Virtual Creative Problem-solving Workshops

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Abstract

All levels of education are facing an unprecedented challenge because of the pandemic; therefore, instructors are making all kinds of efforts to ensure to keep the high-quality education and exploring diverse ways to reach out and engage students in the content delivered. We redesigned a creative problem-solving workshop for online settings to help students think more creatively in their class projects and practice a growth mindset. One of the primary objectives of the workshop is to increase students' awareness of cognitive biases, barriers, and traps that prevent individuals to be creative. The workshop program targets information technology and engineering classes that include significant design components. The workshop is delivered at the beginning of the semester in an hour guest-lecture format. The tools and techniques learned in the workshop can then be applied to subsequent design projects during the semester. The workshop instructors quickly adapted the workshop content to be delivered remotely in Fall 2020. The workshop exercise problems were created in the online format and made available for students through the course management system that the university uses. The evaluation of the workshop program showed that participating students found the workshop beneficial, and it introduced them to design thinking and creativity in both settings, in-person and remote. Furthermore, the effectiveness of the workshop did not diminish in the remote learning mode. In addition, Bono's Six Hats method, which was introduced in a faculty workshop and then applied extensively in the remote environment, had highly positive results.

Introduction and Background

Higher education institutions are facing unprecedented challenges because of the COVID-19 pandemic as they suspended or reduced in-person classes and shifted to various remote learning modalities to slow down the spread of the virus. Although various modes of remote learning have been around for a considerable time and enrollments in remote learning programs have grown steadily in the last decade, remote learning has been never implemented at this scale within a noticeably short period. One of the main criticisms of remote learning has been that remote learning programs mainly emphasize technical skills but overlook professional skills such as teamwork [1, 2], creative problem-solving skills, leadership, interpersonal skills, and global awareness, and self-regulation. These "twenty-first century" professional skills are required to be successful in today's knowledge-based economy, and the importance of preparing students with 21st Century skills has widely been emphasized in the literature [3]. As the long-term effects of this sudden transition of millions of students to remote learning on students' professional skills development are yet to be investigated, instructors and administrators are tirelessly searching for ways to enhance students' remote learning experiences and continue providing students with opportunities to practice and develop their professional skills.

Creative Problem-Solving (CPS) skills are listed among "twenty-first-century" skills. Creativity has been generally described as generating novel and useful ideas and concepts [4]. We can broadly define CPS skills as a set of techniques and processes for finding novel and feasible solutions to complex problems. Although all academic programs include CPS skills among their program goals and student learning outcomes, educators have still been debating the best ways to

introduce CPS skills in classroom settings. Some researchers [5] questioned the merits and effectiveness of a systemic approach to formal CPS training because creativity highly depends on individuals' knowledge and experience, as well as their cognitive style [6]. In other words, applying a systemic approach to CPS, which requires non-linear and divergent thinking might be considered counterintuitive. However, research substantiates the effectiveness and benefits of formal CPS training. Several studies show that CPS training can enhance solution quality and originality [7], increase individuals' fluency and flexibility of ideas [8], and lead to increased creative behavior [9]. Incorporating CPS skills into existing programs and classes requires a theoretical understanding of CPS processes. Osborn [10] provided one of the first frameworks to define the processes of CPS. According to Osborn, a CPS process involves three consecutive stages regardless of the domain of the problem: (a) fact-finding, (b) idea finding, and (c) solution-finding. Table 1 provides some of the CPS techniques that can be used in the three stages of CPS.

Table 1. Common CPS techniques that can be used in various stages of the CPS process.

CPS Stage	CPS Techniques to Be Used
Fact-Finding	Mind Map, Relevance Trees, and Six-Good Man
Idea-Finding	Brainstorming, Idea Space, Morphological Analysis, SCAMPER, and Bono's Six Hats
Solution-Finding	TRIZ and Biomimicry

When the pandemic broke out, we were in the early stages of a campus-wide initiative to better incorporate CPS techniques into engineering and information technology classes. This initiative was a strategic component of a project that aims to accelerate the formation of STEM-based Entrepreneur teams (E-teams) and increase the number of E-teams moving from the ideation phase to the testing phase. The initiative included three action items: (i) educate students about CPS processes, (ii) train instructors on how to integrate CPS techniques into their classes, and (iii) organize workshops to inform the broader public about CPS. We first created short entrepreneurship learning modules (E-modules), such as CPS, design thinking, customer discovery, and intellectual property, based on the content of our entrepreneurship courses, and then we delivered hour-long workshops at introductory level engineering and information technology courses as guest lectures. We also organized instructor training workshops and discussed how various CPS techniques could be incorporated into engineering and information technology classes. As a result, several instructors started using these techniques in their classes.

