**3D Printed Talking Tactile Learning Objects will make Learning by the Blind More Compliant**

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A proof of concept paper was published recently in the Journal of Blindness Innovation and Research (<https://nfb.org/images/nfb/publications/jbir/jbir14/jbir040102.html>) and shows how 3D prints can be made from 2D images obtained from using microscopes, telescopes or earth facing satellites. 2D jpg files can be changed into stl (stereolithography) files needed for 3D printing using PhotoToMesh software. These stl files are flat on one side with the other in tactile form and can be described as a “bas relief”. The 3D prints in the proof of concept paper were made on either the consumer grade MakerBot Replicator 2 3D printer or were sent to i.Materialize in Belgium. It is also possible to make 3D printed line graphics as well as Braille for inclusion in a more complete tactile learning object.

This presentation explores various methods to incorporate audio in the tactile learning object because not all blind students read Braille. Audio would also assist teachers and support personnel who work with blind or visually impaired students. The first method is to incorporate the Livescribe pen which is designed for note taking but can be employed with the special paper that comes with the Livescribe pen to provide audio feedback when used with 3D printed line graphics. A first example of a tactile learning object was included in the JBIR paper and was composed of a 3D printed cell in mitosis (telophase stage) with a 3D printed line graphic leading to a 3D printed Braille structure identification page and also another page for accessing an audio response using the Livescribe pen for more information about structure identification and function. The Livescribe pen provides an easy option to pre-load audio for structure identification and also for the delivery of ancillary information in a mini-lecture format.

The second method for audio inclusion in a tactile learning object employs an Arduino-based microcontroller (duemilanove) with a voice chip shield (SpikenzieLabs) which is designed to utilize capacitance sensing as a way to generate a pre-recorded audio response. A thin copper foil, for example, underneath the 3D printed telophase stage of mitosis was attached to a resistor leading to the Arduino microcontroller so that when the surface of the 3D print was touched, the electrical activity of one’s fingertip causes the capacitance to change which then stimulates the voice chip to generate the audio describing what structure was touched. It is interesting to remember that these initial 3D prints are made from plastic such as PLA (polylactic acid) or polyamide and they are non-conductive so it leads one to conclude that the fingertip is having a measurable effect on the copper plate beneath the plastic 3D print by producing a change in the electric field set up by the capacitance associated with the copper plate.

The third method explored the use of an electrically conductive 3D print composed of steel. Both i.Materialize and Shapeways made steel 3D prints from several of the same mitosis stl files used for making the plastic non-conductive 3D prints. The steel 3D prints were a work of art having a beauty to them that was surprising. They were noticeably heavier and had to be thicker to meet the requirements of the process for making steel 3D prints. They were conductive as measured with a multimeter and also could be used with the Arduino microcontroller to stimulate the voice chip to generate audio, i.e., “talk”. The conductive nature of the steel 3D print required decreasing the level of sensitivity of the Arduino-voice chip software compared to what was required for the non-conductive plastic 3D prints. The sensitivity could be decreased about 100 times compared to what was needed to sense a fingertip with the non-conductive 3D print. The decrease in sensitivity was required so that only the area of the steel 3D print being touched would generate an audio response by the Arduino voice chip. With the same sensitivity level for non-conductive plastic, a finger touch on a steel 3D print even far removed from the area over the underlying copper foil would cause an audio response due again to the high degree of conductivity of steel. It was necessary to decrease the sensitivity of the voice chip software until a finger touch to the steel 3D print generated an audio response only when the 3D print was touched above the copper foil.

The fourth method for incorporating audio into a tactile learning object also utilized the 3D prints made in steel but utilized the iPad as the source of audio feedback. Certain precautions must be followed when placing a 3D print made of conductive steel on the surface of an iPad as the iPad screen also functions in knowing where a fingertip touches the screen by using the capacitance sensing method. Normally, the electrical charge on a fingertip touches a point on the screen and changes the capacitance at that touch point which is then translated by the iPad software into an x-y axis so that a particular function can be carried out. But, when a conductive substance like steel is placed on the screen, portions of the steel 3D print that one does not want to be touched for structural identification must be covered by a non-conductive material or else the whole screen will have a charge delivered to it even by just holding the steel print in one’s hand to set it on the iPad surface. Also, the steel 3D print is heavier than plastic versions so having a non-conductive substance like 3 mm thick paper or plastic between it and the iPad surface helps to protect the surface from being scratched or broken. The areas on the steel 3D print that one wishes to have an audio response provided must then have access to the capacitance field of the iPad screen so holes must be cut into the 3 mm thick paper underneath the 3D print area for which an audio response is desired and then into the hole, one places a piece of conductive foam. The conductive foam now provides a way for the electrical activity on a fingertip to pass through the steel 3D print and then be conducted to the surface of the iPad to interact with the capacitance sensor built into the iPad screen. Audio response from the iPad is generated by opening VoiceOver which is the text reader for the iPad. VoiceOver must be used because the iPad software does not permit a video or audio file to be opened by just touching a surface button because Apple does not want a video to play using up bandwidth unless the user wishes to watch the video so a second selection must be made to start the video or for our use, start the audio response. VoiceOver though generates an audio response by touching a word in html text. So, if an html document contains the text for the desired audio response and VoiceOver is deployed, now a finger touch to a structure on the steel 3D print will carry its electrical activity via the conductive foam which then simulates a real finger touch on the text and the text is then read providing a way to generate information about the structure being touched on the steel 3D print.

All of the described methods employed to produce an audio response by touching a 3D print at a particular spot make the tactile learning object more able to function as a learning method for the blind or visually impaired. This type of tactile learning object, i.e., one that talks or speaks when touched, would also be of value for kinesthetic learners who learn best when touching what they learn. And, it is also important to recognize that making tactile learning objects more useful for learning by the blind or visually impaired can serve to make image-rich courses (online and on-ground) more compliant and anticipates how reasonable accommodations in the future may be changed so that image-rich courses can be made more accessible for the blind or visually impaired student.