DESIGN WITHOUT MAKE A NEW DESIGN PEDAGOGY FOR STEM EDUCATION

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ABSTRACT

This paper describes the first part of a new three-part study of STEM and engineering design research termed Design-Without-Make-to be conducted by NC State University in 2009-10 in an NC high school. The hybrid quantitative, qualitative case study is being developed with the purpose of capturing what new technological learning occurs and how the new pedagogical learning benefits the technological learner. In support of this new design research a three-pronged framework is described, that of basic literature review, social learning theory and project-based learning study. This first paper also includes a description of proposed data collection, analysis, and limitations of the study, and concludes by presenting the implications for Design-Without-Make. Two further papers in the sequence will go on to explain the pilot study and the final study including data results and findings for this new approach to teaching engineering design technology within STEM education.

Keywords: Project-based learning, Design-with-make, Design-without-make, STEM Education

Primary method: Case study

Category: Research in process

INTRODUCTION

Problem Statement

The American Society of Engineering Education (ASEE, December 9, 2008) reported that high school students "are now required to invent a new product or design an improvement to an existing product." Thus, hampered by new standards, shortages in funding, and greater teacher accountability through state testing, technology teachers are pressured for time and funds throughout the educational year. To this end, technology educators have been bridging "gaps" among other core subjects in education. This is often achieved through the use of innovative projects which are creatively designed and implemented to provide students with meaningful learning experiences (Banks, 2007).

Despite teachers being pressured to modify curricula to include fewer projects, which may discourage or stifle creativity, technology educators have the ability to address this issue of invention or redesign in innovative ways. To outline the new engineering design creativity needs within our high schools this paper seeks to explain a new pedagogy and concept of engineering design activity, termed 'Design-Without-Make' which evolved in England (Barlex, 2007).

Students in a design-without-make activity progress through the stages of the design process, much as they would in a design-with-make project, just without the prototyping stage. Since students do not actually build the prototype, they are not limited by the construction skills they possess or the resources available within their school, which allows for greater freedom in creative design for technology students of all ages.

Barlex, (2007) in the International Journal of Technology and Design Education, heuristically states that while still a hands-on project-based approach, design-without-make purports to save time, money, and allow for greater student design creativity. He indicates it places more emphasis on teaching and learning the design process rather than focusing on mechanistic prototyping outcomes. Thus, as teachers of the technology discipline, we believe this student-centered, intuitive, inventive practice has the potential to play an important role in moving forward STEM education.

Research Design Questions and Hypothesis of the Study

Two major research questions drive this study: 1). To identify if students who participate in design-without-make activities will achieve significantly higher learning outcomes than students of traditional design-with-make activities; 2). To identify any attitude outcomes and/or significance of student and teacher attitudes toward design-without-make activities within technology education.

The main thrust of this study is to discover whether the design-without-make pedagogy is an effective alternative to design-with-make within the technology education, project-based learning environment. By its nature, design-without-make claims to resolve the issues of time, expense, and over-emphasis of product construction associated with design-with-make activities, while also encouraging creative and innovative design among students. So the main hypothesis to this study is: will students in a design-without-make environment achieve as good as, if not significantly higher, learning objectives, when compared to students in a design-with-make classroom?

Framework of Paper

In the framework of this paper the authors describe current literature pertaining to design-without-make, a new pedagogical approach to teach engineering design within technology. Originating in London, England, this innovative methodology allows students to come into contact with creative design experiences without emphasis on building or project construction. Barlex (2009), in the International Journal of Technology and Design Education, heuristically suggests that while still a hands-on project-based approach, design-without-make saves time and money, and allows for greater student design creativity. It places more emphasis on teaching and learning the design process rather than focusing on mechanistic prototyping outcomes. They believe it is this student-centered, intuitive practice that has the potential to play an important role in moving forward STEM education.

This PBL practice of design-without-make is intrinsically linked to social learning theory and design and creativity within the engineering design classroom as shown in Table 1.