Prior research has documented the use of CPS in a blended environment [11], which typically consists of a combination of face-to-face and online teaching. Kashefi et al. [12] evaluated the benefits of teaching first-year engineering students CPS techniques using the blended learning format. Limited research has been done on the effectiveness of teaching CPS techniques in a strictly remove environment [13], particularly at the university level. The transition of our CPS workshops, which had been previously conducted in-person, to remote delivery allowed for valuable evaluation of the effectiveness of these workshops.

Our CPS workshops were designed to help students think more creatively in their class projects and practice a growth mindset [14] through short exercises demonstrating cognitive biases, barriers, and traps that prevent people from finding creative, novel solutions to problems. Thereby, we hope that students would be less likely to fall into these traps. According to a recent

study by Burnette et al. [15], students in a growth mindset intervention, relative to the control, reported greater entrepreneurial self-efficacy and task persistence on their main class project and improvement in their academic and career interests. Reducing the negative effect of the cognitive biases, barriers and traps requires deliberate and repeated practice of CPS techniques. Although we were certainly aware that practicing CPS techniques in depth would be impossible to accomplish in an hour-long workshop, we created a set of short interactive exercises on which students could apply the introduced CPS techniques quickly during the workshop [16]. Unfortunately, all workshop activities were originally designed considering an in-person delivery method. In the Fall 2020 semester, we modified the CPS workshop for remote learning while maintaining the core concepts and their interactive nature. This remote workshop was delivered at the beginning of the semester in four remote engineering design classes, anticipating that students could apply the introduced techniques to subsequent design projects during the semester. In this paper, we summarize how the workshop program was adopted to remote learning and compare students' perceptions and feedback of the in-person and remote workshops.

As a result of our faculty development workshops, instructors who had incorporated CPS techniques into their in-person classes also continued to use these techniques in their remote classes. As an example, we also present how Bono's Six Hats Method was used in a remote learning engineering design class and provide students' perceptions about this approach. "Bono's Six Thinking Hats" is an analysis technique enabling groups to explore different perspectives at the same time. Dr. Edward de Bono published this methodology of parallel thinking in 1985. In parallel thinking, all members focus on the same direction at a particular moment resulting in collaborative thinking and a decision free from bias. Traditional thinking considers too many aspects at a time, resulting in thinking that is not cooperative. When using "Bono's Six Thinking Hats", each team member has a role defined by the imaginary color hat they are wearing, focusing thinking into specific frameworks. Utilizing six parallel thinking methods ensures different points of view are considered in the analysis process. The wearer of the white hat assumes the role of neutral objectivity and is concerned with facts and information. The framework for the wearer of the red hat is emotion, enabling them to consider their gut reaction. The yellow hat wearer focuses on the benefit and the logical positive. Ideas are the framework for the wearer of the green hat whose focus is creativity. The wearer of the blue hat concentrates on planning and process control. Judgment or the logical negative is the focus of the wearer of the black hat. By focusing on one perspective at a time, a wide array of feedback is obtained.

Description of the Creative Problem-Solving (CPS) Workshop in Online Delivery Mode
The objective of the CPS workshop is to inspire students to find innovative solutions to challenging problems and to inform students about pitfalls/biases in decision-making processes related to CPS. The detailed program and sample activities of the CPS workshop can be found in [16]. In this paper, we will briefly introduce the workshop program as well as how the program was adopted to a remote guest lecture format after in-person classes were limited or changed to online mode due to COVID-19. In a nutshell, the hour-long CPS workshop introduces common cognitive biases in human decision-making processes and physiological barriers to creativity. In addition, students learn several techniques to reduce the negative effects of these cognitive barriers and apply these techniques to short problems. Since the target audience of the CPS workshop is mainly first-year engineering and technology students, and the workshop content is

delivered during an hour-long guest lecture, the selected problems are straightforward and do not include any domain-specific jargon. Table 2 summarizes the topics covered in the workshop.

