Can Pedagogical Strategies Affect Students' Creativity? Testing a Choice-Based Approach to Design and Problem-Solving in Technology, Design, and Engineering Education

Dr. Jennifer Buelin-Biesecker, North Carolina State University

Jennifer Buelin-Biesecker is a Lecturer in Graphic Communications and Technology, Design and Engineering Education in the Department of STEM Education at North Carolina State University in Raleigh, NC. She teaches courses in Website Development, Desktop Publishing and Imaging Technologies, Technology through Engineering and Design, Game Art & Design, and Ceramics. Jennifer completed her Ed.D. in Technology Education in Spring, 2012 at North Carolina State University. Her primary research interests involve ways of fostering and assessing creativity and problem solving in technology education. Jennifer's work is informed by her past experiences working as a technical theatre teacher and in visual art.

Dr. Eric N. Wiebe, North Carolina State University

Dr. Wiebe is a Professor in the Department of STEM Education at NC State University and Senior Research Fellow at the Friday Institute for Educational Innovation. A focus of his research and outreach work has been the integration of multimedia and multimodal teaching and learning approaches in STEM instruction. He has also worked on research and evaluation of technology integration in instructional settings in both secondary and post-secondary education. Dr. Wiebe has been a member of ASEE since 1989.

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Abstract

Linear models for design and problem solving processes serve as the current paradigm for classroom practice in the United States. However, the need for alternative pedagogies has been identified in the research literature and national standards documents. Two design and problem-solving instructional approaches were explored in this study: the DEAL method (Define/Explore/Anticipate/Look back) and the choice-based approach, a nonlinear, student-driven method. Creative outcomes resulting from student projects developed under DEAL and choice-based conditions were measured and compared in this study involving 132 middle school students. Seventy-two student projects were developed using video game design software, thirty-six for each instructional method. They were completed with students opting to work alone or in pairs. The Consensual Assessment Technique was then employed using seven adult raters to compare outcomes of student work resulting from the contrasting pedagogies. Comparisons of means determined no significant difference in creativity scores between the choice-based and DEAL groups. Factor analysis suggested the existence of a creativity cluster comprising creativity and the three associated items, novel idea, novel use of materials, and complexity. Results demonstrated that creativity was assessed independently from technical strength items and from items related to project aesthetics. Inter-rater reliability was high for all 12 items measured, supporting an operational definition of creativity on which instructional objectives can be built. The results of this research are consistent with those of earlier studies in determining that creativity can reliably be assessed in classroom problem-solving activities. Further application in K-12 Engineering and Technology classrooms is needed in order to draw further pedagogical conclusions as well as to develop instructional strategies for use by classroom teachers.

Introduction

American public education places heavy emphasis on a limited range of skill sets that are simple to assess using standardized multiple-choice testing formats. In order for American students to remain globally competitive, however, a paradigm shift is needed, such that creativity, innovation, problem-solving abilities and intrinsic motivation are qualities fostered and valued in public education. Teaching children creative problem-solving skills helps them become successful adults who can question the accuracy of information and put what they learn to constructive use[1].

Technology education offers a potentially fertile environment for developing students' creative problem-solving abilities and creative behaviors. Creativity and innovation are explicitly stated goals for the field, potentially fostering an instructional environment supportive of creative expression. Technology and engineering education allows for the expression of students' multiple intelligences because it "broadens the range of domains within which talents can be

uncovered"[2].While the publication of the *Standards for Technological Literacy* (STL)[3] – with four of its twenty standards explicitly dealing directly with design – marks a step towards greater focus on fostering students' creativity, there is work to be done in establishing successful pedagogical strategies for fostering creativity in technology labs[4]. The value of empirical studies of creativity-driven pedagogies and assessment in engineering education was noted by Amato-Henderson, Hein, & Kemppainen[5]: "The importance of creativity in engineering education is clear [. . .] A valid method of measuring the impact of educational programs on the creativity of engineering students is needed." Fleisig, Mahler, & Mahalec[6] similarly asserted that "Engineering educators must adapt new ways of thinking, teaching, and learning engineering design from other disciplines" with the curricular aim of introducing students to "collaborative, inter-disciplinary, human-centered thinking, with a strong emphasis on generating continuous innovation through creativity." Walker, et.al.[7] identified *design fixation*, "a state where the results of the ideation or concept generation process have been degraded," as one type of negative outcome that engineering design students can encounter due to instructional variables not conducive to the promotion of creative outcomes.

