

Promoting And Assessing Creativity And Innovation In Physics Undergraduates

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Abstract. Creative thought and the ability to innovate are critical skills in industrial and academic careers alike. There exist attempts to foster creative skills in the business world, but little such work has been documented in a physics context. In particular, there are few tools available for those who want to assess the creativity of their physics students, making it difficult to tell whether instruction is having any effect. In this paper, we outline a new elective course at the Colorado School of Mines in the physics department designed to develop creativity and innovation in physics majors. We present our efforts to assess this course formatively, using tablet PCs and *InkSurvey* software, and summatively using the discipline-independent Torrance Tests of Creative Thinking. We also describe early work towards developing a physics-specific instrument for measuring creativity.

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INTRODUCTION

As the rest of the world catches up to the US in industrial output and technological sophistication, our continued economic prosperity will depend on strengthening our historical success in generating new ideas. There are a number of prominent examples in industry of companies and executives making an intentional effort to increase creativity and innovation in their employees [1-3]. Such efforts are much less common in K-20 education, physics or otherwise. Indeed, many have argued that our educational system tends to stamp out creative behaviors in students [4]. Efforts to address creativity and/or innovation in PER are rare, perhaps in part because of the paucity of options for assessing creativity [5] (though the assessment of creativity has come up during the assessment of problem solving [6]).

At the Colorado School of Mines, we have begun teaching an elective physics course dedicated to improving the creativity of our students. The course makes use of tablet PCs and methodologies borrowed from corporate and industrial approaches to creativity. The primary goal of the course is to determine whether creativity can be taught over one-semester timescales, and if so, to determine how best to do this. A major secondary goal of the course is to develop an instrument for measuring creativity in a physics context. Without such an instrument, it is difficult to tell whether and when we've met our primary goal.

COURSE DESCRIPTION

The CSM creativity course is a one-credit elective in the physics department entitled "Developing Creativity and Innovation in Physics." It was advertised to senior physics majors and physics graduate students for the fall of 2010 and was advertised to sophomores taking modern physics for the fall of 2011, producing two different populations. We will refer to these as the upper-division and lower-division trials. Nine students enrolled in the upper-division version and 29 enrolled in the lower-division class. The course met for one hour per week.

We are not aware of any existing physics courses that focus specifically on creativity, and so we drew from methods used in industry. The text for the course was *Six Thinking Hats*, by E. DeBono [2]. The Six Hats approach involves participants systematically and deliberately taking on each of six different roles corresponding to six hats – a white hat for information gathering, a green hat for idea generation, a red hat for emotional reactions, and so on. We adapted the Six Hats technique to physics activities, giving our students a variety of opportunities to practice creative thinking. For example, the upper-division course was asked to think of as many schemes as possible to measure the rate at which stone is being extracted from a quarry, using the Six Hats to provoke and evaluate new ideas.

Several topics were covered in addition to the Six Hats approach. Students practiced word association and analogical reasoning as tools for generating new ideas. A guest speaker from industry addressed both courses. Students also spent two sessions of each course on the topic of measuring creativity. These sessions had two goals: 1) to get students to better understand the creative process by considering the measurement problem and 2) to solicit student ideas for creating a usable physics-specific instrument.

The creativity course used a variety of technologies to facilitate the above activities. Chief among these were HP tablet PCs using *InkSurvey* software [7]. *InkSurvey* is a software tool created at CSM that enables student-instructor interaction in the style of clickers, but with much more detail. Students can write freehand questions and answers and submit them to the instructor in real-time during class. More detail regarding *InkSurvey* is available elsewhere [8]. Figure 1 shows a sample of the submissions possible through *InkSurvey*. The tablet PCs themselves are housed in a dedicated classroom space with 40 tablet PCs, along with a SMART podium, projector, and a set of whiteboards that wrap around the room.

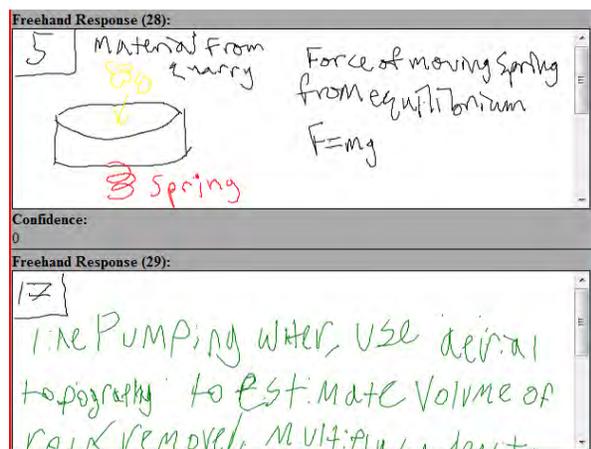


FIGURE 1. Instructor view of sample *InkSurvey* responses.

In addition to the ability to write freehand, tablet PCs afford mobility to the students. We have found that we can make very productive use of the fact that

students can retain computer access while moving around. For example, in one activity students created a whiteboard gallery of illustrations pertaining to quantum mechanical potentials, and then moved around the room discussing and evaluating the illustrations on their tablets.

INSTRUMENTS AND DATA

In each trial of the course, we administered the Torrance Tests of Creative Thinking [5] pre- and post-instruction. The Torrance tests are among the few existing well-validated instruments for measuring creativity [9], and are discipline-independent. The tests come in verbal and figural formats. In the verbal format, students are faced with several tasks that involve written answers, generating lists of questions and hypotheses among other things. The figural version of the Torrance test has students create and modify drawings in a variety of ways. Grading of each is accomplished with a standardized rubric. Responses are scored according to their number (fluency), their originality, their detail (elaboration), and their tendency to shift between different categories (flexibility), plus several other minor factors. Our lower division course received the figural test, and our upper division course received the verbal test.

