Introductory Geological Mapwork—An Active Learning Classroom

Gillian R. Drennan[1,a)] and Mary Y. Evans[1,b)]

ABSTRACT

First year Geology students at the University of the Witwatersrand experience problems with both three-dimensional and "four-dimensional" (or time) visualization when attempting to interpret geological maps. These difficulties have been addressed by the introduction of hands-on modeling exercises, which allow students to construct three-dimensional geological structures and examine their projection on maps and cross-sections. The modeling exercises also enable students to understand the interaction between geological processes such as faulting, folding, tilting, erosion and deposition, and the resultant landforms that these processes create. Pre- and post -tests were conducted to determine the success of the intervention, which revealed an improvement in the students' abilities to understand geological concepts and to solve geological problems relating to map interpretation. © *2011 National Association of Geoscience Teachers*. [DOI: 10.5408/1.3580759]

INTRODUCTION

Geological maps are a fundamental tool for understanding geological concepts and solving geological problems. The interpretation of these maps requires the ability not only to visualize the data presented on a two-dimensional projection in three dimensions, but also to be able to read from maps the fourth dimension (time)—the history of geological events recorded in the rocks. Students in their first year of Geology at the University of the Witwatersrand, South Africa, have difficulty in reading and interpreting geological maps and relating these two-dimensional representations to a real three-dimensional environment. Current research indicates that this is not uniquely a South African problem (see Kali and Orion, 1996; Kali *et al.*, 1997; Libarkin and Brick, 2002 and Calderone *et al.*, 2003), and various attempts have been made to address this problem (for example see Alias *et al.*, 2002; Calderone *et al.*, 2003). Nevertheless, the ability to visualize in three-dimensions from a two-dimensional representation is an essential skill in understanding and interpreting geological maps.

Spatial visualization ability has been defined as: "… the ability to mentally manipulate, rotate, twist, or invert pictorially presented stimulus objects" (McGee, 1979, p. 893 in Alias *et al.*, 2002). As spatial visualization ability is critical to learning and problem solving, this multi-faceted ability helps geology students to conceptualize links between reality and the abstract representation of that reality (Alias *et al.*, 2002).

Lecturers at the School of Geosciences in the University of the Witwatersrand have attempted to address the problem of spatial visualization ability by using traditional methods such as videos, slides, and photographs. These methods have limited success, as these tools are themselves two-dimensional representations of real features and can add to the frustration felt by students. Field trips do go a long way to addressing some of the difficulty but they are expensive in an already financially stressed environment, and as Calderone *et al.* (2003) have noted —it is difficult to find a single area that shows all the exposures that are taught, especially in a broad based Geology I course. Large class sizes also limit the type of field trips that can be run. For example, for safety and logistical reasons it is not possible to take large groups onto mining property or underground into an active mine to expose students to the mining environment and the geological features exposed there.

Consequently, lecturers have devised an intervention program which involves the use of simple interactive models and small group tutorials. Pre- and post- intervention tests were used to evaluate the success of the intervention. Central to the intervention program was the use of small inexpensively produced play dough models with which students could actively create geological features, simulate geological processes, and observe the resultant landforms.

RESEARCH POPULATION AND BACKGROUND

The research population comprised first year Geology I students who were accepted into the Faculty of Science at the University of the Witwatersrand, based on their secondary school ratings (especially in Mathematics and English). However, many of these students have English as a second or third language in a country that has eleven official languages. Many of the students in this sample are from economically and socially disadvantaged backgrounds. It has been noted by lecturers in the School that the spatial perception development in these disadvantaged students' formative years, invariably has an impact on their ability to work with three-dimensionally related problems. These students would seldom have had access to developmental toys such as puzzles, building blocks, and other such stimuli, but would most likely have been carried around on their caregiver's back limiting their depth perception development. Consequently, much of the published literature dealing with spatial visualization abilities at secondary and tertiary education levels (see, for example, Lean and Clements, 1981; Presmeg, 1986; Ben-Chaim *et al.*, 1988; Ishikawa and Kastens, 2005; Orion and Kali, 2005; McConnell *et al.*, 2005; Elkins and Elkins, 2007) do not necessarily address the problems faced by the students in this research population and therefore a direct comparison may be inappropriate.