DEAL versus Choice-Based

This paper focuses on exploring the potential for fostering creative problem-solving behaviors in the classroom and in developing quality creativity assessment strategies for classroom teachers. To do this, a study was designed to compare measures of creativity of projects produced in two distinctly different problem-solving environments: a linear (DEAL) approach versus a more open-ended, choice-based approach.

The DEAL method, currently used in some areas of the North Carolina technology education curriculum, is a somewhat linear approach, requiring that students:
1. *Define* the problem and goals for the problem-solving task;
2. *Explore* possible strategies and new information for accomplishing those goals;
3. *Anticipate* the outcomes of those strategies in order to decide which to *Act* upon; and
4. *Look back* and *Learn.*

DEAL functions as a precursor to more prescriptive, upper secondary level technology and engineering design process models used in such curricula as Project Lead the Way© and Engineering by Design™ courses.

By contrast, the choice-based approach[9-10] is a student-centered, open-ended approach that involves teacher facilitation of student driven decision-making about many aspects of the learning environment and tasks. This pedagogical approach is practiced in the field of visual arts education and offers potential for transferability to the field of K-12 Technology and Engineering education. In this study, the more established DEAL method functions as the contrasting control condition to the choice-based approach.

Research questions include:
- Will creativity scores on students' game art and design projects be higher after using the DEAL method (control) or the choice-based method?
- How will technical strength scores correlate with creativity scores?

- Will the consensual assessment technique yield high levels of inter-rater reliability when applied to middle school children's game, art and design projects?
- Will discriminant validity be demonstrated with regard to the consensual assessment form's separate measures of creativity, technical strength and aesthetic appeal?

Method

The target population for this study consisted of 132 middle school students enrolled in the researcher's middle school visual art classes. Seventy-two projects, thirty-six for each method, were completed with students opting to work alone or in pairs.

All students in both control (DEAL) and treatment (choice-based) conditions were given the option of making a card game, a video game, a board game, or a game that did not easily fit into one of those categories. Video games were required to be created in GameMaker[8].The unit was conducted over three, five-day weeks of daily 45-minute class sessions. Work outside of class was encouraged, especially for the video game designers, but was not required. Before- and after-school open studio sessions were offered 10 times over the three weeks. Nineteen students attended at least one open studio session.

Students began the unit with a day of research in the computer lab. Research was conducted through the school media center's research website. Students identified and described elements of a variety of game types. On Day Two they received and discussed their design brief. Students were required to design and construct an original card, board, or video game. Emphasis was placed on making strong and deliberate decisions about the use of the elements of art (such as color, line, and texture) and principles of design (such as contrast, movement, and unity) when designing original games. DEAL classes also discussed the DEAL method and how it would be used to approach this project. On Day Three students moved around the classroom round-robin style, trying a variety of board, card, and video games. Days Four through 13 were designated work days, during which students researched, designed, and constructed their games. Days 14 and 15 consisted of critique, assessment, and game play.

Rating Procedures. The assessments for this study consisted of 1) a self/peer evaluation, conducted during the critique sessions on days 14-15 with each group; and 2) a series of seven individual assessment sessions, during which individual raters assessed all student projects using the consensual assessment form. The self and peer evaluations are six-item surveys. Following presentations of projects to the class as well as time for game play, students rated their own projects on 1) creativity, 2) aesthetic value and 3) technical strength. The class was then divided into groups of 3-4 students who came to a consensus rating for each project in the small group on 1) creativity, 2) aesthetic value and 3) technical strength. For reasons of simplicity, age-appropriateness, and time, the student rating form contained only the three major dimensions: creativity, aesthetic appeal, and technical strength; the adult form contained additional items subjacent to the three major categories (under creativity: novel use of materials, novel idea, and complexity; under aesthetic appeal: pleasing use of shape/form, pleasing use of color and/or value, and liking; and under technical strength: overall organization, neatness, and effort evident). The consensual assessment (CAT) form developed for this study is a 12-item Likert-type survey. No standardized form for the CAT is available, as design activity contexts vary too

much for such a measure to be useful.