Table 2 Outline of the CPS workshop program

Topic	Objectives	Techniques Introduced
Mental Models	Moving away from past experiences that influence solutions to new problems	Using Analogies Method [17]
Functional Fixation	Reducing functional fixedness that prevents us from finding alternative solutions to problems	Find alternative uses Divide-and-Concur
Problem Framing	Demonstrate how alternative presentations of a problem (e.g., cost minimization versus profit maximization) can lead to different solutions	Problem reframing through generalization
Self-Imposed Assumptions	Eliminating unconscious assumptions and self-imposed constraints that artificially impair our ability to think of novel solutions to problems	List-reverse-solve [17]

In the remote delivery of the workshop, the same workshop content and examples were used with the in-person delivery [16]. Therefore, we were able to compare student experiences and perceptions between the in-person and remote workshops. In the remote delivery mode, the workshop was conducted as a guest lecture over Zoom, and a significant challenge was to replicate the interactive nature of the workshop program, which was designed for in-person delivery. At the beginning of the in-person workshop, participants took an eight-minute test (in a paper-pencil format but anonymous) in which they were asked to solve several problems that required outside-of-box thinking to some degree. In the remote learning format, participants were also asked to take the online version of the pre-workshop test created in the Qualtrics survey tool, which ensured the anonymity of the student answers. The test format was slightly modified by removing questions that required extensive drawings or providing hints about how students could structure their answers in lieu of drawing. A sample problem pertaining to framing biases is given as follows:

> "*The research shows that people get impatient and agitated after about 20 seconds of waiting. In a 30-story building, the average waiting time for the elevator is about 25 seconds, and the tenants frequently complain about this problem. They claim that the elevator waiting time is too long because the elevator is too slow. How can we reduce the elevator waiting time? Provide a solution.*"

In the in-person delivery, the instructor referred to these test problems during the workshop session and asked participants to explain their approaches to the problems. This reflective aspect of the workshop was key to effectively delivering workshop topics while engaging participants. Participants were also asked to reflect on why they could not solve the problems. We should also note that only a few participants were able to solve the problems correctly. Afterward, the instructor pointed out the cognitive biases that made each problem challenging to solve and introduced simple techniques to reduce the negative effects of those cognitive biases. Finally, the instructor presented a few additional problems and asked participants to apply those simple techniques to solve the new problems. This delivery approach was repeated for each of the topics listed in Table 2.

Figure 1 illustrates an example of the interactive delivery approach of the in-person workshop. The same delivery approach was also used in the remote workshop. However, since most of the

students opted to keep their cameras off and online discussions were difficult to coordinate, participants were asked to provide their reflections and responses to questions using Zoom reactions or chat. While responding through the chat, participants were first asked to type their reflections and answers to the posted problems into the chat window and to wait for the instructor's cue for posting them. Thereby, all students posted their responses simultaneously, and the instructor summarized the responses quickly and elaborated on key points of the responses. In fact, this approach led to more inclusive engagement from participants compared to the in-person delivery mode in which several students tend to dominate discussions.
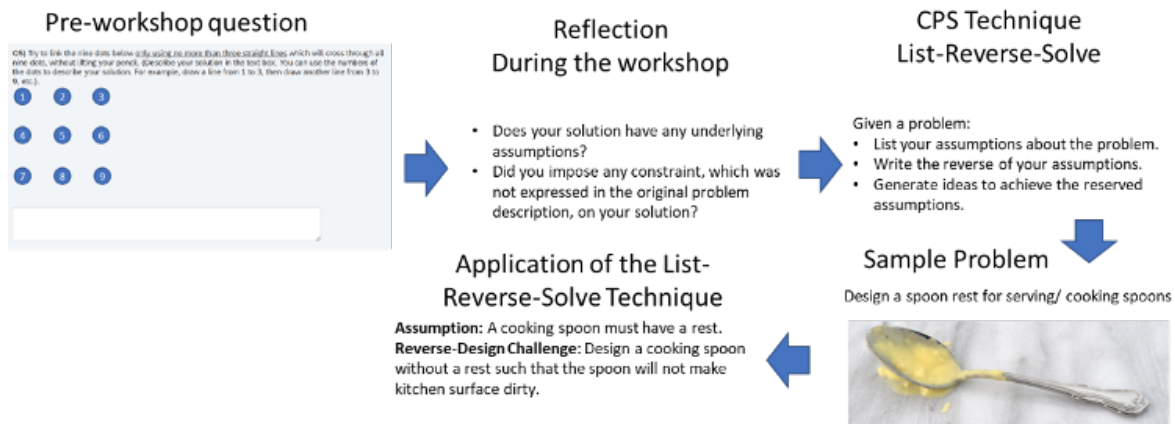

