3D geological modelling and education: teaching geological cross sections with a 3D modelling software to improve spatial thinking skills in geoscience students

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ABSTRACT

The skill in “reading” two-dimension representations (typically geological maps) as symbolic images of the real world is critical for a geologist. Teachers have thus to face the difficulties that several students have when reading geological maps. Furthermore, when students fail, the consequence is often a frustration with the successive reject of the subject. The skill to understand 3D objects can be typically evaluated with the analyses of the geological cross sections produced by geology students.

Spatial thinking skills are related to two main facts: 1) a natural predisposition in the visualization of complex objects and 2) a good training to develop 3D visualization skills. Whereas in the first case the role of the teacher is often ancillary, in the second case, teachers need to find a way to improve 3D visualization skills with specific tools and specific exercises.

In the past, the supports for this educational training was provided by physical models or by perspective images. The development of 3D geological software packages recently provided tools for geological modeling that found applications in different fields of geology. In the academic formation, nevertheless, students learn the basic of 3D geological reconstruction with classical tools, whereas the use of 3D software packages is limited during their education and they mostly meet these tools for professional applications after their degree.

At the Earth Department of the Università degli Studi di Milano we introduced the educational use of a 3D modelling software (Move™, produced by Midland Valley Exploration LTD and provided to our department in the frame of the Field Mapping Initiative) since the Bachelor courses (on voluntary basis), in order to stimulate the 3D visualization skills of the students. Move™ has been used on simple geological situations selected from a number of educational books: students were guided in the production of 3D geological models from digital raster images of simple geological maps, following all the process of data input and elaboration (including DTM production). 3D visualization at different step of the model development strongly improved the skill of the students in the visualization of geological volumes, speeding up the process of learning.

The feedback of this procedure has been strongly positive, with students that, after learning the basic use of this 3D modelling software, asked for the application of the method to real and more complex geological cases.

The use of 3D software packages for the modelling of geological bodies during the educational program potentially increased the precision in the geological mapping process, as the students were able to verify that also minor inaccuracies in data representation are strongly highlighted when geological data are handled in 3D models.

KEY WORDS: 3D modeling, geological cross sections, spatial thinking skills, teaching geosciences.

INTRODUCTION: ON TEACHING 3D GEOLOGICAL VISUALIZATION

One of the obstacles that geology students have to face in their educational career is acquiring the skills to “read” two-dimension representations (such as, typically, geological maps) as symbolic images of the three-dimensional (3D) real world (Liben & Titus, 2012). Spatial cognitive skills have a fundamental importance in geologic thinking, as geology typically is a 3D science, from the microscopic to global scale. High-level spatial thinking is thus especially required in satisfactorily learning geosciences and, eventually, to become a professional geoscientist (Kastens & Ishikawa, 2006).

Spatial data and spatial representations are at the core of geosciences (Liben & Titus, 2012): for small objects with regular geometric constrains (such as crystals or fossils) the 3D visualization is favoured by the small size and by the possibility to represent such objects with physical models. 3D visualization of large geological object that cannot be reduced to general geometric rules is instead more complex and requires some additional skills: 1) the ability to develop a clear visualization of the relative position of geological objects in a volume of space, 2) the aptitude for reconstructing 3D geological objects from a limited number of observations (sampling data points) and 3) the ability to identify inconsistencies in a 3D reconstruction in order to highlight critical points that require additional investigations (i.e. to improve the processes related to data collection and storage).

Furthermore, spatial skills are fundamental for geoscientists in order to unravel the geological history of a place in terms of successive episodes of rock formation and deformational/erosive processes.

As a consequence, the understanding of the geological setting of a specific area from a 2D representation requires not only a solid knowledge of different types of geological processes, but also skills in visualizing 3D objects with the
mind’s eye, so that efficient cognitive processes that involve coordinating 3D data and 2D representations are needed. As there aren’t rules valid for any situation, it is important for the students to develop problem solving strategies, that can be acquired with a long and constant training.

The abilities to easily shift from 2D maps to 3D visualizations is related to two major factors: 1) a natural predisposition in the visualization of complex objects that, according to the theory of multiple intelligences (Gardner, 1983; 1993), can be defined as spatial intelligence, i.e. the ability to visualize with the mind’s eye and 2) a good training to develop, through specific exercises, 3D visualization skills.

In the first case, the role of the teacher may not be essential, as it is mostly limited to the presentation and discussion of different geological situations in order to increase the experience of the student. Nevertheless, in the second case, innate 3D visualization (the ability to “see” 3D geological objects in space) skills can be stimulated and enhanced with the aid of a number of tools and specific exercises able to stimulate the 3D capabilities of each student. The effects of these tools on the ability to understand 3D objects can be typically evaluated in the students during the production of geological cross-sections from geological maps of different complexity (from idealized simplified maps to real geological situations).