For the individual assessment sessions, seven raters were chosen for their expertise in creative design processes and in education. A rater survey revealed the following about the seven raters: They ranged in age from 30 to 57, with a mean age of 41.4. Five of the seven indicated their most professional experience was as an educator, with one reporting both artist and educator and the seventh reporting both designer and educator. Four of the seven indicated they had taught middle and/or high school courses emphasizing creative problem-solving methods. Four of the seven indicated they had taught middle or high school courses emphasizing a specific design process. Raters were asked to commit approximately two to three hours to a rating session during which they would evaluate student projects on dimensions such as creativity, aesthetic value, and technical strength.

For inter-rater reliability to be meaningful, it is essential that ratings be independent. Raters were told they would be assessing middle school game art and design projects for creativity and other measures, but that they would not be trained in, or otherwise given further rating criteria, related to concept definitions, etc. Based on Amabile's advice[11], projects were spread across tables in a different order for every rating session and raters were given the following instructions for rating:

1. Please view all products before making any ratings
2. Please rate products relative to each other, rather than to some absolute standard.
3. Place an X anywhere on the scale from low to high.

Results

Mean creativity, technical strength, and aesthetic appeal scores were calculated for (a) all adult raters, (b) group consensus by peers, and (c) self evaluations. Means were also calculated for each of the nine items that were only rated by adults: overall organization, neatness, effort evident, pleasing use of shape/form, pleasing use of color/value, liking, novel use of materials, novel idea, and complexity. Pedagogical strategies (DEAL versus choice-based) were compared using either the the independent group t-test or the Mann-Whitney non-parametric alternative. To test inter-rater reliability, Cronbach's alpha was calculated using adult raters' scores for the 12 separate items rated. Additionally, pairwise correlations were run among self-, peer-, and adult ratings of creativity. In order to evaluate discriminant validity, correlations were run between the major three dimensions measured: creativity, technical strength, and aesthetic appeal, and factor analysis was then conducted on all 12 items measured.

Comparison of DEAL Method Versus Choice-based Approach

Hypothesis #1: Projects created using the choice-based method will receive significantly higher mean creativity scores than those created using the DEAL method, as measured by seven adult raters using the CAT instrument.

Pedagogical strategies (DEAL method versus choice-based method) were compared for the 12 measured items on the CAT instrument by adults using the independent group t-test and its non-

parametric alternative, the Mann-Whitney, as appropriate. Adult ratings only were considered for this analysis since student self and peer ratings were conducted only on the three major dimensions, creativity, aesthetic appeal and technical strength. There were no significant differences found between the outcomes of the DEAL and choice-based methods. This was true for all of the 12 items measured.

Correlations Among the Three Major Dimensions

Hypothesis #2: Students using the choice-based method will show low correlations between mean creativity scores and mean technical strength scores, as measured by seven adult raters using the CAT instrument.

Adult raters' scores were used to evaluate the magnitude of correlation between the mean scores of the three major scoring dimensions. Table 1 shows all pairwise correlations among the three major dimensions, creativity, aesthetic appeal, and technical strength. Contrary to the hypothesis, the correlation between creativity and technical strength scores for the choice-based method was higher (r=0.8571, $p < .001$) than for the DEAL method (r=0.8119, $p < .001$), and also higher for both methods combined, r=0.8359, $p < .001$. It appears that greater freedom did not result in lower measures of technical strength, as expected.

