The Use of 3D Printing in Behavioral Research – A Proposal for the Interaction Between Engineers and Experimental Psychologists

Dr. Hitesh D. Vora, Oklahoma State University

Dr. Hitesh D. Vora is an Assistant Professor in Mechanical Engineering Technology. He received his Ph.D. and Masters' from the University of North Texas in Materials Science & Engineering (in 2013) and Mechanical Engineering Technology (in 2008), respectively. Dr. Vora is a Director of the Industrial Assessment Center (IAC) at Oklahoma State University, which is funded by the US Department of Energy (DOE) for the year 2016-2021 with total funding of $1.8 million. For those not familiar, the Industrial Assessment Centers help small and medium-sized U.S. manufacturers to save energy, improve productivity, and reduce waste by providing no-cost technical assessments conducted by university-based teams of engineering students and faculty. He is actively teaching several courses and pursuing research in advanced (smart/cyber) manufacturing and energy management to improve energy efficiency (reduced energy, cost, and throughput) for small to medium-sized manufacturers. In addition, he is a Matrixed Professor in the ENDEAVOR Digital Manufacturing Maker Space located in the new ENDEAVOR building, which is a 72,000-square-foot and $30 million building. This maker space provides additive manufacturing support for design courses, laboratory courses, and entrepreneur initiatives. This facility houses several different technology 3D printers that capable of printing parts from polymers, fibers, composites, and metals as well as 3D scanning and subtractive manufacturing equipment. His research focuses on machining and manufacturing with a specific concentration on the use of additive manufacturing processes for advanced materials. He emphasis on design for additive manufacturing (DfAM), topology optimization, lightweight applications, and finite element analysis in additive manufacturing processes. Dr. Vora extensively teaches the additive manufacturing technology through the dedicated undergraduate (MET 4173) class as well as through the hands-on training sessions and certification (level 1 to 4) in the Endeavor Digital Manufacturing Maker Space.

Dr. Charles Ira Abramson, Oklahoma State University Department of Psychology

Dr. Charles I. Abramson is Regents Professor of Psychology at Oklahoma State University and founder of the Laboratory of Comparative Psychology and Behavioral Biology. He earned his PhD. in Psychology from Boston University in 1986. He joined the faculty of Oklahoma State University in 1993 and holds adjunct appointments in the Departments of Integrative Biology and Entomology and Plant Pathology. Trained as a comparative-physiological psychologist, he specializes in studying a wide range of behavior in organisms as diverse as flatworm, earthworm, ant, bee, crab, fish, snake, rat, llama, horse, elephant, and human. His research areas include the development and assessment of training apparatus, development of hands-on teaching experiences, the effect of agro-chemicals on learning in honey bees, the use of essential oils and other biological controls to augment pesticides, explorations into the behavior of Chagas disease vectors, the development of a social insect model of alcoholism using the honey bee, the creation of a mathematical model of the learning process based on the first order system transfer function, general issues related to the comparative analysis of behavior, and the use of conditioning methods in general aviation. In addition to experimental based research, he has conducted historical research on the life of the early African American psychologist Charles Henry Turner.

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Abstract

The past decade has witnessed remarkable advancements in 3D printing or more scientifically called as additive manufacturing (AM). Surprisingly, few behavioral scientists have taken advantage of 3D printing in the design of the apparatus. The use of 3D printing has much to recommend it for behavioral scientists. First, the cost of commercial behavioral apparatus can run into thousands of dollars for a simple “Skinner Box” where animals are trained to press a lever for a food reward. Second, as grant money and start-up funds for young faculty are becoming increasingly difficult to obtain. 3D printers allow faculty members to spend significantly less on apparatus costs. Third, for those behavioral scientists wishing to work with more exotic laboratory species such as invertebrates, there are few commercially available apparatuses. In such cases, the behavioral scientist must construct an apparatus on their own which can be time-consuming and often of low quality and limited applications. The inferior quality of many of these “handmade” apparatuses induces experimental errors that influence the experimental results and replicability. Fourth, by having an ability to print 3D apparatuses, it extends behavioral science to a wider range of individuals. For example, high school students and college undergraduates can now develop sophisticated apparatus to study a wide range of behavioral issues. Fifth, 3D printing of behavioral apparatus will lead to greater standardization of apparatus and greater standardization among behavioral laboratories. Our paper discusses the advantages of 3D printing, the type of 3D printers (printing technologies) we have found most useful for various applications, offers practical suggestions on how engineers and behavioral scientists can communicate with each other on apparatus design issues and discuss how apparatus design with 3D printing can increase student interest in the STEM field. We first document that experimental psychologists seldom use 3D printer technology and then offer recommendations on how to increase the use of such technology in the behavioral sciences.