Teachers have to face the difficulties that several students have to deal with when interpreting geological maps. As the interpretation of geological maps is one of the characterizing skills of geologist (strictly linked to geological survey) a solid preparation on this subject is fundamental for the education of a geologist. This point is strongly critical as, when students fail in the reading of geological maps, the consequence is often a frustration with the successive reject of the subject.

The definition of a teaching process able to promote strong 3D visualization skills is thus fundamental to prepare geologists able to easily identify the effects of different geological processes to a 3D world.

The development of specific 3D geological software packages offers a great chance to improve the teaching of geological interpretation, giving the opportunity to involve directly the students in the process of 3D reconstruction of different types of geological data. Moreover, these software packages have been developed for industrial uses that require the reconstruction of complex geological models, with applications in different fields of geology (e.g. oil industry, engineering geology, mining industry). Their thus use opens interesting opportunities also for geological teaching.

TEACHING 3D GEOLOGY WITH DIGITAL TOOLS: POSSIBLE ADVANTAGES

In the past, the supports for this educational training have been provided by physical models or by static 2D representations (perspective images) of 3D objects. New digital tools are now available (e.g. Reynolds et al., 2006), some of them with easy access from the web: some web sites contain different 3D geological models that can be dynamically explored by software (e.g. British Geological Survey at http://www.bgs.ac.uk/services/3Dgeology/; some 3D subsurface images are available at ISPRA at http://www.isprambiente.gov.it/it/progetti/geot3d-modellazione-e-visualizzazione-tridimensionali-dei-dati-geologici, whereas a collection of geological models can be explored at http://reynolds.asu.edu/) whereas others offer a more interactive approach (e.g.: visible geology at http://app.visiblegeology.com/). The use of visualization tools as a support for the understanding of complex geological settings, is extremely important, accepting that, as observed by Gould (1995), “Primates are visual animals and we think best in pictorial or geometric terms. Words are an evolutionary afterthought”. Well-organized iconographies promote the ability to see previously hidden relationships, increasing the experience of geoscience students in interpreting complex situations.

These tools provide an important instrument for the visualization of real complex geological settings or simple 3D geological models, but do not allow the production of geological models related to specific geological conditions: students are passive and their activity is focused on the exploration of these models. The availability of 3D modelling software provides a professional tool for the construction of 3D models from geological map data. 3D geological models of different complexity can thus be produced by the students during their education: students become active actors, involved in the process of creating 3D geological models.

3D software packages can be divided in generic and geological software types. 3D geological software tools have been specifically developed for geological applications of different types (engineering geology, oil industry, mining etc.). These latter are thus characterized by a geological approach to 3D objects, so that their use is strictly connected with the use of a terminology that is coherent with the learning process of geology students. Furthermore, these software packages can be used with different levels of complexity and potentially represent an important tool for the education of the new generations of geologists.

The possibility to couple simple visualization of 3D geological objects with tools for the construction of these models is promisingly able to improve the acquisition/development of 3D visualization skills. In this sense, the process of creating 3D geological models by geosciences students who can later explore and validate them represents an additional practical experience for developing spatial thinking skills in geology students.

TEACHING EXPERIENCE IN THE EARTH SCIENCE DEPARTMENT OF MILANO UNIVERSITY

In the last years the Department of Earth Sciences of the University of Milano joined the “Field Mapping Initiative” promoted by Midland Valley Exploration Ltd., which, in order to improve the field mapping capabilities of the new
generations of geologists, granted our University its 3D geological modelling software package Move™ for educational use. Move™, currently used by oil companies, is designed to handle vector and raster data sets (e.g. surface geology, wells, seismic lines) from different sources and with different formats. The software provides efficient tools for constructing geological surfaces by interpolation of lines and points. Beside producing geological surfaces, the software also includes modules for 2D and 3D kinematic modeling, geomechanical modelling, fracture modelling and turbidity current modelling. The educational applications of the software has been tested initially as a support for MSc theses on field data, collected directly by the students or updated from existing geological maps. Move™ has also been used for 3D surface reconstruction of microscopic objects from seriate thin sections. This first experience on the application of a 3D approach on the digital handling of geological data was fully positive, but required a training of the students for the use of Move™, that was never introduced before in the geology courses. Considering the positive feedback of the students, the increased sensibility to the precision in the representation of geological data and the acquisition of spatial visualization skills, we experimentally introduced the educational use of the 3D modelling software Move™, since the Bachelor courses on a voluntary basis, in order to provide a tool able to stimulate the 3D visualization skills of the interested students, as well as the chance to learn a modern tool for the digital storage and elaboration of geological data.