The Geology I program has been specifically designed to give the first-year students a broad overview of the

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[1]School of Geosciences, University of the Witwatersrand, Private Bag 3, WITS 2050, South Africa
[a)] Electronic mail: gillian.drennan@wits.ac.za
[b)] Electronic mail: mary.evans@wits.ac.za

Geosciences in the first semester — the "big picture" of the origins of the Universe and the Solar System, the uniqueness of planet Earth within the Solar System, the internal structure of the Earth and how this relates to Plate Tectonic Theory, atmosphere–lithosphere interactions and surface processes, and the origins of life. In the second semester, students focus on the details of mineralogy, rocks, and rock-forming processes, as well as an Applied Geology Course (an integration of the geological history of South Africa and mineral deposits within the stratigraphy, and a practical component of introductory geological map work). The successful completion of these topics, together with credits in Mathematics, Physics, and Chemistry at first-year level, prepares the students to proceed with a degree in Geology.

Students are continuously assessed through essays, projects, and practical assignments as well as mid-year and year-end examinations. In addition to understanding content matter, students are expected to demonstrate a variety of academic skills, and the students who best master the content and skills are most likely to succeed.

Throughout the rigors of the Geology I program, students experience difficulties with subject specific content and skills. The majority of our students have had limited exposure to the world around them (e.g., may not have seen the sea), making it more difficult to understand geological processes and resultant landforms (Drennan and Pinto, 1997; Drennan *et al*., 2000, 2004). They will have learned about the nature of light and sound at school but seem unable to transfer that knowledge of waves into wave activity along the coast or tsunamis formed as a result of earthquakes. These students thus revert to rote learning as a coping mechanism. However, assessments require that students demonstrate an *understanding* of the content and are able to apply the content to solving problems. Yet, owing to increasing volumes of work and the consequent constraints on the timetable, the time students spend "on task" acquiring a solid grounding in the fundamentals of geological map interpretation is continually being eroded (Pinto *et al*., 2000).

INTERVENTION PROGRAM

Pre-intervention Test

Geology I students were given a pre-test to determine their level of spatial ability. The pre-test was conducted at the start of the Applied Geology course during a field trip where students were exposed to a large variety of rock types, geological features, and geological maps. They were asked to complete a task that required them to visualize a three-dimensional geological feature similar to what they had been exposed to in the field. The task involved using a six-sided cut-out box with some geological information drawn on one side of the box and they had to complete the task by drawing in the geology on the remainder of the sides [Fig. 1(a)]. Even while sitting on an outcrop that exhibited similar geology to that shown on the task box (Mondeor conglomerates of the Witwatersrand Supergroup, which dip at 30°to the south), many of the students were unable to complete the task correctly. Figures 1(b)–1(d) reflect examples of the best, average, and worst observations of the pre-test. Of the 56 students who participated, only 12.5% of them scored 50% or more on the test (Fig. 2) and only 1.8% achieved full marks. These results indicated that students have difficulty with relating theoretical geological concepts to the three-dimensional projection of these concepts in space and time and to reality.

Tutorial Sessions

Ben-Chaim *et al*. (1988) noted that spatial activities that require the students to construct, evaluate, and sketch models of building cubes could enhance spatial visualization ability. Thus in an attempt to address the difficulties that Geology I students at the University of the Witwatersrand were experiencing with three-dimensional visualization, small-group tutorials were offered to enhance spatial visualization ability. These tutorial sessions were not compulsory but were attended by students who recognized that they had difficulties with completing the geological map work tasks. During the tutorials, students were given the opportunity to work with small-scale models of key geological features that could be modified to simulate geological structures and processes.

