Incorporating Divergent Thinking Skills Development into a Project-Based Course in Industrial and Systems Engineering

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Abstract

We developed curriculum for a divergent thinking skills development (DTSD) module and incorporated this module into a project-based course in industrial and systems engineering. DTSD curriculum includes a series of idea generation exercises that the students completed individually or in teams. In each divergent thinking exercise, students were asked to generate multiple ideas for a given “problem” under a strict time constraint. After each exercise, a facilitated reflection session allowed for students to learn the idea generation approaches that were used by their peers. We examined the effectiveness of the DTSD module using two measures: (1) changes in self-perceptions of creative ability and mindsets and (2) reflections on the influence of DTSD training. Questionnaires containing the Short Scale of Creative Self and Creative and Fixed Mindset measures were administered before training, after training, and at the end of the course. Reflections on the training were collected after training and at the end of the course. Students responded to prompts about the influence of the DTSD module on their creative self-perceptions, their approach to the course deliverables, and their future careers as well. Data was collected in summer 2019 and fall 2019 semesters. Although first round of data collection in summer 2019 semester provided some evidence on the effectiveness of the training module, the second round of data collection in fall 2019 did not provide further support for the evidence. Our third round data collection is ongoing, and will allow for more in depth analysis of the barriers to teaching divergent thinking to engineering students.

Keywords

Industrial and systems engineering, creativity, divergent thinking, project-based course

Introduction

As the pace of change is increasing rapidly at every facet of human existence, problems are becoming extremely complex. Therefore, individuals with creative mindsets are becoming indispensable members of the future workforce [1]. However, neither the development of creative skills nor the cultivation of creative mindsets of engineering students is being adequately addressed in existing engineering education curricula [2].

Literature on creativity reveals that there exists a rich body of empirical work that examines the processes through which a creative result can be obtained. These studies have led to several theories that provide possible explanations of the sources of creativity. One such theory is from Guilford [3] who distinguishes between divergent and convergent production (i.e., thinking). While divergent thinking relates to an ability to generate and conceptualize multiple solutions to a given problem, convergent thinking relates to an ability to identify and develop one correct solution. Engineering education curricula are primarily designed to develop the convergent thinking skills of students with little or no emphasis on divergent thinking skills development (DTSD). Consequently, there is a need to enhance current educational material and practices in discipline-specific and general engineering curricula to emphasize various exercises for DTSD and provide multiple opportunities for students to utilize divergent thinking skills.

To address this need, we developed a module to provide DTSD training for a required project course in the Department of Industrial and Systems Engineering at the University of Florida (UF). As industrial engineers deal with complex, often multidisciplinary problems, development of divergent thinking skills are imperative to their ability to ideate solutions.

The remainder of the paper is organized is follows. In the next section, we describe the course and the DTSD module content and delivery. The following section gives an overview of the design and execution of the study. More specifically, we describe the participants of the study, present our approach to data collection, and discuss data cleaning and analysis. Next, we present summarized results from our data collection and discuss our findings. In the last section, we give concluding remarks and discuss our ongoing work.

Decision Support Systems Course

The DTSD training was introduced into Spreadsheet-Based Decision Support Systems (ESI 4356) which trains students how to use Excel and VBA features to create a decision support system (DSS). A DSS combines people and technology together to assist user's decision-making processes. It is not intended to replace the user, rather expand their capabilities by transforming data into usable information which can also be used in simulations or optimization models and presented to the decision makers through user interfaces to improve the effectiveness of making a decision.

The focus of this class is introducing how industrial engineering topics can be implemented in Excel and how these topics can be combined to assist users with making difficult multi-dimensional solutions. This course teaches students how to transform large amounts of data into actionable information and important metrics using user-friendly graphics that assist the user in categorizing, analyzing, and comparing solution alternatives. IE topics such as Operations Research, Engineering Economy, and Simulation are heavily expanded upon to show students additional applications and solution methods in Excel.