Social Learning Theories

Success in education can be directly linked to research in

Learning Frame Work	Learning Framework Relevance to Engineering Design	Relevant Scholarship
Social learning theory	Social learning theory focuses on the learning that occurs within a social context. Whereby students learn and reason verbally and the teacher mentor parent acts as a collaborator to provide positive and appropriate social interaction in order to learn from one another. It considers that through social interaction students learn from one another, including such concepts as observational learning, imitation, self-efficacy, self-regulation, motivation and modeling (live and/or symbolic modeling). Albert Bandura is considered one of the leading proponents of this theory.	Bandara (1977); Vygotsky (1978); Davydov & Kerr (1995); John-Steiner (2000); Murphy & Hennessy (2001); Trebell (2007); Gredler (2005)
Design and Creativity	Sternburg cites it as a method of educating students to effectively use knowledge and skills in what is called educating for wisdom. (Wisdom being made up of a combination of intelligence, creativity, and wisdom, which in turn is influenced by one's personal value system on interpersonal, intrapersonal, and extrapersonal levels. Spendlove uses the Intrinsic Motivation Theory Principle of Creativity. He defines that intrinsic, emotionally engaging activities are highly conducive to creative acts. He also lists five 'sure-fire' killers of creativity, which are: expected reward, expected evaluation, surveillance, time limits and completion.	Sternberg, Reznitskay & Jarvin (2007); Standards for Technological Literacy; ITEA; Badran (2007) ; Spendlove (2007)
Project based learning and Problem -based learning	A method of teaching problem-solving skills in which students work together as they progress through a series of steps to design, implement, and evaluate solutions to real world problems.In both Problem- and Project-based learning (PBL), the teacher provides complex tasks based on challenging questions or problems that involve the students' problem solving, decision making, investigative skills, and reflection that include teacher facilitation, but not direction. The teacher is more a facilitator and more focused on questions that drive students to encounter the central concepts and principles of a subject hands-on.	Mills (2003); Banks and Jackson (2007); Matthews (2004); Albanese and Mitchell (2003); Lambros (2002)
Design with-make	Design-with-make uses six basic steps in every Technology Education design-with-make activity. They are 1. Identify and clarify problems; 2. Conduct research which might involve investigations; 3. Generate one or more design proposals; develop these so that they can be scrutinized for predicted performance and social/environmental	Spendlove (2007); Kipperman and Sanders (2007); Trebell (2007); Badran (2007); Schwartz (2007)

Table 1. Learning Framework and Relevant Scholarship (Cont...)

	impact; 4. Construct a prototype of the most promising design; 5. Experiment with sub-component designs as necessary; 6. Test/evaluate the constructed solution.	
Design without-make	The methodology allows students to come into contact with creative design experiences without emphasis on building or project construction. A design-without-make activity is designed around six key concepts. These are 1. The Students design, but do not make; 2. They design products and services for the future; 3. They use new and emerging technologies in their design proposals; 4. They write their own design briefs; 5. They work in teams/ groups"; 6. They present their proposals to their peers, teachers, and mentors and to adult audiences at innovative conferences. Teachers are encouraged to challenge students with design-without-make activities which force students to design products based on conceptual (what it does), technical (how it works), aesthetic (what it looks like), constructional (how it fits together), and marketing (who it's for) criteria without actually having to manufacture a final product for grading.	Barlex (2007); Barlex and Trebell (2008); Banks and Jackson (2007); Atkinson (2000); Peterson (2001)

Table 1. Learning Framework and Relevant Scholarship

social learning as indicated by the Russian Psychologist Lev Vygotsky, (1978) in his Mind in Society book, and in (Davydov & Kerr, (1995), John-Steiner (2000), Murphy & Hennessy (2001). According to Trebel, (2007, p. 2) designing is a "social activity drawing on interaction between pupil/pupil and pupil/teacher." And teaching tools such as scaffolding and group work are important in the social learning classroom. Vygotsky states "… [t]the tasks that the child can accomplish in collaboration with the teacher today, she can accomplish alone tomorrow" (as cited in Gredler, 2005, p. 324). He encourages teachers to challenge students by designing lessons that keep students in their Zone of Proximal Development, which is a level of performance just above what the students can achieve on their own, but no more than they can achieve with the teacher's help. He concludes that students learn and reason verbally and that the teacher is only there to provide the social interaction which the students need since students learn through social interactions with knowledgeable members of their culture (Gredler, 2005).

