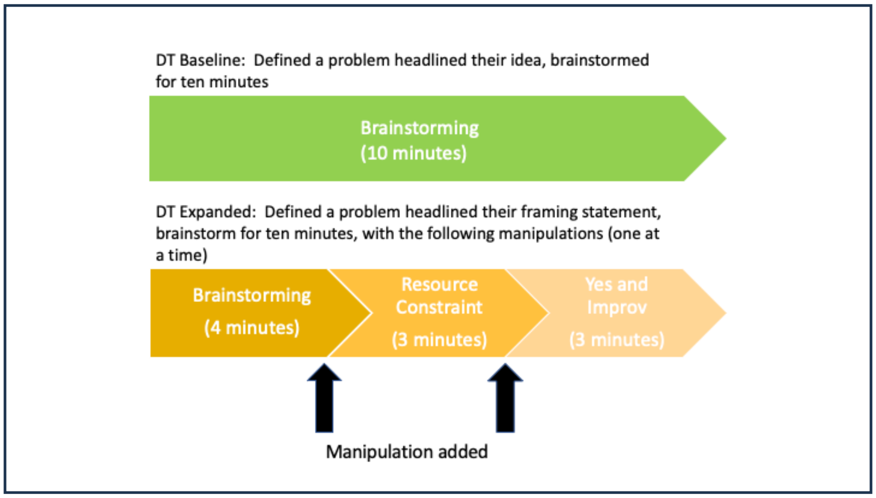

Figure 2. Comparison between DT-Baseline condition and DT-Experimental condition.

After completing the DT Ideate phase, each student rated their team's process and ideas generated using a 9-point innovativeness rating scale. Students were also asked; What was innovative about the process? (See Appendix C.) Later in the semester after teams had identified their best idea and completed prototype solutions, students were asked to evaluate their team's solution and a partner team's solution by rating it on three dimensions.

4 Results

4.1 Descriptives

The 47 teams generated a total of 895 ideas that were coded as described above. DT-Baseline teams averaged 8.53 (SD=6.26) ideas per team during the 10-minute Ideate period, while the DT-Expanded teams generated 12.48 ideas (SD=10.78) per team. (See Table 7.) Breaking down the DT-Expanded team's ideas, 46% were generated during the baseline instructions (4 minutes), 26% during problem resource constraint, and 28% during the improv "Yes and." Of the 895 ideas, 752 were common, 16 were novel, 9 were divergent and 78 were extended ideas (the remainder dropped). Given the small frequency in these idea categories, these three types of innovation collapsed into a single innovative category.

Table 7. Breakdown of ideas by DT condition.

DT Condition	Common Ideas M(SD)	Innovative Ideas M(SD)	Total Ideas M(SD)	Total Ideas
DT-Baseline (n=23)	12.0 (SD=5.59)*	3.56 (SD=2.92)	8.53 (6.26)*	333
DT-Expanded (n=24)	19.8 (SD=9.77)*	4.09 (SD=2.07)	12.48 (10.78)*	562

Note: * is statistically significant, $p<.05$

For the main hypothesis, a 2 x 2 mixed-factorial ANOVA was used to test the effect of *DT Condition* (DT-Baseline, DT-Expanded) and *Idea Type* (Common, Innovative) on the *Number of Ideas Generated.* Post hoc pairwise comparisons were conducted using the Tukey's Honest Significant Difference (TukeyHSD). Each hypothesis and the additional analyses are discussed below.

H1: Compared to teams in the DT-Baseline condition, DT teams that used problem constraints and an improv activity (DT-Expanded) will generate more ideas overall. *H1* was supported. In addition to the interaction, $t(38) = -3.61$, $p = .00004$. there was a main effect of the *DT Condition* on the number of ideas, $F(1,35) = 19.1$, $p = .0001$, $\eta 2 = .35$ which is a large effect. DT-Expanded teams generated more ideas than teams in the DT-Baseline condition (see Table 7).

H2: Compared to teams in the DT-Baseline condition, teams in the DT-Expanded will generate more innovative ideas.