This course is broken into three main sections: VBA, Excel, and Project Work. During the first portion of the class, students are introduced to Excel's programming language VBA which is an Object Orientated Programming (OOP) language. One of the prerequisites for this course introduces another OOP language, and the students can begin immediately with Macros as well as simple programs involving branching statements and loops. A large topic of the VBA section is Advanced User Interface and Charts. This section focuses on how to create user friendly visuals.

The second portion of the course is focused on Excel itself. This includes Functions and Formulas, Pivot Tables, basic Simulation Tools, and solving mathematical programs using Solver. This section focuses on the front end of Excel and transforming and interpreting large amounts of data into an organized fashion. This could either be a summary report, chart, or outputs from a simulation.

The last portion of the course allows students to use all the material they have learned to complete a project. These projects are large scale, multi-dimensional problems that are typically done in groups of 6-8 students. Students are given a prompt that is open ended and asked to create a fully functioning DSS that completes the task set out for them. There is never one way to complete this task, and students can pursue multiple different paths to complete the project. This leaves room for the teams to demonstrate their creativity and drive. For example, in the summer semester of 2019 the final project topic was a production schedule and shipping program, while in the fall semester of 2020, the project topic was a preliminary heart disease prediction and recommendation tool.

DTSD Training Content and Delivery

DTSD training includes a series of idea generation exercises that are to be performed individually or in teams. In each divergent thinking exercise, students are asked to generate multiple ideas individually for a given "problem" under a strict time constraint. These problems are not engineering problems but arts-based exercises based on drawing and sketching. After each exercise a real-time, organic reflection session asks students to ponder and articulate on their individual and team approaches to idea generation. These reflection sessions allow for peer learning as students have an opportunity to hear how their peers approach the idea generation task at hand. First, the students are given a set of individual exercises to explore their own divergent thinking skills. Then, they are asked to work as a team for idea generation.

For individual divergent thinking skill exploration, following idea generation exercises [12] are used:

1. *90 Circles*: Each student is given a set of three sheets each with 30 circles, and students are asked to convert each circle into different recognizable object (say a cookie or a ball) within three minutes. They are asked to complete as many as they can during the allotted time.
2. *Incomplete Images*: Each student is given a sheet different partial images that are repeated three times each. The students are asked to complete each partial image into a recognizable object within three minutes. They are asked to complete as many as they can during the allotted time.
3. *What do you see?* Each student is given a sheet with multiple different images and given five minutes to write down what they recognize in the images. These images can either be interpreted as a side/top/bottom view of an object, the detail of an object under the microscope, or a simple sketch of a complex object, etc.
4. *What is the half of 12?* Each student is given a sheet with the number twelve printed on it, and given three minutes to respond to the question: "What is the half of twelve?" While a straightforward answer based on a mathematical interpretation of the question is 6, a student may interpret 12 as an image, divide this image in half, and report the two halves as 1 and 2.
5. *How many options*? Each student is given a sheet with a square printed on it and given three minutes to divide the image into four equally shaped and sized images in as many ways as possible.

For team divergent thinking exploration, the *Collaborative Comic* exercise [12] is used, which is an adaptation of literary arts exercises or practices of OULIPO (*Ouvroir de Litterature Potentielle*, or *Workshop of Potential Literature*), where constraints are used as means of triggering ideas [4]. More specifically, each student sits in a group, and is given a worksheet for a comic with six panels on it. Students are asked to develop the first panel with a certain word appearing. After four minutes, students hand off their worksheet to someone else and are asked to develop the second panel of the comic with another certain word appearing. The process is repeated until the comic is completed, each panel being done by a different team member.

We hypothesize that the DTSD curriculum will benefit students by introducing the concepts of divergent thinking and its role in ideation and engineering problem solving. Furthermore, the DTSD curriculum will raise students' awareness of their own ability and potential to be creative, by showing that divergent thinking is a skill that can be developed.