Table 1. Correlations for 3 Dimensions of Judgment by Method

Dimensions of Judgment	DEAL			Choice-Based		
	Correlation with Creativity	Correlation with Aesthetic Appeal	Correlation with Technical Strength	Correlation with Creativity	Correlation with Aesthetic Appeal	Correlation with Technical Strength
Creativity	--	0.7758***	0.8119***	--	0.8081***	0.8571***
Technical Strength	0.8119***	0.8258***	--	0.8571***	0.9399***	--
Aesthetic Appeal	0.7758***	--	0.8258***	0.8081***	--	0.9399***

Note. Adult raters' scores only.
*** $p < .001$

Inter-rater Reliability

Hypothesis #3: In both choice-based and DEAL conditions, there will be a significant correlation between scores on students' self- and peer- evaluations for the creativity dimension.

Hypothesis #4: In both choice-based and DEAL conditions, there will be strong (α>0.75) inter-rater reliability among all adult raters for the 12 items measured on the consensual assessment form.

To test inter-rater reliability, Cronbach's alpha was calculated using adult raters' scores for the 12 separate items rated.

Additionally, pairwise correlations were run among self-, peer-, and adult ratings of creativity to inform the discussion of rater types and their usefulness in classroom rating activities. It can be seen in Table 2 that, for adult ratings, all items have reliabilities greater than .70, and that nine of the 12 have reliabilities greater than .80. This includes creativity, with an inter-rater reliability of 0.82. According to the Landis and Koch scale[12], a reliability coefficient between 0.6 and 0.8 is "substantial" and agreement beyond 0.8 is "almost perfect." Agreement coefficients among adults, peer consensus ratings, and students' self-evaluation ratings for creativity, however, were lower, with an overall reliability across all raters of only 0.66 (Table 3). This is consistent with prior research[13-15] which reported only moderate correlations between self-assessments of creativity and ratings made by external observers. Inter-rater reliabilities were also low among the three rater types (self, peer, and adult) for aesthetic appeal, α=0.66, and for technical strength, α=0.50.

Table 2. Inter-rater Reliabilities for Seven Adult Raters

Dimensions of Judgment	Cronbach's α
Creativity	0.8233
Aesthetic Appeal	0.8610
Technical Strength	0.7729
Color/Value	0.8138
Complexity	0.8171
Effort	0.8266
Liking	0.8193
Neatness	0.8545
Novel Idea	0.7383
Novel Materials	0.8483
Organization	0.7983
Shape/Form	0.8331

Note. Seven adult raters' scores.

Table 3: Inter-rater Reliabilities for All Raters

Dimensions of Judgment	Cronbach's α
Creativity	0.66
Aesthetic Appeal	0.66
Technical Strength	0.50

Note. Nine raters total, comprising seven adult raters plus the peer consensus score and the self evaluation score.

Discriminant Validity

Hypothesis #5: Factor analysis will reveal discriminant validity among the three major dimensions of judgment (creativity, technical strength, and aesthetic appeal), appearing as three distinct factors.

In order to evaluate the discriminant validity for this version of the consensual assessment (CAT) form, correlations were run between the major dimensions measured: creativity, technical strength, and aesthetic appeal. Correlations were rather high among all pairings of the three major dimensions. One possible explanation is that the instrument did not measure the three major dimensions independently; e.g., ratings of creativity-related characteristics such as novelty of ideas were very similar to ratings of technical characteristics such as neatness. However, factor analysis conducted on the mean ratings of the 12 dimensions of judgment (promax rotation) suggested two factors, though only one factor emerged with an eigenvalue higher than 1.0. Factor 1 includes overall aesthetic appeal and its subjacent items: pleasing use of shape/form, pleasing use of color and/or value, and liking; as well as technical strength and its subjacent items: overall organization, neatness, and effort evident. Factor 2 comprises creativity and its three subjacent items as categorized on the consensual assessment form: novel idea, novel materials, and complexity. This suggests that raters did distinguish between creativity characteristics and all other characteristics of the students' game designs. It should be noted, however, that factor analysis is far more stable with sample sizes larger than the one used in this study and, therefore, further testing would be necessary in order to make claims about this instrument's discriminant validity.

