Jello Tectonic Plates for Learning Geoscience

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Abstract: This paper introduces a hands-on method for students to simulate the action of tectonic plates and volcanoes with gelatin, or Jello. The authors survey existing demonstrations of volcanoes and describe their affordances and limitations. They describe the Jello activity and outline its potential affordances, then detail its use in a Singapore secondary school geography class. Based on the analysis of observation notes and video transcriptions, the authors discuss how Jello plate tectonics could provide students with a common experience for observation and conversation of earth science processes, and how it potentially enhances their conceptual understanding. This paper outlines the limitations of this classroom activity and suggests improvements for future deployments.

Introduction: Experiential learning and geological demonstrations

This paper introduces a hands-on simulation of plate tectonics and volcanoes, which our research group has used for middle-school students' geography learning in Singapore. As part of a continuing project in earth science education, we deployed the simulation in both formal and informal educational contexts; it seems to work best as part of a participatory learning context in which students contribute to the consensus about geoscience,. Unlike many volcanic demonstrations, this hands-on activity invites participation of all students; this is possible because it is safe and esay to prepare. We discuss previous efforts to make volcanoes alive in various learning contexts, and then how we used Jello to create a common experience with a simulation of plate tectonics, an activity which became a resource to bring about academic discourses among students and teachers.

Teacher demonstrations have been a part of science classes for decades - certainly since John Dewey (Dewey, 1938) promulgated the importance of experience to education over 80 years ago, and perhaps before then as well. Hands-on activities performed by students are less common, but seem to lead to good learning outcomes. Glasson (1989) compared secondary students (ninth grade, or 14 years old) who learned through either teacher demonstration or hands-on activities, and found that the hands-on activities led to better results on tests of procedural, or problem-solving knowledge. Stohr-Hunt (1996) found that eighth-grade students (generally age 13) who participated frequently (once a week) in hands-on activities performed better on tests of conceptual knowledge and problem-solving skills than those who participated less frequently, or not at all.

Probably the most prominent treatment of hands-on demonstrations within pedagogical theory was written by David A. Kolb (1984), who posited them as the first part of a four-segment learning process. According to Kolb, hands-on experiences instigate a virtuous spiral of learning, in which a concrete experience (CE) leads the student to subsequent stages of reflective observation (RE), formation of abstract concepts (AC), and active experimentation (AE), testing these concepts in new situations.[1] Kolb went on to create inventories of learning styles and pedagogies to accommodate them; the appeal of his ideas is reflected in their widespread application in organizational behavior, in formal and adult education and in training courses, and in the amount of discussion, criticism and refinement they generate.[2] But for our purposes it suffices to note that in Kolb's experiential learning the student's physical

[1] Kolb updates his ideas at this website: http://www.learning-theories.com/experiential-learning-kolb.html
[2] For a summary of the criticism, see Roger Greenaway's website, http://reviewing.co.uk/research/experiential.learning.htm.

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experience is the spark for a learning process that teachers can draw out in classrooms to maximize comprehension of difficult subject matter, by providing structure and opportunities for reflection, abstract conceptualization and further experimentation.

The hands-on Jello activity fits in well not only with experiential learning theory, but also with social-constructivist theory. In particular it suits situative learning theory (Lave and Wegner, 1990), which holds that students learn within the context and situation of the social and physical environment. When students perform a hands-on activity it achieves several objectives in the situative learning realm. Most obviously, it provides a direct experience of a phenomenon, a physical stimulus in their environment that they can respond to and learn from i.e., their learning resides in the situation of the hands-on activity. But in the social context, it gives them a common experience to compare and discuss, whether they do the activity individually or in groups. It makes them the experts on what happened before their eyes and under their hands, rather than second- or third-hand receivers of knowledge. If students perform an activity in small groups, as we have them do, it creates a small community of observers and learners, who can then not only compare their ideas within their own group but with other groups. The situative context, the social environment can become one of collaborative learning (Harding-Smith, 1993; Lee & Smagorinsky, 2000; Smith & MacGregor, 1992). And as Chang and Mao (2010) discovered, collaborative learning in earth science can lead to better results when it comes to tests of application (problem-solving) skills, implying a deeper understanding of the underlying processes.

