The Role of Virtual Objects in Performing Engineering Related Task

Diana Bairaktarova
Department of Engineering Education
Virginia Tech
Blacksburg, VA, USA
dibairak@vt.edu

Aditya Johri
Department of Information Sciences & Technology
George Mason University
Fairfax, VA, USA
johri@gmu.edu

***Abstract*— Many engineering disciplines are concerned with the creation of tangible objects, however using physical objects to facilitate learning in the engineering classroom is not broadly applied. Tangible objects are primarily used in design projects, with less attention to objects in other engineering activities. Nowadays a lot of attention is given on the Making and Maker movement. Questions remain whatever these activities help people learn engineering. We have completed two studies investigating the efficacy on concrete objects in the same engineering task with different experiential conditions. This work-in-progress is the third study from a line of research, where now virtual objects are included as a new study condition.**

Keywords—concrete objects, virtual objects, performance, engineering education

I. Introduction

Engineers are makers and users of artifacts. While some engineering disciplines are concerned with the creation of processes, design, algorithms, other engineering disciplines (mechanical, manufacturing, biomedical, civil, electrical, ect.) are concerned with the creation of tangible objects. However, using physical objects to facilitate learning in the engineering classroom is not broadly applied. Mechanical objects are primarily used in design projects, with less attention to objects in other engineering activities. Nowadays a lot of attention is given on the Making and Maker movement. Many, who participate in Maker Fairs (in a variety of settings), are optimistic and engaged people, who are truly immersed in the process of making things. These high stroke events and projects nurture diversity of ideas by making together in a community space. There is a sense of discovery by bringing a community together around figuring out how to solve a range of problems. Lead by President Obama, there is a national recognition of the maker movement's potential to transform how and what people learn in science, technology, engineering, and math (STEM). In his remarks on the Educate to Innovate campaign, the President stated that makers "see the promise of being the makers of things, and not just the consumers of things" [1]. This orientation toward personal fabrication rather than blind consumerism is also seen as the foundation for a flourishing economy. Educators see the potential of the Maker movement not only for economic development and job creation but an opportunity to increase personal motivation that inspires innovation [2]. Scholars see the potential of the maker's mindset as a motivator for people not just to look for STEM related job or creative, but "to make their own jobs and industries, depending on their interests and the emerging needs they see in a rapidly changing society" [3, pg. 7].

Questions remain whether these activities help people learn engineering. There are emerging opportunities for a research focused on leveraging making to develop and test its role in improving the effectiveness of formal and informal learning pathways. These pathways in return, promise the potential to increase retention and to broad participation in STEM for both, students and faculty.

We have already completed two studies investigating the efficacy of mechanical objects in the same engineering task with different experimental conditions. This work in progress is the third study from a line of research, where now virtual objects are included as a new study condition.

II. Background and Previous Work

"Engineering education is probably one of the most material - saturated disciplines" [4, pg.161]. This is one of the few most attracting reasons of why young people choose to pursue the engineering profession. Many choose engineering, looking to the experience to improve and create our material world [5]. These potential young engineers are not far from the true engineering practice as whatever else we do in our various engineering specializations, practically all of us deal with artifacts. Certainty, many engineers are specifically concerned with the creation of tangible objects in one form or another. Some descriptions of engineering define the field in terms of its central concern with the creation of objects. Our study is revolved around tangible objects, more specifically, mechanical objects – a term we chose to use in this paper.

Mechanical objects have a unique nature. They are things, with physical bodies that have geometrical, physical and chemical characteristics. In addition, mechanical objects are functional entities that have an intrinsic relation to mental states and intentional actions [6]. What makes mechanical objects distinctive is not only that they have functional properties, but that their functions are determined by the mental activity of their producers and users [7].

It has been established previously by Kirsch and others that concrete objects can improve learning and performance (under the right conditions) [8]. We argue, it is critical that instruction in engineering, uses mechanical objects extensively and routinely. The literature suggests, however, that the potential contribution of mechanical objects has not been broadly exploited for instruction. Studies suggest that mechanical objects are used as teaching tools narrowly, and primarily as part of design training [9]. Our line of research aims at proving the evidence that mechanical objects offer performance and learning opportunities for engineering students. In addition, as we consider the emerging role of making in education, such evidence can help to provide a context for research on the maker movement. As pointed out by scholars, there is a tension between making and formal education practices. When making and formal learning come in contact with one another, exploring whether the newness attributed to the maker movement is really all that new and reflecting on its potential pedagogical impacts on teaching and learning [10].