Keywords

3D Printing, Behavioral Research, Experimental Psychologists, Additive Manufacturing, Experimental Psychology, Behavioral Apparatus.

1. Introduction

A major goal of psychology is to explore behavioral and cognitive abilities across species. One issue hindering these comparisons is the lack of standardized apparatuses. An example of standardized, commercially available apparatuses for behavioral experiments are Skinner boxes, shuttle boxes, and mazes that typically cost between $2,000 - $5,000 and are restricted to commonly used animals as chimpanzees (and other non-human primates), mice, pigeons, rats, and fish. The lack of standardization has contributed to the general perception that many findings in psychology are not replicable [1, 2]. The goal of the present paper is to help stimulate the interactions between engineers and experimental psychologists in the area of 3D printing by advocating the development of courses, grant seeking for the creation of workshops, and student projects among other suggestions.

Three-dimensional (3D) printing technology, also known as additive manufacturing, is making a big leap in all commercial and educational sectors. This is primarily due to its unique capability to produce parts in layer-by-layer fashion directly from the digital 3D model. 3D printing offers immense versatility in terms of design complexity. A wide range of materials can be used giving the researcher an almost unmatched selection of platforms to choose from (polymers, composite, metals, ceramics, glass, and edibles). 3D printing significantly reduces energy usage by using less material and eliminating steps in the production process. Moreover, no additional tooling is required; parts can be produced with minimal to no material loss. These characteristics enable the creation of 3D apparatuses that may be lighter, stronger, multicolor and multi-material.

This paper was stimulated by anecdotal evidence gathered by the authors that few experimental psychologists utilize 3D printing in their research. The senior author has over 30 years of experience in experimental psychology and has been developing apparatus for various organisms throughout his career. His laboratory is one of the few in the United States that develop apparatus and teach students how to create their own. The use of 3D printing is a natural progression in the construction of apparatus yet surprisingly few experimental psychologists are taking advantage of these remarkable devices. Thus, the purpose of this paper is two-fold. First, we wanted to estimate the use of 3D printing by experimental psychologists and second, to offer recommendations on how to increase the interactions between engineering departments and those experimental psychologists in the area of 3D printing.

The use of 3D printing has much to recommend it for behavioral scientists. With 3D printing, behavioral apparatus can be produced for low cost as well as in expedite manner. Second, as grant money and start-up funds for young faculty become increasingly difficult to obtain, 3D printing allows faculty members to spend significantly less on apparatus costs. This is especially important for faculty at educational institutions where funds are limited and even nonexistent. Third, for those behavioral scientists wishing to work with more exotic laboratory species such as invertebrates, there are few commercially available apparatuses. In such cases, the behavioral scientist must construct apparatus on their own, which can be time consuming, and often of low quality and reliability.

The inferior quality of many "handmade" apparatuses introduces experimental errors which influences the experimental results and replicability. A good example of the lack of commercially available apparatus is the training apparatus for planarians known as "Train-a-Tray." Train-a-Tray was a commercially available device for training flatworms discontinued at least a decade ago. With 3D printing we can reproduce the apparatus. Fourth, by having the ability to print 3D apparatuses, it extends behavioral science to a wider range of individuals. For example, high school students and college undergraduates can now develop sophisticated apparatus to study a wide range of behavioral issues. Fifth, 3D printing of behavioral apparatus will lead to greater standardization of apparatus between laboratories. The latter point should not be underestimated. With few exceptions apparatus in the behavioral sciences are not standardized [3, 4].

