Do Digital and 3-D Printed Specimens Increase Conceptualization of Soil Structure?

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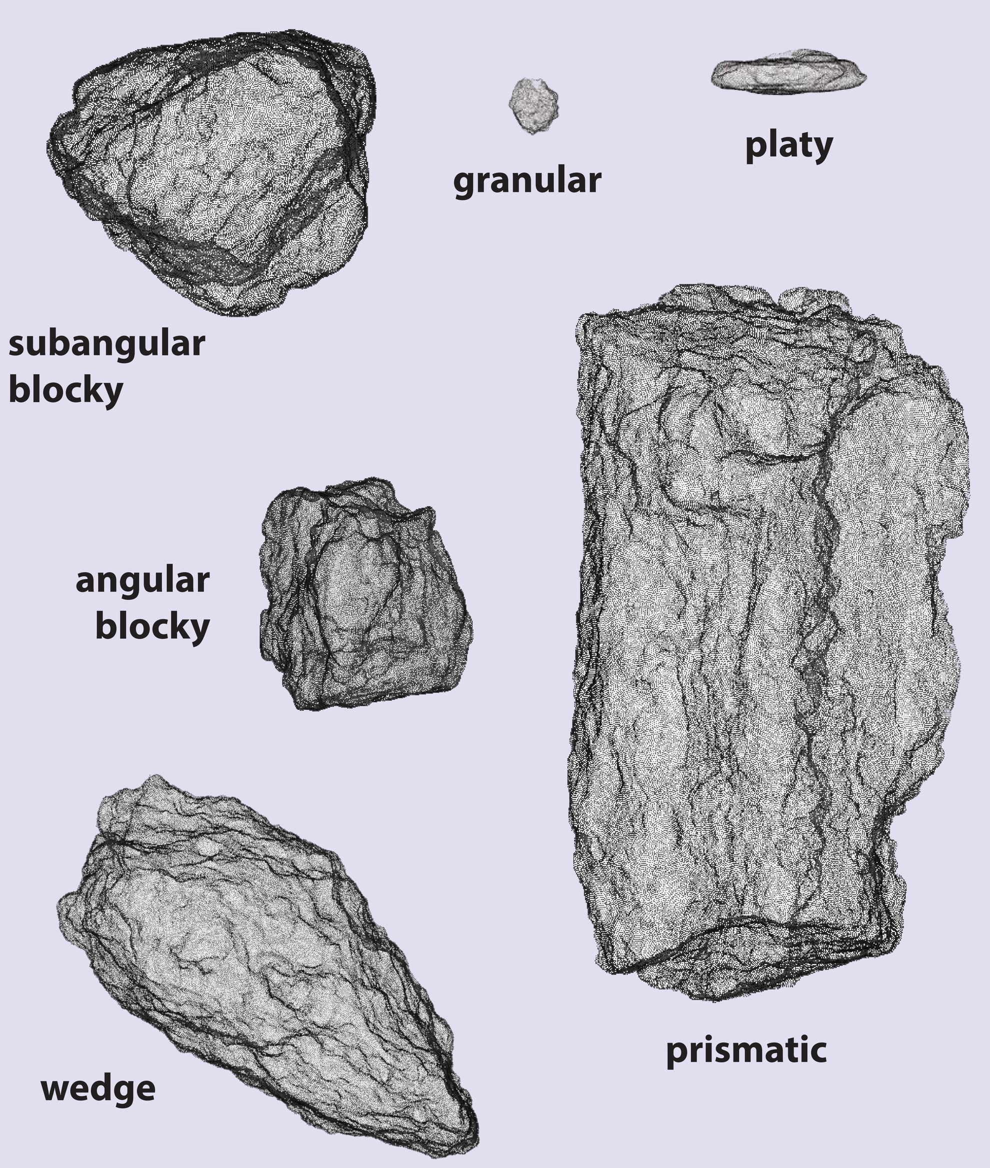
We tested and compared the effectiveness of teaching concepts related to soil structure using two different materials: (i) high-resolution three-dimensional (3-D) digital scans of individual specimens and (ii) specimens that were fabricated (3-D printed) in plastic from the digital scans. Major findings were that 3-D printed specimens improved student understanding of how soil structure effects other processes such as root growth and water flow over digital specimens. No difference was found in other learning goals nor between two methods of presenting the material: traditional (explanation followed by the laboratory exercise) and inquiry (laboratory exercise followed by the explanation).