Case for Design and Creativity

With the abundance of so many standards and standardized testing in the education system today, teachers spend more time teaching to the test than to the skills students really need to be successful in society. Sternberg, Reznitskay & Jarvin (2007) state "[t]he memory and analytical skills that are so central to intelligence are certainly important for school and life success, but perhaps they are not sufficient" (p.144). They indicate that the "purpose of education is to develop not only knowledge and skills, but also the ability to use one's knowledge and skills effectively" (Sternberg, et al, 2007, p.144). This method of educating students to effectively use knowledge and skills is what they call educating for wisdom. They also explain how wisdom is made up of a combination of intelligence, creativity, and wisdom, which is then influenced by one's personal value system on (a) inter-personal, (b) intra-personal, and (c) extra-personal levels.

To support this hypothesis for the teacher of technology, the authors see each aspect of Sternberg's personal value system applied directly to the Standards for Technological Literacy (STL), as developed by the International Technology Education Association (ITEA). Plus, knowledge and skills are always closely tied to the topics addressed in any technology classroom. Standards and testing for standards help teachers ensure that students are gaining the intelligence and knowledge base that Sternberg talks about, but how do technology teachers encourage their students to develop creativity? And why does it matter?

Creativity is becoming increasingly more important to the future because of the "unlimited horizons" it may open up, providing for ever-broadening, multidisciplinary creativity and innovation (Badran, 2007). For years, experts have encouraged technology education teachers to take an interdisciplinary, if not multidisciplinary, approach in their teaching because technology is the field where all other disciplines and skill sets are applied. Most teachers have tried to use projects of varying types as a means to an end of connecting the various disciplines into hands-on creative ventures where the students get to express themselves. As educational standards continue to become stricter from year to year, technology teachers are pressured to modify curricula to include fewer projects, thereby discouraging creativity. Yet, there are other ways to encourage creativity that can be better integrated into curricula than time-consuming, tangible projects?

Encouraging Creativity in the Classroom

According to the literature, there are a few 'must haves' to developing a creative classroom. First, creativity "involves departing from the facts (norms), finding new ways, making unusual associations, or seeing unexpected solutions" (Badran, 2007, p.575). Creativity can be defined as a process, which must be viewed as an investment consisting of a commitment of time, effort, and resources (Badran, 2007). Second, the "Intrinsic Motivation Theory Principle of Creativity…defines that intrinsic, emotionally engaging activities are highly conducive to creative acts" (Spendlove, 2007, p. 52). Spendlove also lists five 'sure-fire' killers of creativity, which are expected reward, expected evaluation, surveillance, time limits and completion. However, Badran (2007) lays out a more positive formula for creativity in the classroom that states

Creativity = Function {Intelligence, Knowledge, Thinking, Personality, Imagination, Motivation, Environment}(p.576)

In order to develop a technology education learning environment that develops and encourages creativity in its students, a well-rounded technology educator must be present. This person should be "creative, well-experienced…capable of steering the interest of students in solving problems, finding new solutions, taking risk…[and have] a mix of academia, practice, art and imagination"(Badran, 2007, p. 581). Badran also indicates that co-curricular activities, team work, diversified activities, and strong ties with industry are also important factors for developing creativity in the classroom. It is this student-centered, intuitive, inventive practice that has the potential to play an important role in moving forward STEM education toward creative education in the classroom.