Surprisingly, *H2* was not supported. Using the 2 x 2 mixed factorial ANOVA described above, there was a statistically significant interaction between *DT Condition* and *Idea Type*, $F(1,35) = 5.56$, $p = .024$, $\eta 2 = .14$, but it was not in the direction predicted (See Figure 3). To evaluate the interaction, planned comparisons of *DT Condition* on the number of innovative ideas and common ideas were conducted separately. There was no statistically significant difference of *DT Condition* for innovative ideas, $F(1,35)=0.33$, $p=0.57$, however, there was for common ideas, $F(1,45)=11.23$, $p=.0016$. This indicates that the *DT-Condition* difference in the total number of ideas generated was driven by the common ideas.

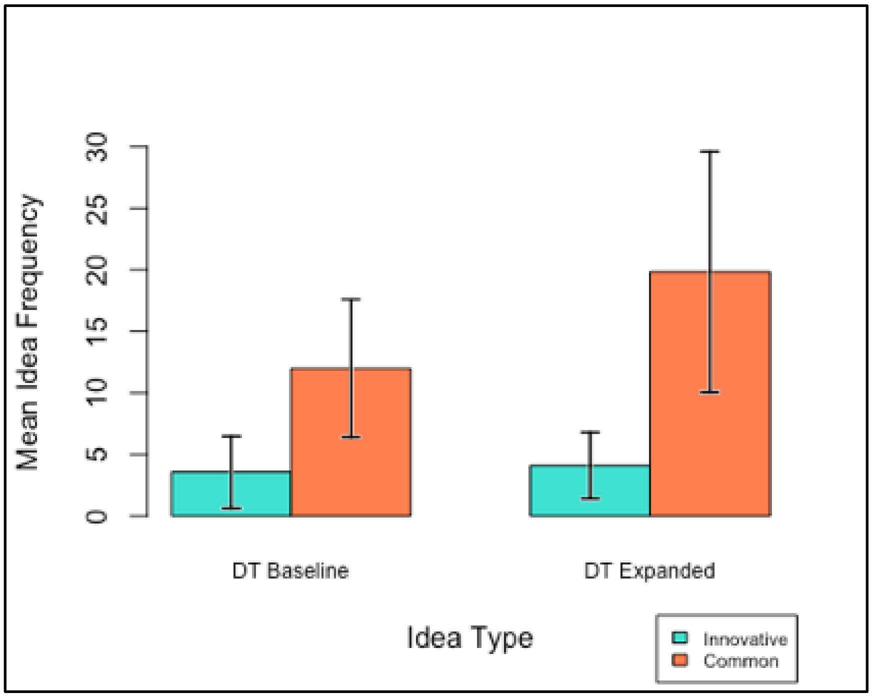

Figure 3. Mean and Standard Deviation for Innovative and Common Ideas by DT Experimental Condition.

H3: Compared to teams in the DT-Baseline condition, DT-Expanded teams will report generating more ideas and generating more innovative ideas (both subjective ratings). (See Appendix C.)

In addition to the actual number of ideas generated which was evaluated in H2, this analysis involved subjective ratings of innovation. Using a *t*-test to compare DT Conditions on these ratings, the DT-Expanded teams (M=7.0, SD=1.5) rated the frequency that they had more innovative ideas, higher than the DT- Baseline teams rating (M=6.46, SD=1.63), a difference $t(138)= -1.92$, $p= .05$, with a Cohen's d =.322, a small to medium effect. (See Figure 4.)