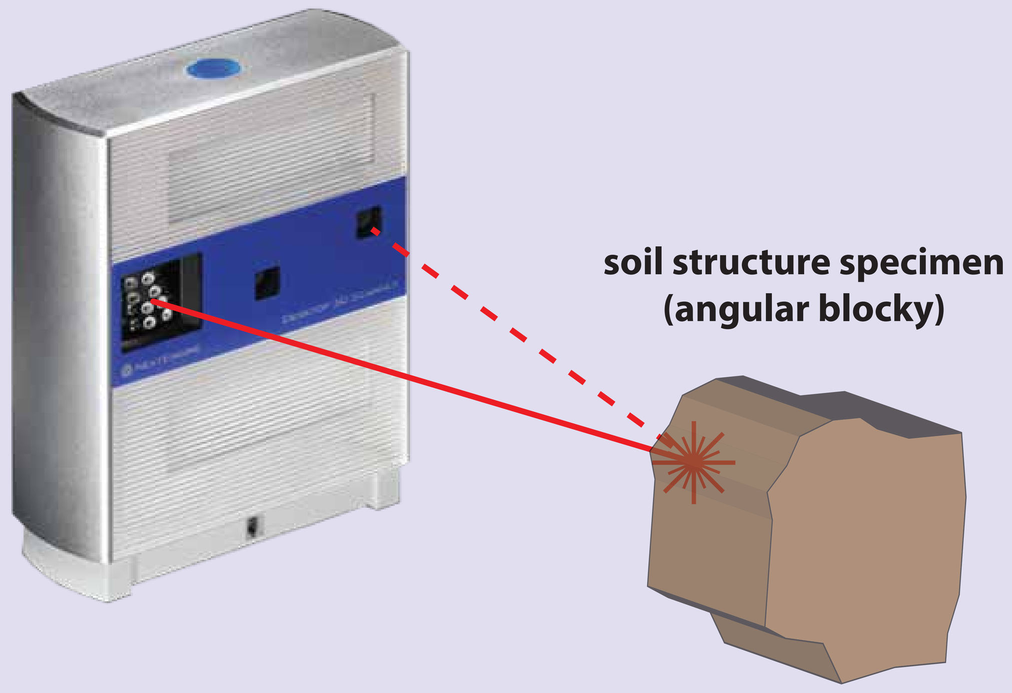
1. Building a collection of soil structure

We assembled a collection of soil specimens that represent common soil structure types including: granular, platy, subangular blocky, angular blocky, and prismatic. Each category included multiple examples ($2 < N < 4$).



2. Digitizing the collection

Specimens were digitized using a 3-D laser scanning technique known as multistripe laser triangulation (MLT) that is able to capture in high resolution (120 μm) the surface topography of soil aggregates.

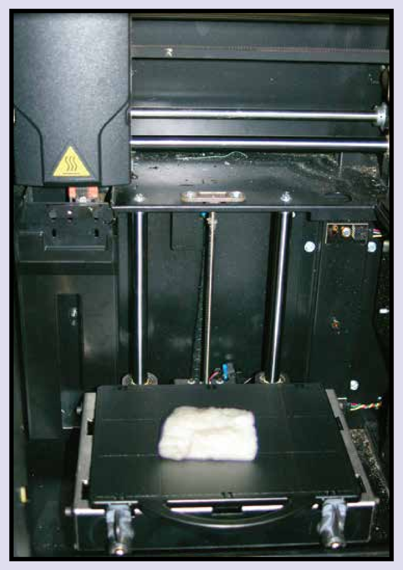


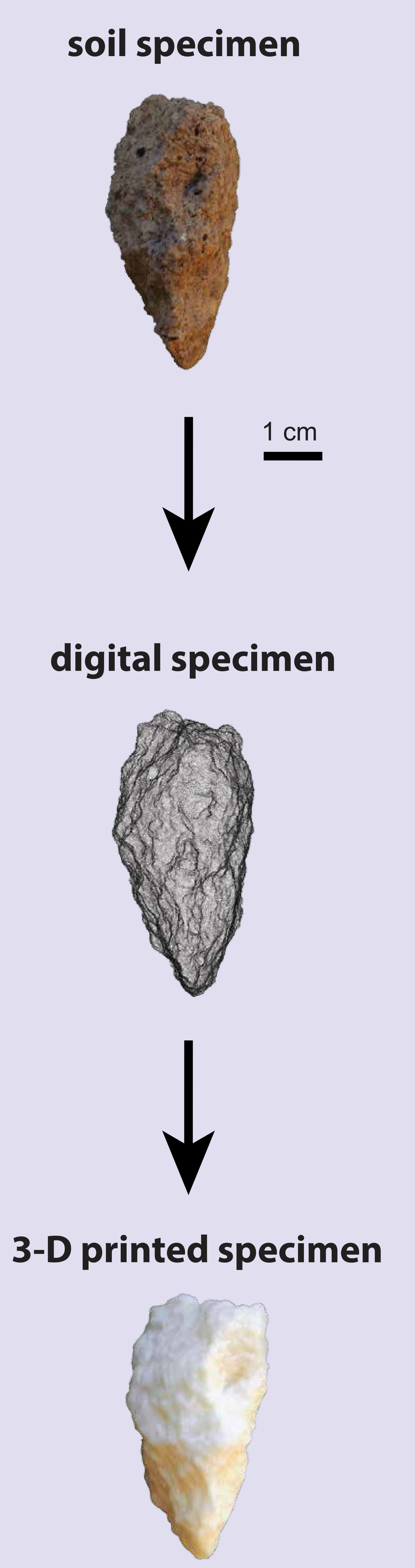
MLT scanner sends out a series of moving laser stripes which are observed by a camera offset from the source.