The models were created with play dough (see recipe and instructions in the Appendix), which were prepared beforehand [Fig. 3(f)] and by cutting away or adding to the models, the students could simulate processes such as folding, faulting, intrusion, and erosion [Figs. 3(a)–3(d)]. The tools that were used to make and modify the models were inexpensive and readily available, such as a rolling pin, sharp knife, apple corer, etc.

After a model had been molded to create the feature under discussion, a Perspex "mapping table" was placed over the model and students could then draw the features from plan or cross-sectional perspectives and so create a map of the model [Figs. 3(e) and 3(h)]. For example, students created a model of an anticlinal fold and then simulated the processes of weathering and erosion through different sections of the fold structure by cutting away some of the model [Fig. 3(g)]. They could then see the result of such modifications on the fold structure, as well as the exposure of the underlying geology. Having created the models, students could draw the modified fold structure as a two-dimensional map and two cross-sections on the overhead transparencies placed on the mapping table. The feature, the map, and other geological problems were discussed with the lecturer acting only as the facilitator of these discussions. Such activities gave students the opportunity to ask questions and build concepts in a nonthreatening environment. Students could address concepts that required them to apply knowledge to new situations and could recognize gaps in their understanding and take action to correct these (McConnell *et al*., 2003; 2005).

The hands-on tutorial modeling exercises were designed to assist students in constructing three-dimensional geological structures that they would encounter in the map-work component of the course, prior to actually working on the geological maps themselves. The intervention was also designed to help students understand geological processes such as faulting, folding, intrusion, erosion, and deposition. The end product models were made available and displayed in the practical sessions for all the students in the course to refer to. The models served as a reference for students who had attended the tutorial sessions, as well as a visual aid for students who had not