Study Design and Execution

Participants. The DTSD curriculum has thus far been delivered across two semesters of the DSS course. There were 10 students enrolled in the summer semester and 39 students enrolled in the fall semester. While all enrolled students were provided with the DTSD training, students were provided an option to participate in the data collection to evaluate the effects of this new curriculum; 49 students (10 from the summer, and 39 from the fall semester) provided at least one response in the follow-up data collection. In addition, students were also asked to provide their consent to allow for direct quotations and answers to be used in publications and presentations, and 97% of the students agreed. Thus, the participation DTSD training and the follow-up data collection was high across both semesters. A final semester of DTSD training is being delivered in the spring semester of 2020.

Data Collection Approach. We collected information using three well-known tools, which are the Big Five Inventory (BFI) [1], the Short Scale of Creative Self (SSCS) [3] and the Creative Mindsets Scale (CMS) [4]. While the BFI is used to measure individual differences, the SSCS and the CMS are used to measure self-perceptions of creativity.

- *BFI* is a short 44-item self-report questionnaire that measures the Big Five personality dimensions: *extraversion, agreeableness, conscientiousness, neuroticism, and openness*. Participants rate on 5-point scale whether they agree (1 = "Disagree Strongly" and 5 = "Agree Strongly") with short statements about how they see themselves (e.g., "I see myself as someone who is talkative"). The final score for each factor is based on the average of the relevant items.
- SSCS is a 11-item questionnaire that evaluates *creative self-efficacy (CSE*) (6 items), one's belief that they can be creative (e.g, "I know I can efficiently solve even complicated problems"), and *creative personal identity* (*CPI*) (5-items), one's belief that they are creative (e.g., "I think I am a creative person"). Participants respond on a 5-point scale between strongly disagree and strongly agree, with a final score being the average of the relevant items.
- CMS is a 10-item questionnaire that measures two types of mindsets towards creativity, a *fixed mindset* (5-items), representing a view that creativity is innate (e.g., "A truly creative talent is innate and constant throughout one's entire life"), and a *growth mindset*, representing a view that creativity is something that can grow and develop overtime (e.g., "Everyone can create something great at some point if he or she is given appropriate

conditions”). Participants respond on a 5-point scale between strongly disagree and strongly agree, with a final score being the average of the relevant items.

We used BFI because previous studies (e.g., [9]) have found associations between high *Openness* and *Agreeableness* along low *Conscientiousness* to higher scores of divergent thinking, and we wanted to account for such differences. We used SSCS and CMS because self-perceptions of both the self-efficacy and self-identity measures may improve with the DTSD training, however, students with fixed mindsets towards creativity may not benefit as much from this intervention.

In order to capture narratives of student experience and opinion, we also designed a self-report reflection questionnaire about their perceptions of the DTSD training as it relates to their own creativity, their ability to demonstrate creativity during their course project, and how the DTSD training may influence their engineering career. Specifically, we requested the students to respond to following questions:

- Please summarize what you learned during the training.
- What is your overall reaction to and impression of this experience?
- How can you see this experience being applicable in this course?
- Do you think this experience will be beneficial to your career as an engineer and why?

After the student teams completed the project, they were asked the following questions:

- Did the Divergent Thinking Training change your approach of the project? If so, how?
- What activities from the Divergent Thinking Training were the most beneficial?

Data Collection Procedure. In order to track students’ development before and after DTSD training and to evaluate the DTSD training’s impact on students’ in the course, we collected data at three points: (1) pre-DTSD training, (2) post-DTSD training, and (3) end of course. In the summer semester, the first questionnaire was administered on paper during class time, while the rest and all the fall questionnaires were administered through Qualtrics® outside of class time.

At pre-DTSD training measurement point, we collected data using the BFI, the SSCS, and the CMS. At the post-DTSD training measurement point, we collected data using the SSCS, the CMS, and the questionnaire. At the end-of-course measurement point, we collected data again using the SSCS, the CMS, and the questionnaire.

Data Cleaning and Analysis. While we received at least one response from 49 students throughout the course of the data collection, only 8 participants from the summer semester and 26 participants from the fall semester provided responses at each of the data collection points. The subsequent data analysis reported in the next section was conducted on this dataset of 32 complete responses.