In summary, projects created using the choice-based method did not receive significantly different mean creativity scores than those created in the control condition using the DEAL method. Students using the choice-based method showed strong correlations between mean creativity scores and mean technical strength scores. In both choice-based and DEAL conditions, there were not significant correlations between scores on students' self- and peer-evaluations for the creativity dimension. In both choice-based and DEAL conditions, there was strong ($\alpha > 0.75$) inter-rater reliability among all adult raters for 11 of the 12 items measured on the consensual assessment form. Factor analysis, though not fully stable at this sample size, suggested two factors rather than the desired three for the consensual assessment instrument.

Discussion

The major research question driving this study was, *will measures of creativity on students' game art and design projects be higher after using the choice-based method rather than the control condition using the DEAL method?* The guiding question led to several related inquiries about pedagogy and assessment that further shaped the study. The most immediate that arose was, if one pedagogical strategy does a better job of supporting creativity in the classroom, how will we recognize it and how will we measure it? Amabile's consensual assessment technique emerged in the literature as a viable option. Amabile's recommendations regarding appropriate open-ended projects led to the choice of the middle school game art and design unit as the study's setting. Her research group's early work in the 1980s involved the evaluation of children's collages, but in recent years their studies branched out to other project types such as poetry, prose, and computer line drawings. Other researchers have extended the CAT to music[16] and even to mixed project types within a single creativity assessment[17]. The question emerged, *will the consensual assessment technique yield high levels of inter-rater reliability when applied to middle school children's game art and design projects?* Questions of inter-rater reliability become particularly important when we think about scaling this assessment technique to real-world classrooms where there may be a range of individuals being used for rating, including students in the classroom.

Reliability and Validity of the Consensual Assessment Technique. Teachers' schedules do not routinely allow for devoting large blocks of time to spreading dozens of projects around the room and bringing in rater after rater to conduct individual assessment sessions. However, the CAT offers benefits to classroom teachers as a viable, adaptable alternative to other types of assessments. Some teachers may be able to recruit knowledgeable adults from the community, such as parents, members of the school's business alliance, and university students and faculty to serve as raters. Meetings of Professional Learning Communities (PLCs) could function as assessment sessions. More often, and for smaller projects, various combinations of students may serve as CAT raters. The use of the CAT for this study did provide beneficial insights into the value of self-evaluations, peer-evaluations, and judges' evaluations of creative products, though not as anticipated. Higher correlations among the three rater types (self, peer and adult raters) were expected. Self-evaluation ratings were also expected to correlate more highly with peer consensus ratings. For this study, students were not trained in self-evaluation and peer-evaluation beyond a brief introduction to the evaluation form on the day it was used. It is likely that with deliberate discussion, explanation and practice, students' ratings would become more reliable and more useful to teachers. While calibration of rater "definitions" is discouraged for adult raters, student raters are not assumed to have expertise, and therefore strict adherence to the recommendations given for adult raters would not make sense. Further study of training students for CAT participation could prove beneficial.

The valuable observations that did emerge regarding the potential benefits of self and peer assessments were qualitative in nature and beyond the scope of this study, but they are fodder for future study. Students were generally quite engaged, and occasionally heated, in their peer consensus discussions. For the most part students stayed on task and were surprisingly thorough in their consideration of other students' games. Many students were seen reading game instruction inserts and referring back to them for comment, testing games for functionality,

thoughtfully critiquing their classmates' designs and decision-making, as well as pulling game pieces out of the packaging a second and third time to justify their opinions. Although the resulting students' scores were inconsistent with each other and with the adult raters, the assessment process for the game design project was a rich experience unto itself and should be studied further.

Seventy-two projects were rated for this study. A larger sample size would be desirable in further studies so that highly stable results regarding the consensual assessment form's discriminant validity could be obtained through factor analysis. A larger sample would also allow for meaningful objective measures to be taken and inferences drawn about variables such as students' choices of game type and medium. Investigation of gender differences might also be of interest in similar future studies of larger samples, as prior studies have intermittently shown girls receiving significantly higher creativity scores than boys[11, 18].