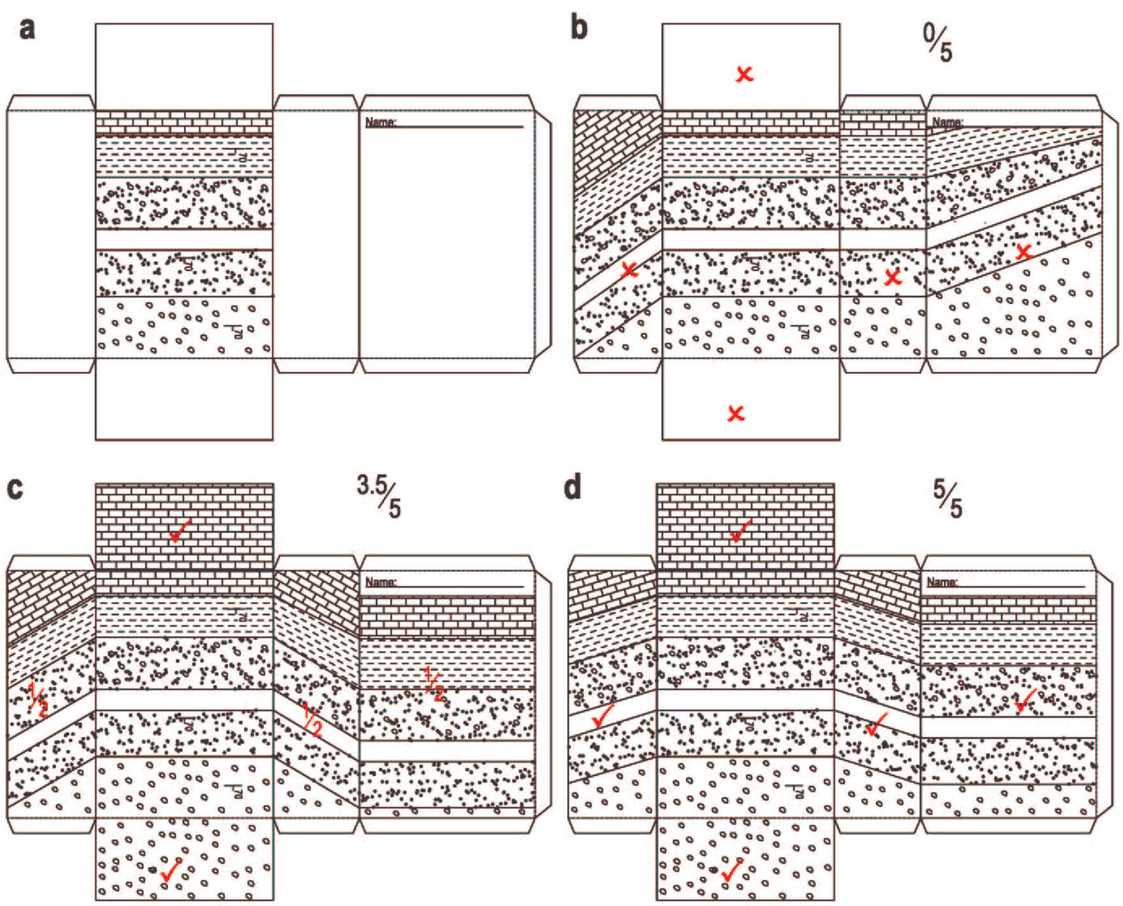

FIGURE 1: (Color online) The pre-test and post-test task boxes. (a) –(d) refer to the pre-test and (e)–(h) refer to the post-test. (a) shows the incomplete box where students were required to draw in the correct geological outcrop patternson the remainder of the sides. (b) is an example of a box where the dip angle, dip direction, and outcrop patterns are completely incorrect. (c) is an example of a partially correct box, where the angle of dip is measured incorrectly and thus the outcrop patterns are inaccurate. (d) is an example of the best completed box where the angle of dip, dip direction, and the geological outcrop patterns are correctly portrayed. (e) is the incomplete post-test task where students were required to draw in the correct geological outcrop patterns on the remainder of the sides. (f) is an example of a box where all dip angles, dip directions, and outcrop patterns are completely incorrect. (g) is an example of a partially correct box, where the angles of dip are measured incorrectly and thus the outcrop patterns are inaccurate. (h) is an example of the best completed box, where the angles of dip, dip directions, and the geological outcrop patterns are correctly portrayed. Half marks were allocated when the dip angles where measured incorrectly, but the dip direction was correct.

attended the tutorials but were experiencing difficulties with interpreting the geological maps.

The tutorial sessions were not compulsory for all students in the Geology I course and so not all students attended the hands-on modeling tutorials. However, all students had access to the models during their compulsory map work practical sessions and often the students who had attended the tutorials could be found explaining various aspects of the models to their peers, (who had not attended the tutorials) during the map work sessions.

Post-Test

At the end of the Applied Geology course, and after students had worked with geological maps, the post-test was given to all Geology I students. The task was to complete a similar (but geologically more complicated) box as the pre-test, with geological information drawn on one of the six sides [Fig. 1(e)], and the students had to complete the other sides [see Figs. 1(f)–1(h)]. The results indicated that students who participated in the tutorials were better able to complete the post-intervention task thus demonstrating a significant improvement in their three-dimensional visualization skills. Of the 52 students who participated in the post-intervention test, 51.9% achieved 50% or more, with 9.6 % scoring full marks (Fig. 2).

It should be noted that the students had received no feedback from the pre-test and had not worked with these box tasks in the intervening time between the two tests. Thus, the students could not have developed a familiarity with the test design. Both the pre- and post-tests were administered under controlled conditions and the students worked independently on the tasks. No assistance or explanations were given by the lecturers.