2. Use of 3D printing in comparative psychology

To document the use of 3D printing in experimental psychology we surveyed the method section of each article in the *Journal of Comparative Psychology*, the *International Journal of Comparative Psychology*, and the *Journal of Experimental Psychology: Animal Behavior Processes* from 2001-2020. The rationale behind the selection of these journals is that they focus on the study of animal behavior, which, we believe, has the greatest opportunity to incorporate 3D printed apparatuses. To capture the use of 3D printing in other forms of psychology, we also conducted a review of articles in the journal *Behavioral Methods, Instruments, and Computers* for the same 20-year period. The latter is the only psychology journal that specializes in technique.

3. Results

Our results were astonishing. Table 1 shows the number of articles appearing in the four journals surveyed. The total number of articles we reviewed were 4,341. Table 2 shows that of the 4,341 articles surveyed, only one used 3D printer technology.

a. *Journal of Comparative Psychology* (JCP):
b. *International Journal of Comparative Psychology* (IJCP):
c. *Journal of Experimental Psychology: Animal Behavior Processes* (JEP):
d. *Behavioral Methods, Instruments, and Computers* (BMIC):

Table 1: Number of total articles for 20-years period

Years	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
JCP	50	53	50	47	49	53	48	52	50	49	50	47	49	49	44	44	38	48	55	11
IJCP	20	21	16	22	31	25	28	7	16	40	25	18	25	39	33	25	33	39	22	3
JEP	30	34	27	27	45	49	42	40	53	47	50	43	38	41	39	38	33	33	34	7
BMIC	70	71	75	83	80	88	121	129	142	114	105	97	112	97	108	126	163	179	179	28

Table 2: Number of total articles using 3D printing in research

Years	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
JCP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IJCP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JEP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0
BMIC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4. Case study

In one investigation, the authors have used a 3D printed apparatus (Y-Maze) to estimate avoidance and foraging behavior in response to increases in magnetic fields. Previously, this kind of experiments were performed with handmade apparatus usually constructed from wood or cardboard. This kind of apparatus are non-standardized and severely lacking in replicability. Our 3D printed "Y" maze contained a clear Plexiglas cover and base to easily see the honey bee's movement (Figure 1, A). A commercially available 3D printer (CraftBot) utilize the fused deposition modeling (FDM) technology to additively manufactured the Y-maze with white color Poly-Lactic-Acid (PLA) polymeric material, removable color panels, and a bee containment box.

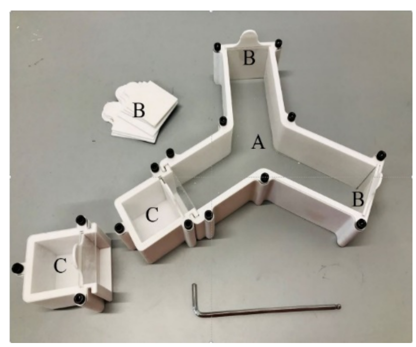

Figure 1: Diagram of the y-maze. A is the 3D printed maze, B are the removable color panels, and C is the bee containment box.

The 3D printing was performed using a 0.4 mm diameter steel nozzle and 1.75mm filament of PLA material with the optimal printing parameters for PLA filament materials (extruder and bed temperature - 220°C and 60°C, respectively). The clear plexiglass cover was cut to size using a CO_2 laser. The maze consisted of three arms: a start box with no choice variable (Figure 1, C), and two choice arms that terminated with a removable colored panel (Figure 1, B). Panels were painted with Testor's paint in either yellow or blue.