Figure 1. An example of the workshop delivery approach using the list-reverse-solve technique [17].

Comparison of the In-Person and Remote CPS Workshops
The in-person CPS workshop program was delivered in three sections of an introductory level engineering design course in the Fall 2019 semester before the university switched to remote learning in the following spring semester. The target course aims to provide students with a foundation for engineering design through hands-on team projects, and it is a required course for all first-year engineering students. In the Fall 2020 and Spring 2021 semesters, we conducted the workshop in five sections of the same engineering design class through remote (online) delivery. In both delivery methods, the workshop took place in the first few weeks of the semester to motivate the students for their upcoming design projects. After the workshop, participating students evaluated the workshop program using a short survey of 12 questions operationalized by the Likert-scale from Strongly Disagree (1) to Strongly Agree (5). The survey measured 5 different metrics as explained below.

The first metric was the "Perceived Usefulness" of the concepts introduced in the workshop. Perceived usefulness is defined here as the degree to which a student believes that using concepts and techniques introduced in the workshop would enhance the students' performance in-class projects. The usefulness metric was measured by the average score of the following three questions.
- Using the concepts introduced in the workshop would improve my class projects that require design.
- The workshop presented useful tips that would help me improve my creative problem-solving abilities.
- I can use the techniques introduced in the workshop in my class projects.

The next two metrics were about affective CPS skills. The first affective skill "Openness to Novelty" was intended to measure the extent that the workshop encouraged students to entertain ideas that seem impossible at first. Like many novice individuals, first-year students often tend to come up with solutions that are familiar to them. This hinders creativity because finding novel solutions to complex problems requires a different perfective than familiar ones. The "Openness to Novelty" metric was measured by the average score of the following three items.

- The workshop will encourage me to take risks with new ideas in my class projects that require design.
- The workshop will encourage me to experiment with different ideas that sound outlandish at first.
- The workshop will inspire me to try new ideas in my class project that require design.

The second affective CPS skill is "Avoiding Premature Closure," which suggests that students should evaluate multiple alternative solutions before making a final design decision. First-year students tend to jump on a solution rather quickly without considering a wide spectrum of ideas. The following two items measured how much the workshop encouraged students to consider alternative solutions to a problem before concluding with a solution.

- I realized that I should analyze problems in more detail before jumping to a solution.
- I realized the dangers of getting stuck with the first solution that came to my mind.

In the context of CPS, diagnostics skills are related to a careful examination of the nature of a problem from multiple points of views [18]. In the workshop, we emphasized the importance of approaching a problem from multiple perspectives and the role of diversity in design teams. Hence, we measured the extent to which the workshop demonstrated the importance of "Embracing Diversity" as one of diagnostic CPS skills as the average score of the following three items.

- The workshop made me realize the importance of approaching problems in a different way.
- The workshop reminded me of the importance of adopting multiple perspectives when dealing with a problem.
- The workshop presented the value of having team members with diverse backgrounds and experience.

Finally, we evaluated to the extent that the workshop made the participants aware of conditions and circumstances that could hinder CPS ("Contextual Skills") using the following two questions.