ASSESSING THE INTERVENTION

A subset of students (between 10 and 20 students from week to week) attended the modeling exercise tutorials whereas the entire class participated in the

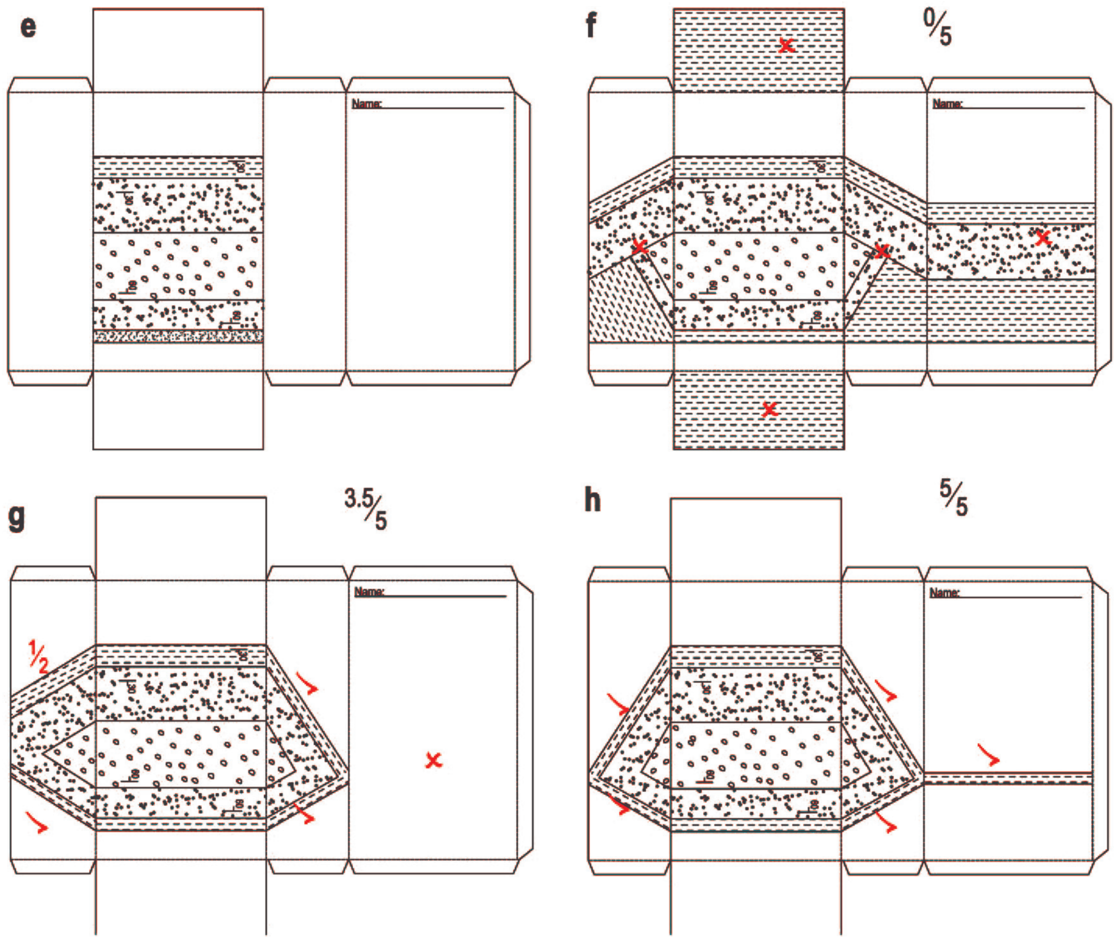

FIGURE 1: (Color online) continued.

compulsory map-work practical sessions and the pre- and post-test. At the end of the map-work course, lecturers administered a questionnaire to all students in order to assess the success of the intervention for those who had participated in the tutorials, as well as the relative success of the intervention for students who were exposed to the models on display during the formal map-work practical exercises.