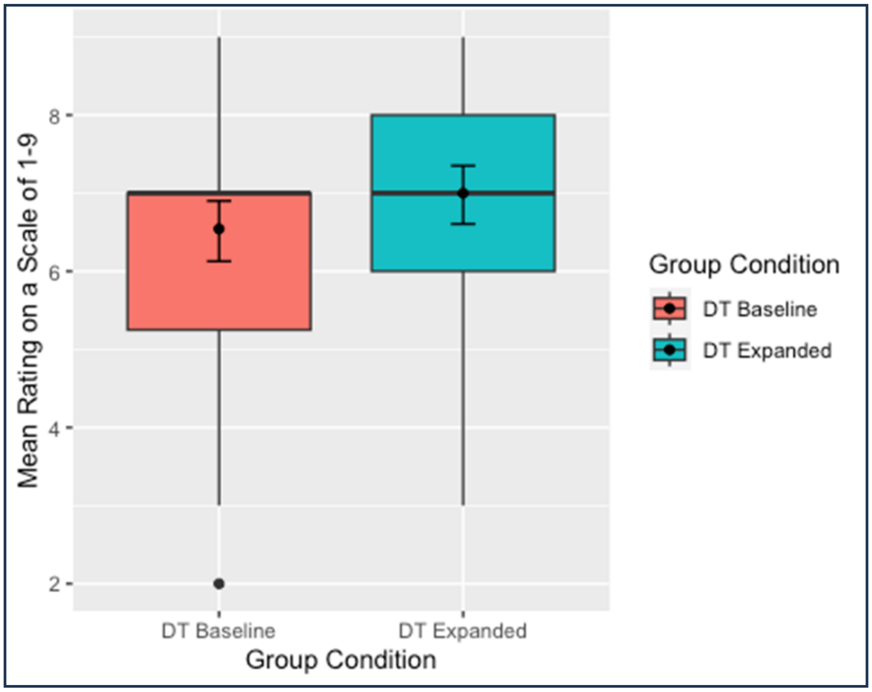

Figure 4. Mean and Standard Deviation for Number of Ideas Rating by Group Condition.

However, the second part of this hypothesis is not supported. The difference between the number of ideas rated as innovative between the DT-Baseline group and the DT-Expanded was not statistically significant. DT-Baseline team (M=6.18, SD= 1.64) and DT-Expanded group ratings (M= 6.62, SD =1.55) did not statistically differ in their innovativeness ratings at the end of the Ideate phase $t(135)= -1.53$, $p=.12$, with a Cohen's $d=.265$. (See Figure 5.) While teams felt that they generated more ideas when using problem constraints and an improv activity (DT-Expanded) than in the DT-Baseline condition, the DT-Expanded group did not feel that their results were more innovative than the DT-Baseline condition.

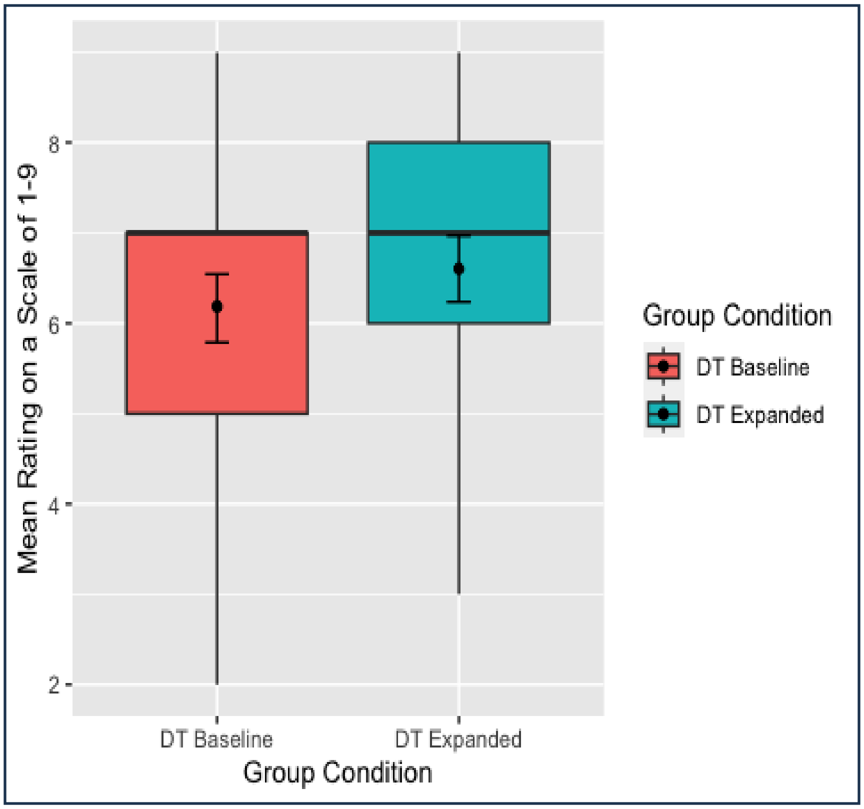

Figure 5. Mean and Standard Deviation for Innovativeness Rating by Group Condition.