- The workshop made me understand some of the circumstances and factors that can hinder creativity.
- The workshop presented some of the mistakes that I make while solving problems.

Table 3 summarizes the comparison of the average scores of the five metrics that measured participants' perception of the workshop. We compared the average metrics scores across the responses of in-person and remote participants using ANOVA. The F, p, and Eta-squared (η^2) values of the ANOVA, as well as the Cronbach α values of the metrics, are also provided in the table. Firstly, the average metric scores showed that both in-person and remote participants had an overwhelmingly positive view of the workshop, and both groups benefited from it. The average scores of all the five metrics were between Agree (4) and Strongly Agree (5). Although

the average scores were slightly lower for the remote workshop, the differences were not statistically significant (p-values ≥ 0.05), excluding the Perceived Usefulness metric (p-value of 0.03). The significant difference in the Perceived Usefulness metric might be attributed to challenges of applying the presented concepts in remote settings. The Eta-squared (η^2), which is a measure of effect size, suggests that the delivery method had a very small effect on student perceptions and experiences. As seen in the Perceived Usefulness, students found the workshop immensely helpful to support their design and problem-solving projects. The other learning outcomes of the workshop were supported. These positive scores encouraged us to continue the workshop in the remote delivery mode.

Table 3. The statistics of ANOVA comparing the five metric scores of in-person and remote CPS workshop participants.

Metric (Cronbach α)	In-Person (n=44)		Remote (n=58)		F	p	η^2
	Mean	Std. Dev.	Mean	Std. Dev.			
Perceived Usefulness (0.75)	4.67	0.39	4.37	0.53	9.42	0.030	0.086
Openness to Novelty (0.80)	4.42	0.60	4.24	0.55	2.52	0.115	0.025
Avoiding Premature Closure (0.58)	4.48	0.55	4.37	0.52	1.19	0.276	0.012
Embracing Diversity (0.67)	4.49	0.54	4.30	0.51	3.15	0.079	0.031
Contextual Skills (0.78)	4.44	0.60	4.28	0.68	1.49	0.224	0.015

Bono's Six Hat Method

Bono's Six Hats [19] approach has been used to evaluate student presentations in both the cornerstone and capstone courses at a university in the Northeast US. The cornerstone engineering design course consists of mostly first-year students and is comprised of two separate design projects. At the end of each project, the design teams present their project to the rest of the class. The capstone engineering design course is taken during a student's final year. The year-long project uses Bono's Six Hats to evaluate four presentations over the course of the project. The first presentation is on the design requirements of the project, the second is on their design solution, the third is on the assembly of their design, and the fourth is on the testing of their design. In both classes, the quality of the presentation, the merit of the design, and the team's effective use of the design process are evaluated using Bono's Six Hats.

The transition to remote learning has also resulted in the opportunity to perform the exercise both in-person and remotely. The method was simplified by only considering four of the six hats: red (emotion), yellow (benefit), green (ideas), and black (judgment). The classes using the "Six Thinking Hats" method consisted of several teams of four members each, with each team member assigned a different hat to wear. Each member of non-presenting teams would wear a single-color hat for a given presentation, and then change hat color for every subsequent presentation, allowing them to play different roles over the course of the presentations. The members within each team wore different colored hats. As a result, presenters were provided with multiple opportunities for feedback from each hat color, and all evaluators' opinions were considered.

To apply Bono's Six Hats in person, a packet of forms is distributed to each team. The forms define the job assumed by the wearer of each hat. The team members need to coordinate for each presentation. The goals are no one on a single team wears the same color hat while evaluating a single presentation and no one on a single team wears the same color hat more than once. The forms are then collected, sorted, and the feedback distributed to the appropriate team. To accommodate a remote learning environment and minimize in-class coordination time, some additional preparation was required. Electronic forms were created for each student in the class. The electronic forms preassigned which color hat each student would be wearing for each team's presentation. This ensured the same requirements would be met without the teams needing to coordinate between each presentation. The electronic forms were also collected, sorted, and distributed to the teams but in electronic format.