Each bee was captured from a 20% aqueous sucrose feeder and brought to a nearby indoor laboratory facility 12.4km from the apiary. A 1:2 mixture of honey: sucrose was provided to bees after removal from the feeder until transfer to Figure 1, C. Upon arrival to the laboratory, bees selected for immediate use were transferred to a 3D-printed box (Figure 1, C) and held for 10 minutes. The rational for placing the bee in the holding area (C) was to allow the insect a period of adaption and reduce post-handling stress variables. Further handling was avoided after the adjustment period. Magnetic field disks were attached vertically behind panels B at the end of both choice lanes and painted sucrose wells were placed at the base of Figure 1, B. The inside walls of each well were painted with the corresponding color of B. Both wells contained 200µL of 1M sucrose for use throughout the experiment. Magnetic field strength directly above each well was tested before each experiment. Each experiment included two honeybees. Boxes (C) containing each bee were labelled accordingly. To start each trial, the box containing a bee was docked at C, the start gate was opened simultaneously with the start of a 5-minute timer. After 5 minutes, the experimental bee was coaxed back into C with minimal handling and C was replaced with the other bee-box, allowing a 5-minute rest period for each bee between trials. Bees were recorded from above for the entirety of the experiment (10 total trials per bee). Videos were later coded for total amount of time spent per choice lane and amount of time spent drinking. While the maze may seem simple, the discussions between engineers who designed and printed the apparatus and experimental psychologists who provided parameters of the maze taught all of us a lesson on how to communicate between the two disciplines.

Figure 2: Image of the shuttle box apparatus. The controller is in the upper left corner.

As another example, Figure 2 shows an early model of a 3D printed shuttle box for honey bees. This apparatus was used for several publications and, by using 3D printing we can easily refine the apparatus. The box in the upper left corner is a low cost experimental controller that presents experimental conditions and records data automatically.

5. Questions

This paper brings together two ideas not previously considered as complimentary. To encourage discussions and conversations between engineers and experimental psychologists, we recommend the questions below serve as the basis for communication. These questions were developed based on the experiences of the authors. Suggested outcomes are also provided with regards to the educational benefits to engineering students.

Question 1. What is the purpose of the apparatus?

- Relevance to Engineering education – they gain knowledge about the types of behavioral apparatus used by social scientists, and social scientists learn how to express their ideas in a way that engineers can understand.

Question 2. What is the species to be used (aquatic, flying, crawling, etc)?

- Relevance to Engineering education – they will be confronted with interesting real-world problems. Designing an apparatus for a rattlesnake is not the same as for a honey bee, or for a beluga whale. Each species presents both the behavioral scientist and the engineering student unique challenges. Each species presents a unique set of problems for engineering education.

Question 3. What materials should be used in the design of the apparatus?

- When designing a behavioral apparatus, engineering students must be able to know a wide range of materials in order to make the appropriate choice. As a behavioral scientist will probably be unfamiliar with the type of materials offered by 3D printers, the engineering student must have knowledge of materials. For example, when making a shock grid for an insect, the surface must be designed in a way that when fluids from the insect touch the grid, the grid will not short out. The discussion between an engineering student and a behavioral scientist is another example of fruitful interactions between the two disciplines.

Question 4. How is the behavior in the apparatus to be measured (i.e., placement of sensors, and what type of sensors)?

- During the design phase of the apparatus, the engineering student must have a knowledge of the sensors that are used to record the behavior and what type of sensors to be used. For example, only infra-red sensors can be used for honey bees as other type of sensors may unconditionally attract the insect. Moreover, where should they be placed? If a honey bee is to be used in a choice chamber, where should the sensors be placed. Should there only be one sensor traversing the mid-line of the chamber? Alternatively, should two sensors be used that are located slightly off the mid-line so that if the honey bee crosses the mid-line it is known that it actually is in a particular compartment of the choice chamber? An interesting sensor problem occurred in Turkey when the sensors detecting a honey bee would not turn off. After much effort to fix the problem it was discovered that, while the sensors worked well in the United States, the fluorescent lightbulbs in Turkey gave emitted a frequency that activated the photocells.