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H4: Compared to teams in the DT-Baseline condition, DT-Expanded teams' final solutions will be rated as more innovative by their own *Individual Team* and by an *Other Team* in the same DT Condition. (See Appendices D & E.)

While the previous analysis focused on the ideate phase output, this analysis focused on final prototype solutions. A *t*-test comparison was used to evaluate the quality of the design project solution at the end of the semester. Each participant on a team was asked to rate their own team's and another team's final prototype solution on three dimensions: innovativeness, doability, and impactfulness.

First, I will discuss the *Other Team* rating results. Other ratings of team's innovativeness statistically differed by DT-Condition, $t(145)= -2.06$, $p= .04$, Cohen's d =-.33, a small to medium effect. Descriptives (means and standard deviations) are reported in Table 8. As hypothesized, the DT-Expanded teams were rated as more innovative than the DT-Baseline teams' solutions. They were also rated as more doable, $t(143) = -2.32$, $p = .02$, Cohen's $d = -.38$, a small to medium effect. However, there was no difference between the DT-Baseline and DT-Expanded teams on the impact scale, $t(148) = -1.058$, $p = .29$, Cohen's $d = -.17$.

Table 8. Team solution outcome ratings by own team and other team.

DT Condition	DT-Baseline		DT-Expanded	
Team Condition	Other Team Evaluation	Individual Team Evaluation	Other Team Evaluation	Individual Team Evaluation
Innovative	M=6.56 (1.35)*	M= 6.49 (1.47)	M=7.08 (1.72)*	M=6.61, (1.77)
Doable	M=7.5 (1.38)*	M = 8.01 (1.11)	M=8.0 (1.25)*	M= 8.2 (1.08)
Impact	M= 6.87 (1.67)	M=6.83 (1.62)*	M=7.17 (1.83)	M=7.51 (1.33)*

Note: Scale of 1(low on the dimension) to 9 (high on the dimension); *is statistically significant, $p<.05$

Individual teams were also asked to rate their own final solutions across the same three dimensions: innovativeness, doability, and impactfulness with descriptives reported in Table 8. Interestingly, when looking at their own team prototypes, DT-Expanded did not rate their solutions to be more innovative or doable than DT-Baseline, but they did rate their projects higher on impact. DT-Baseline teams and DT-Expanded did not statistically differ for innovativeness, $t(134) = -.044$, $p = .656$, Cohen's $d = -.07$.

Both groups thought their solutions were very doable with a score of 8 out of 9, but there was no statistical difference by DT Condition, $t(144) = -1.03$, $p = .302$, Cohen's $d = -.17$.

However, there was a statistically significant difference for the impact rating $t(143) = -2.80$, $p = .005$, Cohen's $d = -.46$, a medium effect. DT-Expanded teams rated their impact as higher than DT-Baseline teams.

Innovativeness of another team's final solution was rated higher by DT-Expanded teams, but individual DT-Expanded teams did not rate their own solutions as higher. Doability and Impactfulness were a proxy for quality and not part of our hypothesis but gathered to give us an indication of the effectiveness of the manipulations.

5 Discussion

The first hypothesis, *H1*, that DT-Expanded teams will generate more ideas overall was supported. Therefore, we can infer that resource constraints and an improv activity (Gerber, 2007) stimulated idea generation. This is consistent with DT research that the Ideation phase leads to more solutions, idea creation, and taking multiple perspectives (Parnes & Meadow; Honebein, 1999; Savery & Duffy, 1995).