In Table 1, we present a summary of the Torrance test data for each course. Only students that chose to provide track-able identifiers and took both the pre- and post-tests were included (6 students in the upper division trial and 10 in the lower division trial). The results indicate that student performance increases significantly from pre to post in every subcategory of the verbal test in the upper-division course. The pre-post differences for the figural test in the lower-division course are less pronounced, though still statistically significant under a one-tailed t-test for the “Originality” category. It is not clear at this time whether the smaller pre/post differences in the lower division trial stem from the difference in course level (lower vs. upper division) or the difference in exam version (figural vs. verbal).

TABLE 1. Pre/post results from the Torrance Test of Creative Thinking. The verbal test includes categories for fluency, flexibility, and originality. The figural test includes fluency, elaboration, originality, and a few others. All of the pre/post verbal test differences are statistically significant ($p \sim 0.02-0.03$, one tailed t-test). The “Overall” and “Originality” categories for the figural test show significant differences at $p \sim 0.04$.

	Results from Torrance Tests, Verbal and Figural			
	Verbal Test, First Course (N=6)		Figural Test, Second Course (N=10)	
	Pre	Post	Pre	Post
Overall	161	251	71.6	84.3
Fluency	70.8	108	23.0	26.2
Flexibility	41.3	59.8	5.2	6.3
Originality	49.2	83.2	19.1	24.6

Figure 2 shows a comparison of the Torrance test results to a more standard measure: GPAs. Specifically, we compare the fractional pre/post changes in students' Torrance test scores to their cumulative GPAs. One of the upper-division students was removed from the data set (a graduate student with no undergraduate work at CSM). We see a very strong negative correlation (-0.82) between GPA and Torrance gains for the upper division students, and no significant correlation between the gains and GPAs for lower division students. These results are unchanged if we consider post-test scores instead of gains.

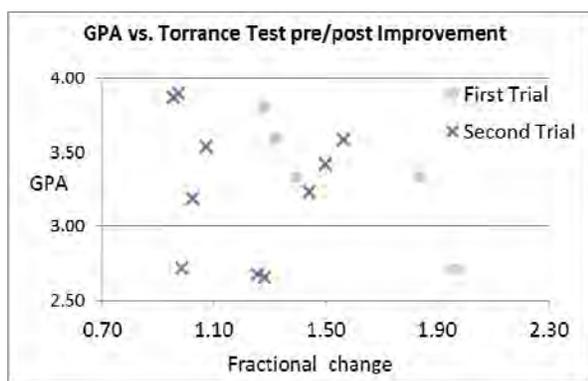


FIGURE 2. Individual Torrance post-test scores divided by pretest scores, plotted versus individual GPAs. Correlation between Torrance test improvement and GPA is -0.85 (statistically significant) for the first trial, and -0.12 (not significant) for the second trial.

Very recently, we have used the results and feedback from the first two trials of the creativity course to create a pilot version of a physics-specific creativity assessment. The instrument is designed to depend as little as possible on physics knowledge outside of what is obtained in any standard curriculum. Some of the tasks in the assessment are adaptations of tasks in the Torrance tests; others are based on discussions with students and faculty at CSM. A short description of the tasks in the instrument is provided in Table 2.

TABLE 2. Tasks used on pilot version of a physics-specific test of creative thinking. Students have ten minutes to work through each task. Task descriptions shown are abbreviated compared to actual instructions. Idea Generation and Figure Matching tasks are variants of Torrance tests tasks, “Impossible” Jobs and Idea Synthesis tasks came from discussions in the described creativity course.

Tasks in pilot physics-specific creativity instrument	
Idea Generation	Think of as many ways as you can to convert wind energy to another form.
“Impossible” Jobs	Think of as many ways as you can to exceed the speed of light. Be creative with definitions.
Figure Matching	Come up with physical situations that match the following graphs, and label the axes accordingly. (followed by set of 15 graphs of varied functions)
Idea Synthesis	Consider a list of physics concepts, and try to combine items from the list in interesting ways. (followed by list of 20 concepts, such as conservation of energy and reference frames)

We have administered this exam to six upper division physics majors so far. Results indicate that a typical physics major at CSM can generate a variety of responses for each task, and that variations from student to student can be substantial. A complete version of the pilot test and sample student responses can be obtained from the authors by request.

DISCUSSION AND FUTURE WORK

Our results so far are tentative, given the small number of students in the trials. Physics student performance on the Torrance tests definitely changes after an elective course on creativity, though it is not completely clear that the gains come from instruction. We note that tasks that are explicitly focused on creativity are not common in a students' experience. It is possible that simply experiencing the Torrance test (or something similar) once prepares students to perform better on it during the second round. When possible, we plan to administer the Torrance tests pre/post to students not enrolled in the creativity course to establish a proper control. If the opportunity arises, we will also administer the verbal Torrance test to a lower division creativity course and the figural version to an upper division course.

In comparing Torrance test results to student GPAs, we found one case in which higher GPAs were strongly associated with lower Torrance test performance. This allows the tempting interpretation that success in traditional physics courses deadens creativity, though we would strongly caution against making such a statement based on an N of five, especially when the other trial showed no such association.

Pilot work is proceeding on a physics-specific instrument, though much remains to be done. Coding said instrument as it is currently conceived will require a large set of baseline responses to establish which responses are common and which are unusual. Creating such a baseline will be a very long-term endeavor.

Speaking generally, our experiences suggest that it is possible to measure the creativity of our physics students using standard instruments and that it may be worthwhile to develop a physics-specific instrument as well. Our results also suggest that it may be possible to improve creativity through direct instruction, though that is far from clear with the data available.

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