Study 1

Our prior work reports a study on the effect of the presence of mechanical objects on the creation of engineering assembly instructions of 383 undergraduate engineering students (N=383). Specifically, the control group created the instructions based on only a blue print, while the experimental group created the instructions based on a blue print and a box of parts (BOP, i.e., the actual objects needed for the assembly). Results indicated significantly increased efficiency, functionality, and creativity of the instructions created by the experimental group. This was a quasi-experimental study to evaluate the value-added of physical objects for improving engineering students' performance on an engineering related task. We compared the two groups of students, which were evaluated by practicing engineers working in industry, who were blind to the students' experimental conditions. There was a statistically significant multivariate difference between the control and experimental groups on the engineering task performance: F (3, 373) = 3.47, p = .02; Wilks Lambda =. 97; partial eta squared = .03 [11].

The results from the first study suggested that the box of parts may induce students to think of the object-to-be-fabricated (or the blue print) in terms of three-dimensional components. This three-dimensional thinking, in turn, may have induced superior comprehension of the mechanical object beyond those done in the two-dimensional blue print-only condition. Hypothesizing that the "active ingredient" is through visualization, we continued our search by designing and implementing a follow-up study.

Study 2

In the follow-up study, in addition to the objects manipulation, a second object condition with a page containing colored three-dimensional images of the components was presented to a second experimental group. We hypothesized that the control group will perform worse on the engineering related task than the treatment groups, which will not differ from one another. There was a statistically significant multivariate difference between the control and two experimental groups on the engineering task performance: F (3, 314) = 3.25, p = .004; Wilks Lambda =.93; partial eta squared = .03. In summary, there is a statistically significant multivariate main effect for group membership. The follow up univariate ANOVA's using the same 3 X 2 design format show that on all three of the dependent variables, there is a statistically significant main effect of treatment/group membership.

Post hoc analyses using Tukey b decomposed the univariate main effects and pinpointed the significant differences. They show somewhat different effects for the three dependent variables. For creativity and for functionality, the control group (blue print only) is significantly lower than the two experimental groups. There is no evidence that the two experimental groups differ from each other. For efficiency, however, the pattern is somewhat different. For efficiency, blue print only control differs from BOP. Control does not differ from Blue print + image and the latest does not differ from BOP. Put another way, the distribution of efficiency scores overlaps quite a bit among the three conditions, but the control group does differ significantly from BOP [12].

Informed by the results from the two studies described above, we continued further our search for the "active ingredient" this time investigating the efficacy of 3D virtual objects. In addition, designing the third study, we also considered how engineer's practice in the digital workforce [13] and the fact that the Maker communities have been built up around digital fabrication tools such as Additive Manufacturing (AM, or also known as 3D printing). Although additive manufacturing existed for nearly 30 years, its widespread presence has the potential to revolutionize modern manufacturing and it is already bringing 3D printing to schools and homes. As makers need to create the object and test if a design or part is printable, efficiently manipulating 3D virtual objects is becoming critical.

III. The Present Study

This study introduces a task simulating a real-world engineering application and uses this task to examine how direct manipulation of mechanical objects (physical and virtual) influence students' performance on the engineering activity.

Method

The participants are undergraduate students from engineering, technology, and non-engineering majors at two Universities in the United States. Background data was collected from students before the experiment. Participants were divided into three treatments, (i.e., with physical objects, with 3D virtual objects, and without both, physical or virtual objects).

Participants were asked to create instructions for assembling an engineered object. They were randomly assigned to create instructions with a blue print only, with both a blue print and a box of component parts present, and with both a blue print and a virtual component parts present. Assembly instructions are currently being evaluated by professional engineers blind to the experimental conditions. Students also evaluated their performance on the engineering task. Students from the experimental groups were observed to see how they manipulate the mechanical and virtual objects.

This work in progress is guided by the following research questions:

1. How the presence of mechanical objects facilitates engineering students' performance on engineering related tasks?
2. Do individual differences (mechanical aptitude, spatial reasoning, and thing orientation) moderate the effectiveness of mechanical objects when these are present in the completion of engineering related task?
3. How does the mechanical object fare among non-engineering students?
4. What do students do with the mechanical objects when these objects are present in the completion of engineering task?

In Table 1 below we present an alignment of the research questions, methods, and data analysis.