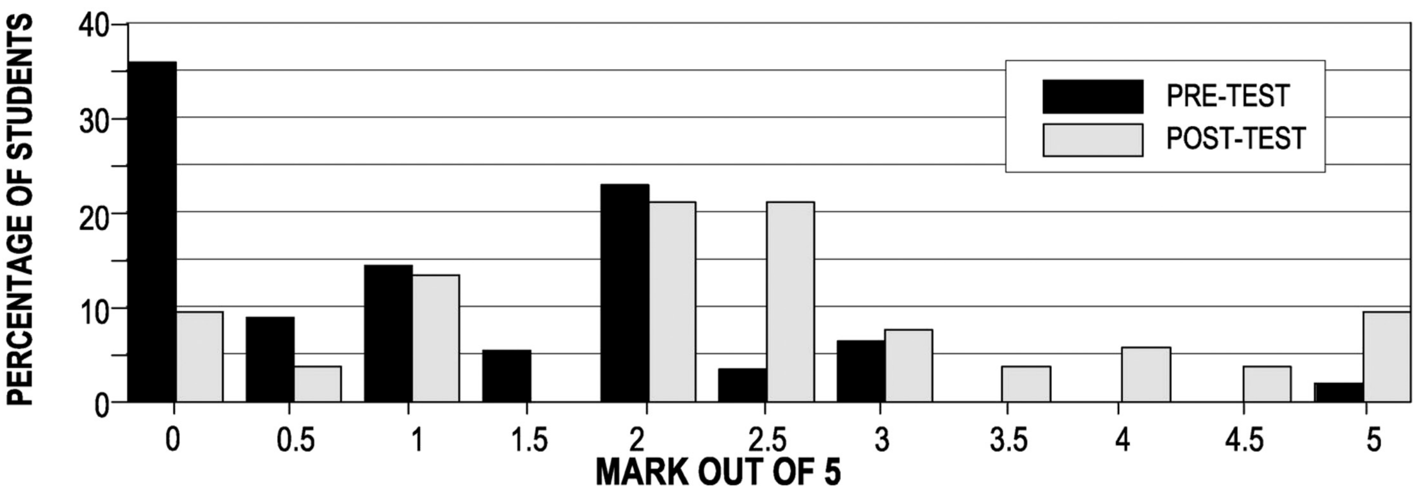

FIGURE 2: The pre-test and post-test results. The pre-test shows the results of 56 students, in which 12.5% score 50% or more for the test. The post-test shows the results of 52 students in which 51.9% achieved 50% or more for the test. The difference in the number of respondents between the tests reflects the number of students who were absent on the post-test day.