Prior to adopting Bono's Six Hats approach, peer evaluation of student presentations was minimal, with most students unwilling to critically evaluate their peers. In contrast, the benefits of adopting Bono's Six Hats, were apparent each time the method was used, independent of delivery methodology or course level. Students provided much more thoughtful, focused, and constructive feedback than they did when just asked for feedback. Students were more likely to participate, less inhibited, and not afraid of offending their classmates because they had a job to do. The different colored hats provided a balance of feedback, offering both positive and constructive criticism. Students embraced change for future improvement.

Remote learning has provided unique challenges, particularly in a course that relies heavily on teamwork. Students are less engaged and opportunities for peer evaluation are reduced. Successfully garnering student participation has been particularly difficult. The unique, structured framework of the "Bono's Six Hats" method was perfectly suited for the remote learning environment resulting in more student participation than during any other classes. Students could not remain silent because they had a role during each presentation. Discussions that ensued after the presentations were thoughtful, specific, and beneficial to the presenters. Students did not feel overwhelmed because they only needed to focus on a specific aspect of the presentation. Their feedback was often discussed audibly but was also successfully shared via the Zoom chat if needed. "Bono's Six Hats" proved to be just as beneficial remotely as in the classroom, regardless of the level of education. Students were receptive to the method and valued the feedback they received from their classmates, making it a highly successful part of their educational experience. Several students who learned this method applied it in future decision-making processes, making it an extremely valuable tool.

Evaluation of the Bono's Six Hat Method in Remote Setting
We used the same instruments with the five metrics to assess the student perceptions of using Bono's Six Hat Method to give and receive feedback. We modified the items by replacing the term "workshop" with "Bono's Six Hats Method." For example, the first question of the Perceived Usefulness construct was modified as: "Using the concepts introduced in Bono's Six Hats Method would improve my class projects that require design." At the end of the semester, the students (n=39) evaluated Bono's Six Hat method using the modified instrument. Although it is not included in this paper since the class level and the learning modes are different, a small in-person class also used the same approach in their senior design projects.

As seen in Table 4, the average scores of the "Perceived Usefulness," "Openness to Novelty," and "Embracing Diversity" constructs were between Agree (4) and Strongly (5). It was clear that the students found Bono's Six Hat Method useful with an average score of 4.38. The average scores of "Openness to Novelty" and "Avoiding Premature Closure" were between Neutral (3) and Agree (4). To some degree, these moderate scores compared to the higher averages of the "Perceived Usefulness," "Embracing Diversity," and "Contextual Skills" dimensions were justified because "Bono's Six Hats Method" was used to solicit feedback rather than generating ideas. In summary, these results indicated that "Bono's Six Hats Method" was a viable technique to engage students in critical analysis of one another's work and provide constructive feedback in remote learning classes.

Table 4. The statistics of the five metric scores of remote Bono's Six Hats Method participants

	Remote (n=39)	
Metric (Cronbach α)	Mean	Std. Dev.
Perceived Usefulness (0.65)	4.38	0.53
Openness to Novelty (0.86)	3.76	0.80
Avoiding Premature Closure (0.53)	3.99	0.66
Embracing Diversity (0.73)	4.25	0.62
Contextual Skills (0.43)	4.15	0.66

Conclusions

In this paper, we presented an initiative for increasing engineering students' CPS skills by integrating creative program solving techniques into engineering classes. The main activities of the initiative including CPS workshops, faculty development and training, and integrating CPS techniques into engineering classes, especially the ones with a design focus. Originally, all activities were planned for in-person classes, but when the university shifted to remote learning due to COVID-19, we adopted our approach and activities accordingly. We evaluated the programs of this initiative using a standard instrument. Our findings showed that participating students found the CPS workshop greatly beneficial, and the effectiveness of the workshop did not diminish in the remote learning mode. Furthermore, our analysis showed that "Bono's Six Hats Method" presented to faculty was a viable technique to engage students in critical analysis of one another's work and provide constructive feedback in both in-person and remote learning classes. In addition, the course professors commented that the workshop helped to reinforce the concepts that their students had been learning before the workshop. These promising results encouraged us to adopt our other workshops (e.g., Design Thinking Workshop and Idea Sprints), which were also originally designed for in-person instruction, for remote learning.

Acknowledgment

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