Project Based Learning

Project-based learning is an active method of teaching problem-solving skills in which students work together as they progress through a series of steps to design, implement, and evaluate solutions to real-world problems (Mills, 2003, Matthews, 2004). Technology education in North Carolina is built around this concept with its "hands-on" laboratory exercises that allow students to gain real-world experiences in developing, implementing, and evaluating technologies (NCDPI, 2006). In their research, Banks and Jackson (2007), describe how many students are motivated to take classes in technology education simply by its hands-on, project-based approach. And for technology educators, it is this interaction that drives and motivates our STEM students and students of engineering design and technology, through a hands-on approach in either the design-with-make or design-without-make option. In PBL these components are crucial to provide team motivation, social interaction, and individual enthusiasm for a student of technology (Matthews, 2004).

Design-With-Make

Traditionally, technology educators have used design-with-make projects to enhance, encourage, and allow for creativity among their students. After all, when students are provided with LEGO™ robotics programming modules, they can easily create and develop interactive storylines and props to accompany any discipline; even literature (Berg, 2008). However, research has shown that "[p]oor practice with education is often focused for reasons of expediency on the product stages of the creative process and in doing so bypassing the essential creative (person) and learning (process) elements and resulting in embellished, rather than creative, novel and inspiring, outcomes with limited contextualized learning, emotional engagement or opportunities to engage in risk taking and uncertainty" (Spendlove, 2007, p. 53).

Kipperman and Sanders (2007) outline six basic steps in every Technology Education design-with-make activity: "identify and clarify problems; conduct research which might involve investigations; generate one or more design proposals; develop these so that they can be scrutinized for predicted performance and social/environmental impact; construct a prototype of the most promising design; experiment with subcomponent designs as necessary; and test/evaluate the constructed solution" (p.227). They also recommend that "during this process the students should document all design, construction and testing procedures"

(Kipperman, 2007, p. 227).

In Technology Education this is commonly referred to as a Design Log, a Design Brief, an Engineering Log, or a Design Journal. Regardless of the name, portfolio assessments tend to be ineffective as they are commonly not completed during the design and construction process, which is largely dominated and regulated by the teacher, but rather after construction is finished to save time and reduce effort on the students' part. Trebell (2007) refers to this process as "the development of creativity in students, the opportunity for them to propose imaginative solutions, take risks, be intuitive, inventive, and innovative in their work." He goes on to say "… it has been sidelined by an approach which has become far too mechanistic" (p. 3).

Some easily integrated substitutes for projects that fit well into standards-based technology-education curricula and still encourage creativity are history of engineering, biographies of inventors, technical writing, and visits from professionals in technological fields (Badran, 2007). But many students enroll in technology education courses because in their other classes they say "there was too much note-taking in the classroom and not enough hands-on learning" (Schwartz, 2007, p. 94). To this end, a middle-ground solution still exists allowing for a hands-on design project effect without the time-consuming prototyping phase. A process called "Design-Without-Make."

Design-Without-Make

A design-without-make activity is designed around six key concepts. These are "pupils design, but not make;" "pupils design products and services for the future;" "pupils use new and emerging technologies in their design proposals;" "pupils write their own design briefs;" "pupils work in groups;" and "pupils present their proposals to their peers, teachers and mentors and to adult audiences at innovation conferences" (Barlex & Trebell, 2008, p. 124). In their article, Design-without-make: Challenging the conventional approach to teaching and learning in a design and technology classroom, Barlex and Trebell (2008), define creative activities as "having four characteristics: (i) imaginative thought or behavior, (ii) purpose, (iii) originality (new to the creator), and (iv) an outcome of value" (p.121). They also acknowledge that to develop creativity, "children must be actively involved in the learning process…[and] group work and collaboration are now seen as key elements" (Barlex, 2008, p.121). Barlex and Trebell encourage teachers to challenge students with design-without-make activities which forces them to design products based on conceptual (what it does), technical (how it works), aesthetic (what it looks like), constructional (how it fits together), and marketing (who it's for) criteria without actually having to manufacture a final product for grading (Barlex 2007, Barlex 2008).