TABLE I. RESEARCH QUESTIONS, METHODS, DATA ANALYSIS

Q1: How the presence of mechanical objects facilitates engineering students' performance on engineering related tasks? **Assessment:** The engineering related task – Students will be asked to create an assembly procedure for building a solar boat. The solar boat was chosen as the mechanical object because energy applies to many fields of engineering. Energy is a topic discussed in physics, chemistry, and a variety of different engineering disciplines. All students were given a blue print for the assembly of the solar boat. The students randomly assigned to the first experimental group will be also provided with a box of component parts (BOP) for the boat. The students randomly assigned to the second experimental group, in addition to the blue print, will have an access to virtual objects (VBOP) mimicking the physical components for the boat. Evaluation of students' assembly procedures by professional engineers blind to the conditions. **Analysis:** Analysis of variance and Regression to compare students' performance on the task (Blue print only vs BOP vs. VBOP). **Outcome:** Identify the contribution of virtual objects to performance on engineering related task. Compare gains in performance categories (functionality, efficiency, creativity) for the three groups.
Q2: Do individual differences (mechanical aptitude, spatial reasoning, and thing orientation) moderate the effectiveness of mechanical objects when these are present in the completion of engineering related task? **Assessment:** Students will complete mechanical aptitude test, spatial reasoning tests (Santa Barbara Solid Test) and person-thing orientation scale provide demographic information (sex, race, major, SES, ethnicity) at the beginning of the study. **Analysis:** Hierarchical, centered cross-product regression analyses. **Outcome:** Identifying if individual differences will moderate the effectiveness of giving engineering students component parts for mechanical objects.
Q3: How does the mechanical object effect fare among non-engineering students? **Assessment:** Non-engineering students will complete mechanical aptitude test, spatial reasoning tests (Santa Barbara Solid Test) and person-thing orientation scale and provide demographic information (sex, race, major, SES, ethnicity) at the beginning of the study. **Analysis:** Hierarchical, centered cross-product regression analyses. **Outcome:** Generalizing results across a considerable range of engineering and non-engineering students to validate if minimum threshold on mechanical aptitude, spatial skill, or thing orientation are needed for better performance.
Q4: What do students do with the mechanical objects when these objects are present in the completion of engineering task? **Assessment:** Observation and video recording on how many students attempt to assemble the objects. How many try to coordinate the components with the blue print? Do they vocalize verbal labels for mechanical objects? **Analysis:** Video-recordings of participants engaged in the task and transcripts of the participant. These data will be coded according to typologies of actions that emerge from an analysis of participants' performance of the task. **Outcome:** Determine which typologies are unique to interactions with mechanical objects.

We completed the data collection at the end of the spring semester. Data was cleaned, de-identified and students' assembly instructions were sent to six practicing engineers for evaluation. We regret to not being able to report preliminary results yet as so far we received only the evaluations of two engineers. We will present analysis and results of the full data set at the conference in October.

IV. Discussion

Our anticipated/hypothesized result is that the visualization process is the active ingredient in performing engineering task. If our hypotheses are corroborated, then both, the presence of objects, concrete and virtual, will enhance performance on engineering related task.

We predict that engineering students would generate better assembly instructions when they have the box of component parts (BOP) (physical or virtual) than when they have the blue print only. Having a deep understanding of how students manipulate mechanical objects will help us design instructional methods that utilize mechanical objects (physical or virtual) as learning tools in the classroom.

We predict that the presence of objects (concrete and/or virtual) will enhance performance in some students more than in others. Three attributes in particular warrant attention as potential moderators – mechanical aptitude, spatial reasoning, and thing orientation. Next step in this line of research will aim on creating instructional interventions to improve students with low mechanical aptitude, spatial skills, and to provide opportunities for more interactions with objects through the curriculum.

Another anticipated result is that the visualization process is the active ingredient in performing with objects. Alternatively, it is possible that manipulation of virtual objects activates processes different from those used in manipulation of physically present mechanical objects. This outcome will be particularly important in engineering courses where a wide range of objects (with different scale, complexity, affordance, etc.) are needed to address conceptual understanding, which makes it very difficult, if not impossible to use physical objects to enhance student learning. The outcome will be to create a virtual library with the mechanical objects for the use in courses where physical objects cannot be manipulated. Results from our studies so far support the hypothesis that the presents of concrete objects enhance performance of students on an engineering related task. The findings from the present study will inform us on the efficacy of virtual objects on performance. Our next studies will aim at addressing variables related to learning as learning can occur without performance differences and as performance is often used as an indicator of learning, but the two variables are not isomorphic [14 - 16].

In the next studies we will introduce more complexed assembled objects to account for sensitive of the tasks and considering the characteristics of the learner. In our studies so far we focused on the unexperienced students, who had low levels of prior knowledge with mechanical objects and engineering drawings. If we engage in the same engineering task experienced students, we may not have found support for our predictions. Our next study will aim at addressing variables related to prior knowledge and experience with manipulation of concrete and virtual objects and engineering drawings.

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Diana Bairaktarova is an Assistant Professor in the Department of Engineering Education at Virginia Tech. Dr. Bairaktarova has over a decade of experience working as a Design and Manufacturing Engineer. Her research is focused on human learning and engineering, i.e. understanding how individual differences, aptitudes and abilities affect interaction with engineered physical and virtual objects to enhance learning and performance in engineering.

Aditya Johri is an Associate Professor in the Department of Information Sciences & Technology at George Mason University. Dr. Johri studies the use of information and communication technologies (ICT) for learning and knowledge sharing, with a focus on cognition in informal environments. He also examines the role of ICT in supporting distributed work among globally dispersed workers and in furthering social development in emerging economies. He received the U.S. National Science Foundation's Early Career Award in 2009. He is co-editor of the Cambridge Handbook of Engineering Education Research (CHEER) published by Cambridge University Press, New York, NY.

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