The DEAL and Choice-Based Methods. Both the more established DEAL method and choice-based method offer potential for fostering students' creativity through scaffolded instruction that guides and supports creative expression. For example, students with a variety of disabilities have been shown to thrive in more structured environments in which instructions are explicit. This can manifest itself in a variety of ways, from simply a higher rate of completion of assignments to the demonstration of more creative, innovative thinking. Some students, alternately, are turned off by the idea of doing creative work under strict process constraints. When gifted students are given a DEAL handout, they might see potential for greater clarity of goals and processes. They might also see a built-in map for the minimum effort required to obtain an "A" on the assignment. Perhaps there is no best pedagogy for fostering creativity, but at its best this kind of research can help teachers better serve individual students through differentiated instructional strategies.

A greater distinction between pedagogical strategies' creative outcomes might have been seen had this study not taken place in the researcher's own classroom. It is difficult to know in this situation how much of the prior classroom culture—most likely biasing the entire sample slightly toward the choice-based approach—was brought into the game art and design activity. On the other hand, any implementation hinging on students' perceptions of openness brings with it control challenges, and other types of classroom settings could bring unexpected complications. Ideally, the treatment would be given to multiple groups with randomly assigned teachers administering it. Such a treatment would also deem any results more directly generalizable to the larger population.

Conclusion

The American education system deemphasizes creativity and innovation in favor of a particular skill set that is more easily and cheaply measured using standardized tests[19]. A need for the promotion of creative thinking and innovative problem-solving has been identified in the research literature[2,15], while the field of technology education has identified creativity as a core piece of its mission for technological literacy[1]. Unfortunately, creativity has not always explicitly been part of the goals, objectives and measured results in technology classrooms for a variety of reasons, including the perceived difficulty in assessing it[21-22,4]. However, studies have shown

that the reliable assessment of creativity in students' work is possible [11,18,16]. Many models for creative problem-solving have been developed, but there is still work to be done in determining effective pedagogical strategies for fostering creativity in the classroom. To that end, this research looked at both the DEAL problem-solving method (Define/Explore/Anticipate/Look back) and the choice-based approach, borrowed from visual art education, as approaches that have potential for fostering creativity in technology classrooms. To address the issue of assessment, the Consensual Assessment Technique (CAT) was used both to assess the efficacy of these two pedagogical approaches in enhancing creativity instruction in the technology education classroom and to, at a meta-level, evaluate its efficacy as an assessment instrument. This study compared the creative outcomes of the DEAL and choice-based methods and examined the reliability and validity of the CAT in the context of middle school game art and design projects.

This study builds upon previous research in supporting the notion that (a) creativity can be recognized by raters who are knowledgeable in a domain, and (b) that it can be reliably assessed in the classroom. Inter-rater reliability among the seven adult raters was consistently high for all 12 items of judgment measured in this study. Strong correlations between technical strength and creativity scores support a more student-driven, choice-based classroom environment in which students are not required to work at the same pace on a teacher-directed assignment. A number of factors were discussed which could prove useful in future instructional design for promoting creativity and technological literacy.

Since these findings add to a research base that continues to show creativity can reliably be assessed, technology and engineering teachers should not hesitate to include creativity as an explicit objective in classroom activities. A combination of self-evaluations, peer-evaluations and teacher evaluations at both formative and summative levels can be used toward the determination of creativity scores as appropriate in a wide range of classroom applications and disciplines. Members of teachers' professional learning communities (PLC), in person and virtually, can potentially collaborate in adaptations of the consensual assessment technique (CAT). These findings are important to discussions of how curricula and assessment methods might evolve in technology and engineering education. Further study is needed to develop practical classroom projects and assessments for students and teachers that will spur students toward meeting their creative potential. Creativity was shown to be a successful student outcome of the game art and design project, and the Consensual Assessment Technique shows promise as a method for measuring creativity in technology education laboratory activities as well as the integrated STEM learning environment.

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