Design-without-make activities work well in creative learning environments as defined by Isaksen (as cited in Peterson, 2001). He concludes that the more challenge, freedom, support, trust, prestige-free discussions, humor, and risk-taking the individual perceives in the immediate social work environment the more opportunity students have to be creative. This description is closely linked to the beliefs Barlex (2007) identifies as necessary for teachers who wish to host design-without-make activities in their classroom. He says teachers who believe "students' intellectual abilities are socially and culturally developed"; "tasks need to be culturally authentic"; "prior knowledge and cultural perspectives shape new learning"; "learners construct rather than receive meaning"; "pupils share responsibility for learning with teachers"; and "pupils are motivated by dilemmas to which they are emotionally committed" (Barlex, 2007, p.156), will be most successful at integrating design-without-make activities.

Banks and Jackson (2007) point out how, despite many students being motivated to take technology courses because of the hands-on process of physically making a product, these physical artifacts often lack any creativity or innovation on the point of the student, due to teacher designed plans. While these projects are easy to implement and fun for students to complete, often they are evaluated based on the completion of the product and an accompanying portfolio activity. In his research, Atkinson (2000) describes how when it comes to portfolio evaluation teachers tend to reward 'thin' evidence before rewarding students for exhibiting higher-order thinking skills. Barlex (2007) in a series of interviews with students in design-with-make classrooms learned that students tend to develop design portfolios after the product has been completed, which undermines the entire portfolio activity. When an entire class of students' products are identical in appearance and they are not performing the proper design and problem-solving processes during the creation phases of said products, are they putting innovation in action? More simply stated, are these students studying technology effectively?

This is our case for implementing design-without-make activities into Technology Education classrooms. Barlex's research has "revealed that pupils can be successfully engaged in designing without attendant making and that the current use of the portfolio for assessment purposes is for many pupils a highly demotivating experience" (2007, p.160). He attributes this "demotivation" to the fact of students not recognizing the value of the portfolio due to the way in which it is ineffectively implemented with the project, while he also points out that "the advantages of collaboration between pupils can be lost when there is an over emphasis on making" (Barlex, 2007, p.160).

Advantages of Design-Without-Make

The implementation of design-without-make activities in place of some design-with-make activities within the Technology Education classroom has many advantages. First, design-with-make is often approached as if the act of designing is a linear process, rather than an inter-connected, reflective, non-linear series of steps (Barlex, 2008). Figure 1 shows Barlex's design decision pentagon, which demonstrates the interconnectedness of the elements within the non-linear approach to design as taught in design-without-make activities. Second, group work and active involvement in the learning process and risk-taking are all encouraged in design-without-make activities (Barlex, 2008, Trebell, 2007). These happen to be also important aspects of a creative learning environment, which is necessary for students to be innovative designers. A third major advantage of design-without-make in the classroom is the lack of large amounts of physical resources required in traditional design-with-make activities, such as tools, equipment, and consumable materials (Barlex, 2007).

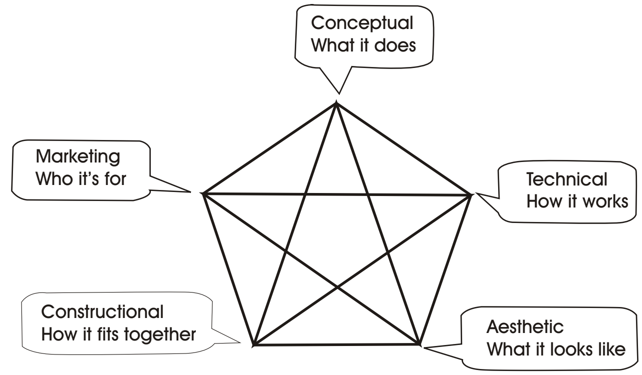

Figure 1. The design decision pentagon.