Question 5. Where to place stimulus cues and what type of stimulus cues can be used?

- A related issue to the type and placement of recording sensors is where to place cues and what type of cues should be used. For example, if olfactory cues are used, how should they enter the apparatus, how are the olfactory cues removed, what is the interaction between the olfactory stimuli and the type of material used to print the apparatus.

Question 6. How is the apparatus to be connected to the control apparatus?

- When the apparatus is built how is the apparatus to be connected to control equipment for the automated presentation of stimuli and the recording of responses.

In short, these questions are important for engineering education as we expect that over the coming years there will be a greater interaction between behavioral scientists and engineers. We believe that our paper is a good place to start.

6. Recommendations

The results of our survey show that few behavioral scientists in psychology utilize 3D printers. This is true both within and between the journals we selected to survey. Somewhat disappointing is that as the number of years increased over the two decades, there was no significant increase in the use of 3D printer technology. The authors of this paper represent the fields of engineering and psychology, respectively and believe our experience working together can serve as a potential model to increase the use of 3D printers in experimental psychology. We offer the following recommendation:

- Apply to the National Science Foundation (NSF) for funds to support 3D printing workshops. The NSF and other granting agencies often have funds to support such workshops. State agencies may have grant funds as well.
- Develop an undergraduate/graduate course such as "3D printing for experimenters." Such a course would stimulate collaboration between psychologists and engineers, improve communication between the two fields, and teach students vitally important skills.
- Create a library of schematics for 3D printed apparatus. This library would be open access and help standardize apparatus across various laboratories.
- Assist laboratories in developing countries who cannot afford behavioral apparatus. For example, we have designed, printed and distributed various 3D apparatus to educational institutions in Africa, Brazil, Egypt, Iran, and the U.S. Territory of Puerto Rico.
- Submit "summer camp" grants focused on 3D printing for high school students. Under the dual supervision of an engineer and experimental psychologist, students develop behavioral apparatus that can be used at their home institutions and/or home school. It has been our experience that 3D printing is a wonderful way for students to become interested in science and has the added benefit of encouraging students to understand the more natural science portions of psychology. There is no better way of knowing your animal that to design an apparatus to study its behavior.
- Extend the knowledge and use of 3D printing to other than engineering fields by conducting interdisciplinary collaborative research on developing standardize apparatus.

7. Discussion

The paper provides a compelling "Call to Action" for increased development of connections/collaborations between engineering and behavioral psychology. It also calls for experimental psychologists and students to learn how to use and incorporate 3D printers into their research. In the course of this collaboration both psychology and engineering students would benefit by being exposed to a new area of research/technology. We believe that engineering students would be especially challenged as they would be faced with solving unique design problems.

Our article is the first we know of that attempts to reach out to behavioral scientists regarding the advantages of 3D printing. Despite the many advantages of 3D printing behavioral apparatus, our results showed few in the behavioral sciences utilize 3D printing. In some ways this should not be a surprise as few students in psychology and perhaps other behavioral sciences, learn how to construct apparatus [5]. The laboratory of the senior author is one of the few where students learn how to construct apparatus for a variety of organisms. 3D printing can lead to better interactions between engineers and psychologists, produced standardized techniques that are needed in the behavioral sciences, and encourage skills which may encourage students to enter the STEM aspects of psychology.

8. Acknowledgment

The authors would like to acknowledge the Endeavor – Digital Manufacturing Maker Space at Oklahoma State University's College of Engineering, Architecture, and Technology. This laboratory was designed to increase undergraduate laboratory and exploratory time for interdisciplinary, hands-on, and industry-aligned learning. We would also like thank Dr. Brad Rowland for providing the Endeavor facility for this project and Jon Bramsch and Hannah Lancaster for designing and printing the Y-maze for this project.

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