3. 3-D Printing of soil specimens

Each specimen was fabricated in ABSplus plastic using a rapid prototyper (Dimension uPrint 3-D Printer). Specimens were printed 4 times to create kits that were passed out to each group in laboratory sections of the class.

The 3-D printer uses a spool of plastic which is fed to a nozzle where it is melted and laid down one 250-μm layer at a time to "print" the specimen from the bottom up.





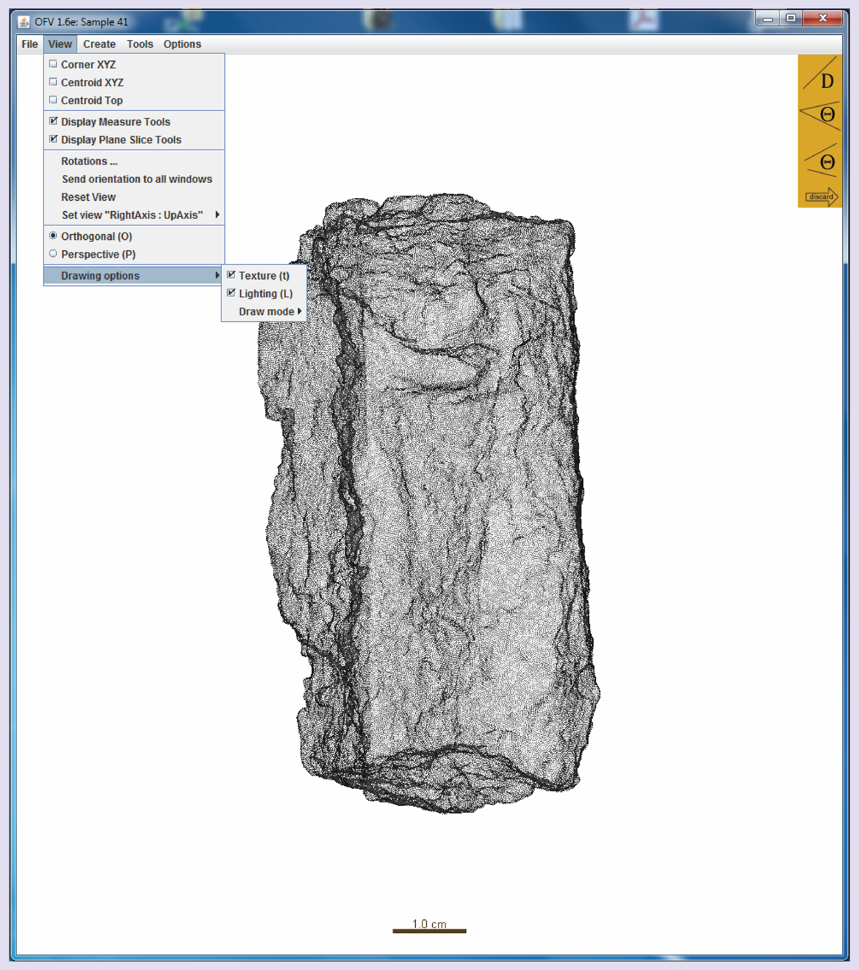
4. Laboratory exercises

Two types of laboratory exercises were developed: a traditional passive learning approach (O1) where students were given a short lecture explaining the concepts needed to understand the laboratory assignment prior to each exercise and an inquiry learning approach (O2) where students were given the exercises to complete with only a minimal amount of background information.

The same lecture slides and explanations were given to students either before or after completing the 4 laboratory assignments developed in this study.

5. Viewing the digital specimens

We developed a Java-based software available at: http://people.eecs.ku.edu/~miller/NSF_TUES/NSF_TUES.html to allow the viewing of the digitized structure specimens. Care was taken to ensure that the software mimicked the experience of the physical specimens as much as possible including allowing multiple structures to be viewed at the same time and the simulateneous scaling of any specimens open in the software window. This program allows for complete user control over the viewing experience including zoom, rotation, and panning.



