Using 3D-printed models to improve pupil comprehension of fossil foraminifera

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Background and Objectives

The use of visual models in natural sciences is a commonplace. Physical scale-models of organisms, organs and cells are frequently seen in classrooms and lecture halls. Foraminifera are not an exception to this. D'Orbigny, the scientist who named the group in 1839, was the first to create a set of three-dimensional scale-up models of foraminifera (Miller, 2002). His aim was to make foraminifera available to everybody without entailing the necessity of observing them under the microscope (Heron-Allen, 1917). Since then, several scientists and artists have reproduced scale models of foraminifera (Miller, 2013). However, most of them are treated as museum objects. The reason behind this is simple: foraminifera have complex shapes that are difficult to massively reproduce without loosing the fine detail of the original. Therefore many teaching models of foraminifera usually lack detail and have an unnatural look.

The recent development of three dimensional printing technologies enables us to create low cost, yet highly accurate objects. Although 3D printing has been around for decades, only the last years it became affordable to the common consumer. This study examined the impact of a modeling-based instructional intervention on students in primary / early secondary school using different tools: 3D printing, museum objects and microscope images that support modeling. Our aim is to evaluate the use of tactile models could help pupils understand images from the microscope.

Theoretical Framework

The literature of the science education offers important data to the scientific modelling. Many researchers agree that modeling should be the main technique of teaching sciences (Mellar et al., 1994). For science education, it is especially important that students learn how to develop models and how to draw explanations of natural phenomena (Coleman, 1998). The modeling process in Sciences' teaching has been studied via the use of different pedagogic tools: objects from everyday life used for the experiments and technology-based learning environments. The results show that the advantages of different pedagogic tools can contribute to the act of learning the sciences' concepts taking into consideration the cognitive processes that are involved in the modelling (Smyrnaiou & Weil-Barais, 2005; Smyrnaiou & Dimitracopoulou, 2007).

Models can play a role in the learning process when we ask students to construct models. In this "*learning by modeling*" students are required to construct an external model with the objective to make the model behave as similar as possible as the real system (Penner, 2001). We speak also of "*learning from models*" when students can interact with the model. Students' learning processes center around the exploration of this model by changing values of input variables and observing resulting values of output variables. In this process they experience rules from the domain or (re-) discover (aspects) of these rules (de Jong, 2006). Finally, both ways of using models can be combined in what we will call "*model-based inquiry learning*".

Gerard Vergnaud (1987) has proposed, in a constructivist aspect, a general theoretical framework (schema) which emphasises to the relationships that the student has to construct in order to be able to understand and interpret situations, to communicate their purpose and to make predictions, inferences, etc. He emphasises the role of the student's actions and cognitive resources in the elaboration of knowledge, within a constructivist approach. He distinguishes three functioning registers: a) the register of actions on real objects; the register of mental representations; the register of symbolic representations (maths, language, etc.).

Methods

Specimens of *Globigerinoides ruber* were scanned on a XMCT system (Friedrich-Alexander Universitat Erlangen-Nurnberg, Erlanger, Germany). The specimens were scanned at 80kV, detector array size of 2000*1336, 1500 projections/360^{o}, 2,5s/projection) slice thickness. The 3D reconstruction and visualization of the CT data was performed in AVIZO (www.vsg3d.com). The created 3D meshes were prepared for printing in Autodesk Meshmixer (www.meshmixer.com) and Slic3r (https://slic3r.org). The models were printed on a Prusa i3 MK2S fused filament fabrication printer. Two types of polylactic acid (PLA) filament were used: light gray and semitransparent. The models were printed as complete shells, with the exception of one model, whose shell was sliced in half so that its internal structure can be observed. All printed models were 200 times larger than natural size.

We set up an installation with binocular microscopes, foraminifera pictures and 3D models. The fundamental concepts micropalaeontology and using microscopes were explained to the pupils. After that, the pupils were asked to examine foraminifera under the microscope. Then they were given the models and were asked to examine the foraminifera under the microscope again.

The research was set out to explore students' descriptions and manipulations while being exposed to the different mediums: symbolic objects; real objects. Furthermore, students' models while using "3D printer" and microscope were explored. Finally, the extent to which the combination of the two mediums enhanced students' understanding was investigated.

Results and Conclusions

At the end of the session, the pupils were asked to evaluate the 3D models. In particular the pupils were given a short survey that had the following statements. Nearly all pupils have never used a microscope before and only a small percentage of them (24%) had ever seen a 3D printed object. The 3D printed models helped to the better understanding of the foraminifera structure (97%). However, most pupils were mostly impressed by the microscope itself rather than the 3D models.

In many cases 3D printing is used as a support technology in teaching including printing of scale up models of microscopic objects (see for an overview, Ford and Minshall, 2018). As expected, our foraminifera models helped pupils underhand the fine details of the foraminifera shell. The models do not replace the experience of the real object (as that is seen through a microscope), but do contribute to the better understanding of the subject. Fused filament fabrication 3D printing enables scientists to cheaply create teachable objects of high quality. Our experiment demonstrated that the use of objects that are increased in scale, makes them more accessible, and helps the underfunding of microscopic organism and structures. Similar projects in the future should be more complex and thus capitalize on the growing affordability of 3D printing.

Figure 1. A pupil examining a foram under a microscope (left) and looking at a 3D model of the same organism (right).

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