However, interestingly, this difference was not driven by the number of innovative ideas as predicted by the DT literature and our second hypothesis. It is thought-provoking to note that the number of common and overall ideas was statistically greater in the DT-Expanded condition than in the DT-Baseline condition. If we assume that the more ideas generated during brainstorming will increase the chance of innovative ideas being generated, and that generating innovative ideas drives the final product evaluation, then this result is surprising (Putman & Paulus, 2009). During brainstorming, students were prompted to create as many ideas as possible. Teams were building on the ideas generated initially by using a resource constraint and then the “Yes and” improv prompt. No difference in the number of innovative ideas suggests several potential explanations. One explanation of these data is that the prompts were not effective for lateral thinking. The resource constraint used was “an idea that could be implemented tomorrow.” This may have shifted students towards pragmatic rather than innovative solutions. As amateurs in this problem space, they may have chosen more conservative ideas rather than ideas that were more broadly influenced (Cagan et al., 2013). Another explanation in support of this interpretation was demonstrated by the ideas generated during the “Yes and” prompt. When building off another idea, students anchored on the original solution rather than their shifting perspective to a novel solution. Kahneman (2011) provides evidence of the anchoring effect observed during decision making. Individuals anchor on initial information presented and use that information as a baseline for their decision making. An alternative explanation of our data is that innovative thinking happens either earlier or later in the DT process, not during the DT-Ideate phase. If it happens in an earlier phase, one might expect a higher baseline of innovative ideas than the 11% of ideas in this experiment. If it happens later in the DT-Ideate phase or in the DT-Prototype phase, one might expect that the prototype, informed by reflection and the discovered parameters from creating a prototype, would differ significantly from the brainstormed ideas. However, this was not collected in the current study. Adding resource constraints and the “Yes and” prompts was theorized to help teams shift their perspective, but they did not (Moreau & Dahl, 2005; Gerber, 2009). While the resource constraints helped students to generate more ideas it may have limited the students' ability to think laterally. It may have been the prompt used of the method generally, future research will need to evaluate these hypotheses as we cannot tell from the future experiment. Rather than shifting their perspectives, students instructed to come up with a “solution that could be implemented tomorrow” for the resource constraint may have shifted towards known ubiquitous solutions. Further research should focus on second DT study with less pragmatic resource constraints and new lateral thinking strategies besides “Yes and,” should be applied. This research would allow a stronger test of the shifting perspective hypothesis suggested by DT guru Tim Brown (2008). DT is a tool to find hidden requirements to identify innovative solutions that address gaps in status quo solutions. If lateral thinking prompts during the Ideate phase of DT generated a statistically greater number of innovative ideas than the prompt used in the current study, it will provide evidence that perspective shift is a key cognitive strategy that leads supporting creative cognition and innovation outcomes during DT (Cagan, et al., 2013;). Lateral thinking strategies such as remote association, analogical transfer, visual synthesis, conceptual combination, and restructuring are some of the potential strategies supported by the creativity literature (Sassenberg, 2017; Holyoak, 1985; Finke & Slayton, 1988; Smith & Osherson, 1984; Weisberg, 1995).

The third hypothesis was partially supported. Teams felt they were more productive in terms of the quantity of ideas, but not more innovative. These subjective ratings mirrored the empirical outcomes in *H1* and *H2*.

Finally, DT-Expanded teams' final project solutions were rated as more innovative than DT-Baseline teams. Curiously, when individual teams in the DT-Expanded condition evaluated their own final solution, they did not feel that their final solution was more innovative. However, in the DT-Expanded group, teams did rate another team's solution as more innovative. An explanation may be that the DT process seemed innovative to them, and other teams' final solutions were different from their own, seeming novel. However, when rating their own team's project solution, they did not feel that they shifted away from common solutions into innovative solutions. This meta-analysis supports the explanation that perspective shift did not occur.

When looking at additional measures, apart from our hypotheses, we see some interesting patterns. With regard to impactfulfulness, the DT-Expanded (Other Team) did not rate the Other team's final solution as more impactful, even though they did rate the Other team's ideas as more innovative. The DT-Expanded (Individual Team) rated their final solution as more impactful but they did not rate their Individual solution as more innovative. We speculate that the reason for this may be that the teams interpreted impactful like doable and therefore were reflecting on a lack of perspective shift. However, it is impossible to conclude this without further studies. What is evident is that the evaluation of Other Team solutions was thought of differently from one's own.

Team innovation is a constructive process in which the team breaks away from existing information to create something new and novel. DT-Expanded teams with two additional prompts did not do that more than the DT-Baseline teams, surprisingly. Surveys about the DT Process outcomes as well as the final prototype created indicate that team members themselves did not feel a perspective shift within themselves, but they did attribute it to another team.