6. Experimental design

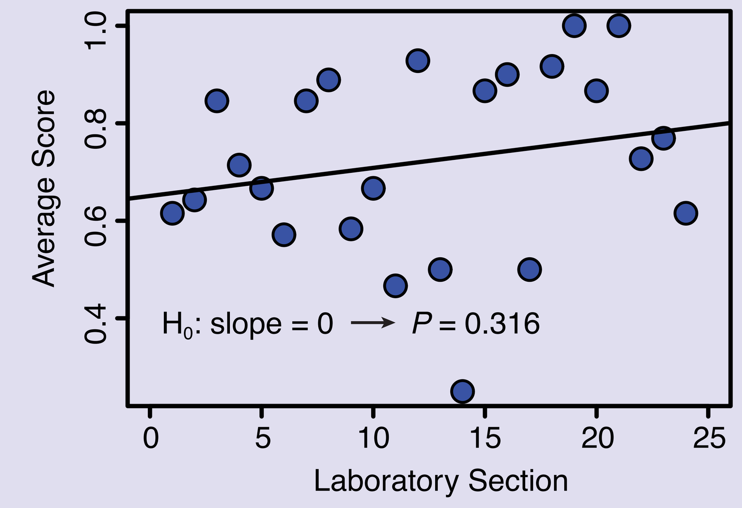
The developed exercises were deployed in place of the usual soil laboratory in 24 two-hour sections (~15 students per section) of an introductory physical geography course at the University of Kansas during the 2014 spring semester.

Lab Section	Teaching Assistants (Blocks)					
	EZ	NK	KF	MN	KA	CT
1	O2M2	O1M2	O1M1	O2M2	O1M1	O2M1
2	O1M1	O2M1	O1M2	O1M2	O2M2	O1M1
3	O1M2	O1M1	O2M2	O2M1	O2M1	O2M2
4	O2M1	O2M2	O2M1	O1M1	O1M2	O1M2

The two materials:
M1 = 3-D print specimens
M2 = digital specimens
and the two approaches:
O1 = passive learning approach
O2 = inquiry-based learning approach
were combined (yielding a total 4 of treatments) and stratified by teaching assistant in a randomized block design factorial experiment.

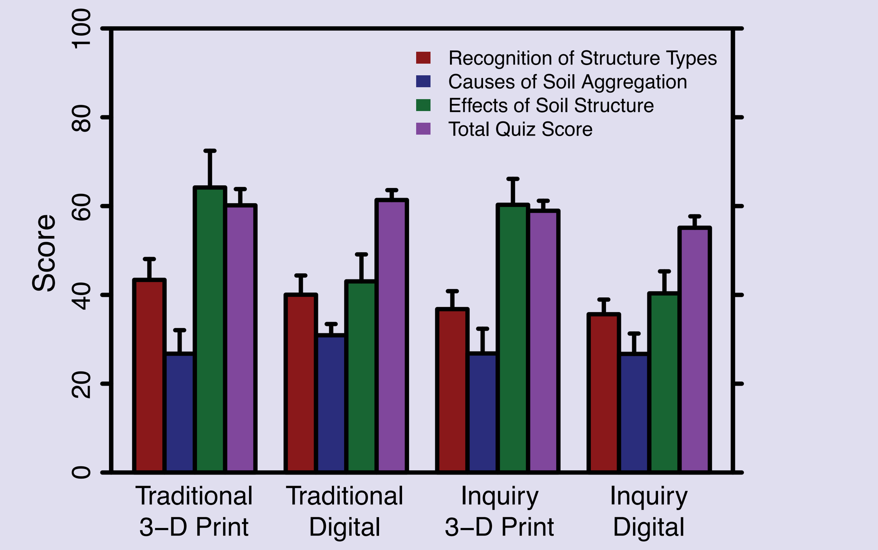
7. Assessment

Teaching assistants were trained for 3 weeks prior to implementation to maintain consistency among sections. A combination of 16 multiple-choice and short-answer questions were used to quiz the students at the end of the laboratory section. Four faculty and post-doctoral experts judged the short answers using a rubric developed in this study to ensure an unbiased scoring. We added a question unrelated to soil structure to test if students were sharing information over the 2-week period that materials were implemented:



8. Results and conclusions

Three learning outcome goals were evaluated using the quiz given at the end of the laboratory. We found significant ($P < 0.05$) differences between student understanding of the effects of soil structure, with 3-D specimens providing a 50% gain in learning over digital specimens. No differences were seen in either total quiz score or other learning outcome goals. Future work will focus on understanding concpetual bottlenecks that can explain student inability to recognize soil structure or understand its formation.



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