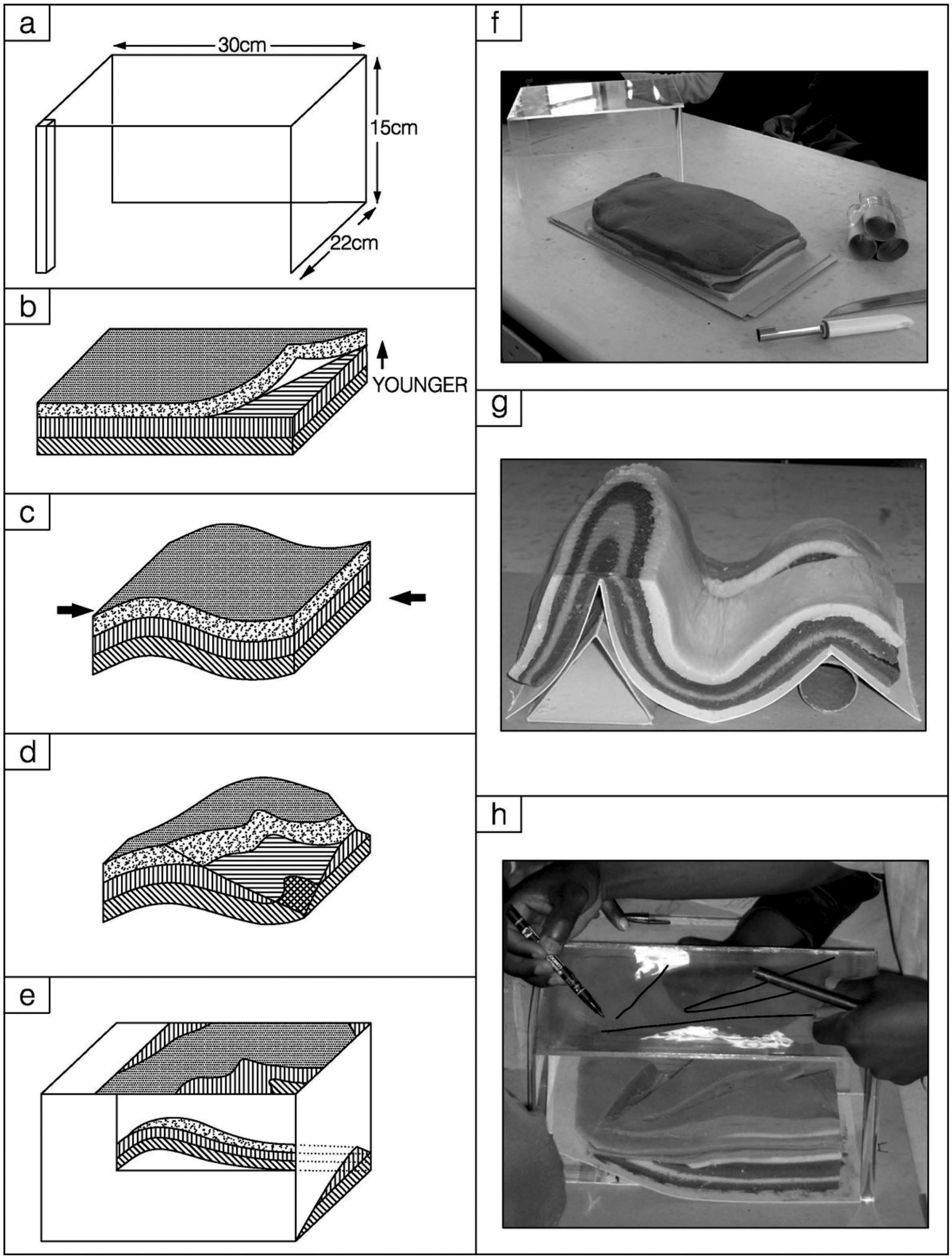

FIGURE 3: Schematic and pictorial representation of the 3-D visualization intervention; (a) the dimensions of a clear Perspex "mapping table", which can be made by gluing the measured Perspex sheets and rods together; (b) play dough model simulating various horizontal strata; (c) modification of model simulating folding of strata due to compression; (d) further modification of model simulating erosional processes; (e) projection of map and cross-sections onto mapping table; (f) a photograph of a play dough models showing the pre-modified horizontal layers and the simple tools used in the intervention; (g) a model of two anticlines and a syncline where the surface has been cut to simulate erosion and the underlying geology is revealed; (h) students drawing the geological map (plan-view) of the outcrop pattern of the model onto the Perspex table.

The results of the pre- and post-tests were analyzed and all observations that did not have both pre- and post-tests were removed, leaving a sufficiently large sample size of 50 respondents. As the sample was large in comparison to the population, the need to do a statistical analysis in terms of the hypothesis test was reduced.

The mean of the post-test is markedly higher than the pre-test and the analysis showed that the means of both the pre- and post-tests differ significantly at 1% level of significance (Table I). There was a greater variance in the results of the second test, suggesting that although there was an improvement in the results, not all students performed uniformly better. This suggests that higher marks were possible the second time around — probably by the more conscientious student or because spatial visualization ability had been improved by training (as suggested in Baenninger and Newcombe, 1989; Ishikawa and Kastens, 2005). However, there were also likely to be lower marks in the post-test, indicating that some students did not take advantage of or benefit from the intervention.

The correlation of the marks of the two tests is not particularly high, although there is a positive correlation. This adds weight to the results that some students fared better in the second test, while others did not improve or possibly did worse. However, the fact that the mean increased dramatically indicates that those who did improve, did so considerably.

The tests were designed to determine the students understanding of the three-dimensional orientation of geological features. The range of observations for the tests were small (0–5) and as a result the variance is quite high in both tests. However, the tests were designed to determine spatial ability rather than content knowledge and as such required fewer observations.