WORK FLOW

To avoid adding obstacles related to the use of a new digital tool as Move, with complex geological situations, bachelor students have first been focused on simple geological situations (e.g. simplified geological maps) selected from a number of educational books (e.g. Simpson, 1960; Bennison, 1990; Powell, 1990). A common training (defined thanks to the previous experience with MSc theses) has been planned and tested during the last two years, to guide the geology students during the production of 3D geological models from digital raster images of simple geological maps. Students have been involved in all the steps required for the production of a 3D model from surface geological data. The process (Fig. 1) starts with the input of the raster image of the geological map with the correct size and, if needed, coordinates. After that, the students have been introduced to the process of digitalization of different geometric elements (geological boundaries, bed attitudes, faults, contour lines) and all the different elements have been stored in a simple database. Successively, the DTM has been created from contour lines and, when available, altitude points, obtaining a surface where the geological elements have been projected. At this point, each element and node of the database was characterized by X, Y and Z spatial coordinates, so that a first 3D visualization of geological elements (lines and points) has been possible. At this point students have been invited to define the orientation of the geological sections, according to the geometry of the most significant geological surfaces. The selection of the orientation of the geological cross sections (two different orthogonal sets) has been aided by the use of analytical tools of the software, able to evaluate the orientation of geological elements in the map. According to the results, students have been involved in the definition of the number, spacing and orientation of the geological cross sections needed for the reconstruction of 3D
surfaces for the final model. Geological cross sections were drawn by hand on printed profiles (with the projection, if available, of apparent dip along the section plane and intersections). Once all the sections have been completed and compared, they have been scanned and introduced in the 3D database as vertical images along the line representing the section trace. After digitalization of the geological elements from the hand-drawn geological cross sections (aided by a number of tools able to consider thickness of the units), the database was critically analyzed, pointing out major geometric and geological problems (Fig. 1). Students become conscious of the critical aspects of their interpretation thanks also to the 3D visualization of all the geological elements included in the sections and in the original map. Students became aware of the importance of geometric coherence of a geological model and thus acted to correct the major critical points of their model.
even before creating geological surfaces. Once a preliminary coherence of geological data was reached, the geological surfaces have been constructed, both below and above the topographic surface. The first models obtained were still characterized by errors and geological inconsistencies of different type and importance. The 3D visualization efficiently pointed out those errors, which have been identified by the students, who managed to eliminate irregularities and errors correcting the original data (e.g. geological cross sections). Students become aware of the importance of the precision in the 2D representation and digitalization of geological maps.

When a model was satisfactorily produced, students have been invited to interrogate the model, producing, with the software tools, geological cross sections with different orientation and dip, creating tunnels or, in a few cases, working on the retrodeformation of 2D geological cross sections.

RESULTS

The effects of the use of a 3D modeling software on the improvement of the spatial thinking skills in geoscience students has been evaluated in terms of 1) feedback from the students, 2) precision in the construction of geological cross sections and 3) results from the validation of 3D geological models. Students joined this project on voluntary basis: a reduced number of them abandoned the project after a few days of practice, mostly due to problem with the digital approach to the creation of digital cross section and to the fear of a time consuming activity. This latter aspect is probably related to two different problems: 1) the suspected complication of the procedure for the construction of a significant number of geological cross sections of different complexity and 2) the need of learning the use of a new software package, that is typically not intuitive and requires a specific training.

The students’ feedback has been strongly positive: some students, after learning the basic use of this 3D modelling software (Fig. 2), asked for the application of the method to real geological cases, also learning the process of external data input from different sources (e.g. GIS databases) for the production of more complex 3D geological models (Fig. 3). In these cases, the students directly worked on field data collected by themselves or on data available from existing digital databases (e.g. CARG project, new geological map of Italy). In the first case, field data have been collected in the classical way, than stored in a GIS and eventually imported in Move™ for the production of the 3D digital model.

The use of these types of digital tools during the educational processes also increased the precision in the geological mapping process, as students were able to verify that also minor inaccuracies are strongly highlighted when geological data are handled in 3D models.

The experimented educational processes highlighted that 3D visualization at different steps of the model development strongly improved the skills in visualizing geological volumes, speeding up the process of learning the interpretation of complex geological contexts.

In general, the digital handling and elaboration of geological data improved the spatial cognitive skills in the students, who improved their ability in the construction of geological cross sections. The students also acquired the perception of the importance of a 3D visualization of the data since the field work, improving the quality of the data collected in the field, specifically regarding the precision in the mapping process.