5.1 Limitations

There are several potential limitations in this study. First, students may not have been creative due to inexperience in either DT or the domain. Students were challenged to come up with a solution to one of the 17 Sustainable Development goals (https://sdgs.un.org/goals) but may not have had enough knowledge to generate innovative solutions, regardless of DT prompts. Students themselves were amateurs in both areas in which this problem is frames, psychology, and sustainable development. This may have led them to build on a presented solution, rather than generating a different solution. Second, the only evaluation of the innovativeness of the project solutions generated were individual team ratings and other team ratings. It is possible experts might have rated the solutions differently. Finally, this was a single quasi experimental design study as part of a class that only compared DT methods. It did not compare the overall DT process to a control condition without DT, therefore, we cannot make claims about DT innovation relative to other methods. For this type of comparison, this study would need to run in a controlled lab experiment, compared to other design methods, and replicated in additional longitudinal studies.

5.2 Conclusion

As we face the challenges of the 21st Century, tools like Design Thinking offer a lens in which to study team innovation. DT holds the promise of facilitating team innovation, yet it should be better understood at a cognitive psychology level in order to adapt it as this tool. To do this we need to better understand which strategies are most effective in various contexts. During the DT phases, where is perspective shift happening? How do DT practitioners best support lateral thinking? Better understanding of DT at a cognitive level will have implications towards a better understanding team innovation. What are the factors that support the team innovation process and innovative outcomes? It is the goal of this research to better understand cognitive processes such as perspective shift and strategies to support to understand how we might improve lateral thinking during team innovation. This has implications for both higher education, corporations as well and their stakeholders.

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Appendix A: DT Condition – Procedure Details

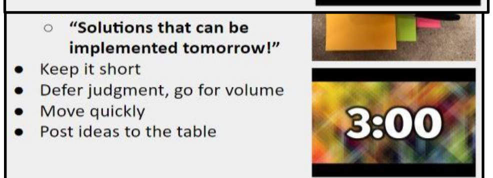
DT Condition - Procedure Details

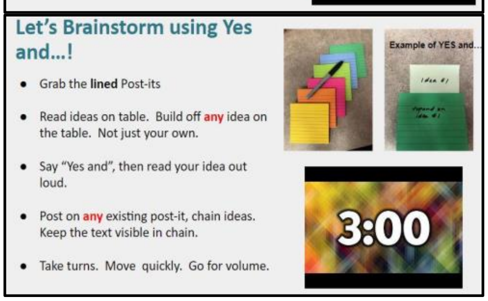
DT-Baseline: Defined a problem, headlined their framing statement, and brainstormed solutions for 10 minutes.

DT-Expanded: Defined a problem, headlined their framing statement, brainstormed solutions for 10 minutes broken down by:

- baseline brainstorm, 4 minutes
- problem constraint - “A solution that could be implemented tomorrow” and brainstormed for 3 minutes (perspective shift)
- “Yes and” improv activity to build off others’ ideas for 3 minutes (collaboration)

DT-Expanded Instructions to class -





Appendix B: 17 Sustainable Development Goals

17 Sustainable Development Goals

Appendix C: Innovation Survey

Innovation Survey

Subjective rating items at the end of the Ideate Phase.

Using the scale provided, please answer the following questions:

- Compared to other brainstorming experiences, did you feel that your team generated more ideas?

(Fewer ideas) 1 2 3 4 5 6 7 8 9 (More ideas)

- How innovative were your team's ideas?

(Not very innovative) 1 2 3 4 5 6 7 8 9 (Very innovative)

- Briefly describe what part of the process made it innovative in your opinion.

Appendix D: Final Solution – Individual Team Evaluation

Final Solution - Individual Team Evaluation

Questions:

- How innovative does your solution seem?

(Not very innovative) 1 2 3 4 5 6 7 8 9 (Very innovative)

- How doable does your solution seem?

(Not very doable) 1 2 3 4 5 6 7 8 9 (Very doable)

- How impactful does your solution seem?

(Not very impactful) 1 2 3 4 5 6 7 8 9 (Very impactful)

Appendix E: Final Solution – Other Team Evaluation

Final Solution - Other Team Evaluation

Questions:

- How innovative does your solution seem?

(Not very innovative) 1 2 3 4 5 6 7 8 9 (Very innovative)

- How doable does your solution seem?

(Not very doable) 1 2 3 4 5 6 7 8 9 (Very doable)

- How impactful does your solution seem?

(Not very impactful) 1 2 3 4 5 6 7 8 9 (Very impactful)