Based on the questionnaire, the students' responses to the usefulness of the modeling exercise were very positive. An interesting outworking of this intervention was that the students who had created the models could explain the processes and resultant landforms to their colleagues in their mother-tongue, improving the understanding of students and creating a stimulus for an interactive classroom similar to what McConnell *et al*. (2005) noted about group interaction appearing to be a significant contributor to the improvement of reasoning.

TABLE I: Significance test. The *t*-test used to determine whether the difference in the mean between the pre- and post-tests were significant.

t-test: Paired two sample for means		
	Variable 1	Variable 2
Mean	1.23	2.34
Variance	1.47	1.90
Observations	50	50
Pearson correlation	0.31	
Hypothesized mean difference	0	
df	49	
t stat	5.13	
$P(T \geq t)$ one-tail	2.46×10^{-6}	
t critical one-tail	2.40	
$P(T \geq t)$ two-tail	4.92×10^{-6}	
t critical two-tail	2.68	

CONCLUSION

The recognition of the difficulty that first year Geology students had with three-dimensional visualization led to the initiation of an intervention program using small-scale interactive models. The models were introduced in non-compulsory tutorial sessions for students and were made available for all students in the introductory geological map-work practical sessions. The intervention was assessed by means of a pre-test to determine the student's level of spatial ability and a post-test after the intervention to determine if there was any improvement in their three-dimensional visualization.

The intervention proved to be a success with a significant improvement in the results of the post-test. However, there were concerns about the program in that the tutorial interventions were not compulsory for all Geology I students. This meant that often the students who should have participated in the tutorial support did not and those who were already coping, but who wanted to improve their grades, participated regularly.

One of the limitations of this intervention is that the three-dimensional models are small and thus work most effectively with a small group of students. The challenge now is to expand this modeling intervention to reach larger groups of students within the allocated tutorial time. To address this problem, the tutorial sessions have been made compulsory for all Geology I students, thus all the students will be exposed to the intervention. The large class will be divided into smaller working groups with a facilitator for the modeling exercises; and as the models are reasonably inexpensive and easy to make, each group can then simulate a different process or create a different structure, which can then be circulated in the class. In this way, more students will see more of the features that they will be exposed to in the course and in the field.

Acknowledgment

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APPENDIX: MODEL CONSTRUCTION

The following items are required to construct a model:

- Play dough of various colors,
- Perspex tables [see dimensions in Fig. 3(a)],
- Sharp knife,
- Thick A4 size cardboard, and
- Thin cardboard to form supporting wedges.

The following ingredients are needed to make the play dough:

2 cups of cake flour
1 cup of salt
2 tablespoons cream of tartar
3 tablespoons oil
2 cups of boiling water
Food coloring (various)

Combine all the ingredients (except the food coloring), then knead together to form an elastic dough. Subdivide the dough and add the food coloring as needed. The ingredient quantities can be increased to make larger amounts of play dough, which can be kept for a long time in an airtight container and stored in a cool dark place.

Directions to make and modify the models:

Roll out the different colors of play dough to create thick layers of roughly A4 sized. Use the A4 card as the base and prepare it depending on the feature being simulated, for example: the base may need to be cut in half for the fault; scored in the middle for a syncline or anticline or cut out a circle for the later insertion of a bowl for an intrusion.

Place the dough layers on top of each other on the card. Trim the edgeswith sharp knife so that the different layers are clearly visible. This representsthe original horizontal depositional sequence. From this point, the model can befolded, cut (faulted) or cut (eroded) to show the different geological processes andresultant landforms.

Use small cardboard triangles or rolls to support the structures when needed.

To map the feature, tape clear overhead transparencies onto the sides and top of the Perspex mapping table, then place the mapping table over the modified model. Use different colored overhead pens to draw the top view (plan view or map) and side views (cross-sections) of the model. The transparencies can be removed and used for further explanation, discussion and student engagement.

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