Findings and Discussion

Table 1 summarizes the data we obtained from the BFI. Tables 2.a and 2.b present the summary of the data we obtained from the SSCS and the CMS. Recall that creative self-efficacy (CSE) is a measure of one’s belief that they can be creative, whereas creative personal identity (CPI) is a measure of one’s belief that they are creative. Also recall that *fixed mindset* represents a view that creativity is innate whereas *growth mindset* represents a view that creativity is something that can grow and develop overtime. These four constructs together are used to assess the impact of DTSD training.

Big 5 Traits	Summer 2019 Average (*n*=8)	Summer 2019 St. Dev. (*n*=8)	Fall 2019 Average (*n*=26)	Fall 2019 St. Dev. (*n*=26)
Extroversion	3.56	0.70	3.43	0.73
Agreeableness	3.56	0.69	4.12	0.51
Conscientiousness	3.40	0.71	4.06	0.57
Neuroticism	2.94	0.82	2.76	0.73
Openness	4.00	0.59	3.58	0.62

Table 1. Average of Big 5 Traits for Summer and Fall 2019

Creativity Self-Perception Summer 2019 (*n*=8)	Pre-Training Average	Pre-Training St. Dev.	Post-Training Average	Post-Training St. Dev.	Post-Course Average	Post-Course St. Dev.
Creative Self-Efficacy	4.14	0.49	4.38	0.47	4.54	0.40
Creative Personal Identity	4.05	0.87	4.40	0.60	4.48	0.60
Growth Mindset	4.58	0.46	4.65	0.48	4.50	0.66
Fixed Mindset	2.08	0.83	2.08	0.95	2.18	1.01

Table 2.a. Creative Self and Creative Mindset Scores Summer 2019.

Creativity Self-Perception Fall 2019 (*n*=26)	Pre-Training Average	Pre-Training St. Dev.	Post-Training Average	Post-Training St. Dev.	Post-Course Average	Post-Course St. Dev.
Creative Self-Efficacy	4.01	0.52	3.90	0.61	4.03	0.65
Creative Personal Identity	3.92	0.85	3.78	0.79	3.85	0.85
Growth Mindset	4.32	0.42	4.18	0.71	4.22	0.55
Fixed Mindset	2.31	0.67	2.29	0.85	2.34	0.79

Table 2.b. Creative Self and Creative Mindset Scores Fall 2019.

Correlations between Openness and CSE, CPI. For the summer semester, there was a strong positive correlation between the self-reported *Openness* measure from the BFI (openness to new experiences) and both CSE, $r(6) = .86$, $p <.01$ and CPI, $r(6) = .88$, $p < .01$. Similar results were obtained for the fall semester, where again *Openness* was strongly positively correlated with CSE, $r(24) =.71$, $p <.0001$, and CPI, $r(24) = .78$, $p < .0001$. No other correlations between the Big Five factors and the SSCS measures were significant, $p>.05$, *ns.* These results mirror findings that have found that the *Openness* is tied to increased creativity and divergent thinking [9, 10]. However, we were unable to find strong relationships between the other Big Five factors and our creativity measures, as were found in some studies and meta-analyses [6, 11].

Summer Semester Changes. The effects of the DTSD training were measured at three points: pre-training, post-training, and at the end of the course (i.e., final). We expected that the DTSD would result in higher self-perceptions of CSE and CPI immediately following the training. Also, we expected that through exposure and use of the divergent thinking methods during the course project, these effects would persist until the end of the course. Planned comparisons were conducted between the pre-DTSD training, post-DTSD training, and end-of-course data using paired *t*-tests. In the summer semester, we found some evidence supporting these hypotheses. We also found a significant increase in CSE from pre-DTSD training and the end of the course, $t(7)=5.33$, $p=.001$, $\Delta=0.41$. We found marginal evidence that CSE increased immediately after the training (i.e., pre-post comparison), $t(7)=2.31$, $p=.054$, $\Delta=0.24$, and between the post-DTSD training and end-of-semester measurement point, $t(7)=2.16$, $p=.068$, $\Delta=0.17$. For CPI, we found marginal increases in the scores from pre-DTSD training to post-DTSD training, $t(7)=2.14$, $p=.07$, $\Delta=0.35$, and from pre-DTSD training to final, $t(7)=2.01$, $p=.085$, $\Delta=0.43$. However, no significant differences were found for the growth and fixed mindsets, $p>.1$, *ns*, suggesting that the mindset measures may less malleable. Given the small sample size and the preliminary nature of the DTSD training in the summer, these results provided some promising indications that the DTSD training was effective in increasing self-perceptions of creativity.