From "Design-without-make: Challenging the conventional approach to teaching and learning in a design and technology classroom," by D. M. Barlex and D. Trebell, 2007, International Journal of Technology and Design Education, 18: p. 122. Copyright 2007 by Springer Science + Business Media.

Yet another advantage is that design-without-make allows a teacher to bring the latest, newest, still-developing technologies into the classroom without any new cost to the school. This gives students' unrestricted access to innovative design decisions that they may not have had otherwise. When students are limited by their own personal skill at building, they cannot design solutions outside of their own abilities. With design-without-make activities, however, they can design solutions to future problems, using future technologies and techniques (Barlex, 2007, Barlex, 2008, Trebell, 2007). Design-without-make activities are not meant to completely replace design-with-make activities. There is an inherent need for an understanding of how things are made (Banks, 2007), but design-without-make is useful in emphasizing the preconstruction phases of product development (Barlex, 2007, Barlex, 2008, Trebell, 2007), which is often referred to as the design phase.

Research Design Study

Problem Statement: This study seeks to discover if the *design-without-make* pedagogy is an effective alternative to *design-with-make* within a STEM, technology education, project-based learning environment. Design-without-make, by nature, resolves the issues of time, expense, and over-emphasis of product construction associated with design-with-make activities, while also encouraging creative and innovative design among students. The hypothesis in this study is that students in a design-without-make environment will have as good as, if not better, learning objective achievement than students in a design-with-make classroom. Using both quantitative and qualitative methods of data collection, this study seeks to determine if design-without-make is as effective a tool in student learning as the traditional design-with-make approach within technology education.

Research Questions: The main research questions in this study are 1). To assess whether students who participate in design-without-make activities achieve learning outcomes as successfully as or better than students of traditional design-with-make activities; 2). To determine student and teacher attitudes toward design-without-make activities within technology education.

Data Collection and Results

Data collection in this hybrid study consists of quantitative and qualitative components. For the quantitative component a non-equivalent quasi-experimental design will be used. The control group will be the traditional design-with-make class, while the treatment group will consist of a design-without-make class. Both groups will be presented with pre- and post-tests, which will then be compared statistically, using an ANOVA test. Qualitative data will be collected in semi-structured teacher and student interviews. Data results will also be gathered from pre- and post-assessments as well as interviews in which teacher and student attitudes are deduced. The results of the research and findings will be submitted to peer-reviewed journals in engineering technology and related disciplines. Table 2 shows the for quasi-experimental research design.

Conclusion & Recommendations

Conclusions and recommendations will be identified collaboratively and will be submitted for publication after the initial pilot study and major study are completed. As shown in Table 2, quasi-experimental statistics will use an ANOVA to compare data from the self-selected groups, plus pre- and post tests and qualitative interviews.

Group	Pre-Test	Treatment	Post-Test
Treatment	01	X	02, 03, 04
Control	02	Y	02, 03, 04

01= knowledge pre-testX= Design-without make learning treatmentY=Design with make learning
02= knowledge post-test03= Attitude interviews 04= Design review & self-evaluation

Table 2. Quasi-experimental Research Design

How this research contributes to new knowledge in STEM education

Many technology teachers have augmented different project types in order to connect various disciplines into hands-on creative ventures where students can express themselves. However, as educational standards continue to become stricter from year to year, teachers are pressured to modify curricula to include fewer projects, thereby discouraging creativity. Moreover, what other ways are there to encourage creativity in STEM education and engineering design projects?

Design-without-make is the direct response to this question. In a design-without-make activity, students progress through the stages of the design process, much as they would in a design-with-make project, just without the prototyping stage. Since students do not actually build the prototype, they are not limited by the construction skills they possess or the resources available to their particular school. In essence, this allows for greater freedom in creative designing for technology students of all ages.

Thus, this study seeks to open teachers' eyes to design-without-make, a more feasible approach to teach design within the project-based learning environment of technology education.

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