Furthermore, students learned a professionalizing tool, such as a 3D modelling software and acquired the general rules of the 3D geological modelling, so that they are potentially able to use this approach independently from a specific software package.

In case of the introduction of the use of a 3D modelling software in a statutory course, a major aspect should be critically faced: the learning of a 3D software requires a significant training, more easily acceptable if motivations are strong. The experience developed with the use of Move™ in our department allowed the definition of the basic elements (and thus the evaluation of the required teaching time) sufficient to provide the needed capabilities in the use of the software.

The work on digital 3D models promoted in the student an evolution form a qualitative/approximate geological approach toward more constrained and geometrically coherent geological models. The quantitative approach to the geological data handling increased the sensibility of the students toward the improvement of the precision of data collection and storage, eventually increasing the attention on the care in the geological cartographic representation. Students became acquainted to understand from the beginning of their formation the importance of 3D visualization and then to learn the possible application of 3D geological models to real situations.

A database of about fifteen 3D geological models was produced during the last two years following this educational procedure. The activity in the Earth Science Department of the University of Milano permitted the creation of a portfolio of 3D digital exercises of different complexities, that can be used as educational stuff potentially in different courses, anytime a 3D database is required, from the simple visualization of geological objects (basic courses) to the possible use of these models to as data-base for specific applications (e.g. engineering geology).
Fig. 3 – Examples of 3D models produced by the students from real geological maps from different part of the Permo-Mesozoic sedimentary succession of the Southern Alps. a) geological map of the Permian succession of the Central Southern Alps (from Berra & Felletti, 2011); b) view of the network of geological cross sections used for the construction of the 3D model; c) dataset of the lines used for the construction of the 3D model (from geological cross sections and the geological map); d) view of some of the surfaces created for the model: note the angular unconformity between the upper surface (base of the Late Permian succession) and the underlying geological boundaries (the red sub-vertical surface is a fault); e) geological map draped on the DTM of a Late Triassic succession in the Central Southern Alps (red lines: trace of geological cross sections); f) 3D view of the geological cross sections used for the model construction (dishes represent bed and fault attitudes); g) and h) view of the 3D geological model produced from the field data. In h) the model is seen from below the topographic surface: it is possible to recognize the gently folded succession cut by different faults.
CONCLUSIONS

The teaching methods tested in the Earth Department of the University of Milano in the last two years with the use of a professional 3D modelling software (Move™, provided by Midland Valley Ltd. for educational use) represent a contribution to the development of a geologic teaching and training, focused on the improvement of spatial thinking skills in geoscience students. The efficiency of this approach has been evaluated according to the results obtained in the students’ education and by the feedback from the students that ended their training. Feedbacks are generally positive and mostly documented by and improvement of the 3D visualization skills in students. Students become more confident in the process of producing geological cross sections and their ability in identifying major tectonic and stratigraphic elements in geological maps increased. This result is potentially able to reduce the common frustration generated by the failure in the correct reading of geological maps, that frequently affects part of the students, triggering a typical and dramatic (for geologists) consequence: the refuse toward field mapping. This stresses the importance of experimental learning, critical for the education of geoscience students: “I hear and I forget, I see and I remember, I do and I understand” (Chinese proverb, ascribed to Confucius).

Geometrical problems in the construction of 3D models also increased the sensibility of the students toward the precision in data collection and storage.

A positive result of this teaching approach is also the creation of a portfolio of geological models both from simple idealized geological situations (from the exercise maps such as those from Simpson, 1960; Bennison, 1990: Powell, 1990; Fig. 2) and from real geological situations (Fig. 3).

Our experience indicates that these results can be achieved during the bachelor degree, but it opens new possibilities for the following educational levels (MSc and PhD). At present we focused on the Bachelor degree, presently considering the possibility to introduce the use of Move in a statutory course.

The possible further step in this in teaching 3D geological modelling could be represented by the introduction of digital field mapping. This evolution requires additional funds (mostly for the hardware) that at the moment are not available.

Furthermore this approach should be also directed to MSc and PhD students, who previously achieved sufficient skills in 3D data visualization and a significant degree of autonomy in field data collection and organization.

Our experience indicates how the classical geology teaching can be improved in terms of results by the integration of new digital tools in learning processes that maintain their “classical” scope (teaching field mapping and interpretation of geological maps). Considering the central role of spatial thinking in geosciences, the introduction of new teaching methods involving digital tools (able to support the teaching of basic and advanced geology concepts and 3D visualizations) should be carefully considered when defining (and updating) the educational processes for the new generations of geologists.

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