Fall Semester Changes. The same analysis was conducted on the data collected for the fall semester. However, we did not find the same beneficial effects from the DTSD training for either CSE or CPI, $p>.05$, *ns*. In fact, Table 2.b shows a small drop across all four constructs post-training. While these results are not statistically significant, they were surprising since they were actually in the opposite direction than we hypothesized and found in the summer semester. We also constructed linear regression models to examine whether CSE and CPI was impacted by the training phase and *fixed mindset* interaction. However, the interaction term was not significant in either of these models, suggesting that the mindset did not significantly change the effect of the DTSD training. However, we hypothesize that the class composition and/or the class size may have had an impact. During the summer semester, there were a few Innovation Academy (IA) students enrolled in the class (accounting for 25-38 percent of the enrollment). Students enrolled in IA at UF complete a Minor in Innovation that focuses on creativity among others topics required for the minor. Hence, the students in this academy have some pre-existing understanding of their creativity related skills. DTSD may have helped them to put creativity-related skills in perspective within engineering. Furthermore, in a smaller class, students have fewer peers to observe to benchmark their own divergent thinking skills against. Hence, the students in the summer semester may have reported higher perceived gains in the four constructs. We are still exploring other explanations for why we were not able to replicate our results from the summer, and the data from the spring 2020 semester will be critical in further understanding the underlying processes. Furthermore, we may have to consider additional measures to gauge gains in divergent thinking skills other than self-reflection.

Student Reflections. The DTSD training was received positively by the students. Some comments that we received in the questionnaires are as follows:

I think this experience was very applicable to the upcoming DSS project. The DSS project can be kind of open-ended as far as what to do for a solution, so this experience has really helped with allowing our group to be creative and not restrict ourselves to typical engineering methods. We are even planning on having a fun, creative presentation based on past groups in senior design having to do interpretive dance.

– Fall 2019 Student

I am very open minded and receptive to new ideas and methods different from the status quo. I really enjoyed hearing Dr. Akcali speak on divergent thinking and how engineers need to be more creative. The activities definitely foster a more connected type of thinking. What I mean by that is that the activities forced you to make connections in your mind that usually aren't made. I had to grab from different experiences and different ways of thinking in order to come up with a novel idea.

– Summer 2019 Student

Yes, it is [beneficial to my career as an engineer] and will be. Most engineers turn off when they find the solution. These exercises showed me that you need to think as a dancer or musician who will continually improve on their craft and their work. I learned that the solution can be continually improved on and to see your work as a creative process more than anything. I can see this as being a major selling point to an employer.

– Summer 2019 Student

However, there was still some resistance to the DTSD training. As some students pointed out, the creativity aspects of the training were not aligned with their self-perceptions as engineers, and overcoming this self-perception will be one of the biggest challenges for the DTSD training:

Overall, I think the Divergent Thinking Training was unnecessary. I understand that Dr. Akcali likes to have us think outside the box like art majors. However, we are engineers and there typically is one correct answer (not necessarily solution)…

– Fall 2019 Student

Concluding Remarks

Divergent thinking is an important skill that contributes to the creative capacity of an individual. To develop divergent thinking skills of engineering students, we developed a training module and incorporated it into an existing, required, project-based course in industrial and systems engineering curriculum. Thus far, we taught the module and collected data twice and are currently teaching it again and will be collecting one more set of data. Although our results from the first round of data collection in summer 2019 semester provided some evidence on the effectiveness of the training module, the results from the second round of data collection in fall 2019 did not provide further support for the evidence. Our data collection is ongoing, and will allow for more in depth analysis of the barriers to teaching divergent thinking to engineering students.

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