The underlying processes of plate tectonics are difficult to teach; as Gobert (2000) observed, it is hard for students to understand them for several reasons: we can not actually observe the earth's structures and processes; the geological scales of size and time are difficult to grasp; and it requires us to understand and integrate spatial, causal and dynamic information, not to mention the fundamental physics and chemistry of the underlying processes involved. Students find it hard to understand that huge layers of rock melt and solidify; that tectonic plates move around the surface of the earth, pushed by spreading oceanic ridges that are in turn fed by convection currents within the mantle; that volcanoes can spout things besides molten lava, and that our earth has been changing its form for nearly 5 billion years. Some ways teachers have tried to get these ideas across include having students study textbooks, draw sketches of earth science concepts, write stories and engage in other activities. Additionally, there are now many web-based resources, such as Google Earth to demonstrate subduction trenches and the Ring of Fire,[3] the US Geological Survey website to show constantly updated earthquake information,[4] and Youtube videos of volcanoes erupting or people reacting to earthquakes and tsunamis.[5] However, even with these resources teachers have difficulty making the link to students' own experiences.

Most volcanoes in the classroom are demonstrations, performed by an expert and witnessed by the students. Table 1 summarizes the affordances and limitations of these activities. The baking-soda and vinegar volcano is quite common in teaching the expansion of matter and the flow patterns of lava down slopes and one horizontal surfaces.[6] The appeal of this approach is reflected in the viral popularity of Youtube videos of the demonstration of the same phenomenon with Diet Coke-and-Mentos.[7] Some teachers create volcanic domes from gelatin, Jello or agar-agar, and inject colored water into them from below; then they cut cross sections of the gelatin, allowing students to see the formation of cracks and fissures by a magma analogue.[8] Recently college classes have taken to employing the depth-charge trash can volcano; this is compelling – it is noisy and explosive, but safely reproducible by anyone with access to water, liquid nitrogen, and a spare trash can (Harpp et.al., 2005).[9] It shows the sudden expansion of matter under certain conditions and the explosive power that that expansion can have; and if you use the metal type of trash can, it will blow out the welding seam at the side and produce a reasonable facsimile of the

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[3]] Google Earth (Version 5.2.1.1588) [Computer software]. Retrieved September 1, 2010 from http://www.google.com/earth/index.html.

[4] United States Geological Survey. http://earthquake.usgs.gov/earthquakes/recenteqsww/ Accessed 18 October, 2010.

[5] http://www.youtube.com/watch?v=CgpNqrR318U Accessed 21 October 2010, and http://www.videosurf.com/video/tsunami-thailand-koh-phi-phi-2004-50835616 Accessed 20 October, 2010.

[6] Columbia Scientific (2010) http://www.columbiascientific.com/science-projects-for-kids/baking-soda-volcano-science-project Accessed 20 October, 2010.

[7] http://www.youtube.com/watch?v=9vk4_2xbo0E. Retrieved Feb. 9, 2011.

[8] Hawaii Space Grant Consortium (1996). http://www.spacegrant.hawaii.edu/class_acts/GelVol.html Accessed 19 October, 2010.

[9] http://www.youtube.com/watch?v=iXEj45QJQWw&NR=1 Accessed 12 October, 2010.

sideways explosive pyroclastic eruption of Mt. Saint Helens.[10]

All of these demonstrations show a controlled version of volcanic eruptions to students in a safe environment, but do not necessarily provide concrete experiences (CE) or allow students themselves to explore the geological forces at work. Nor do they really show much about the underlying causes of volcanic activity that could allow abstract conceptualization (AC): the convection currents in the Earth's mantle, the collision of tectonic plates in subduction zones, or in the case of explosive eruptions, the exposure of inert chemicals under the volcano's surface to the oxygen that creates their sudden voluminous expansion and escape. Convection currents are hard to see, although one university class in Florida had students observe them in lava lamps (Tolley, 2003).[11] This is an excellent way for students to visualize some of the dynamic forces at work below the surface of the earth, allowing RE & AC, although it is not a hands-on experience.

Activity	Affordances	Limitations
Baking soda/ vinegar volcano	Expansion of matter in enclosed place, resulting pressure and eruption; flow of lava down slopes and onto horizontal surfaces	No heat involved; focus solely on chemical factors in eruptions; no earth systems involved
Gelatin volcano with colored-water lava injection (http://www.spacegrant.hawaii.edu/ class_acts/GelVol.html)	Shows fractures developing as magma is forced upwards in gelatin volcano analogue	No heat involved. No tectonic activity, no explanation of what forces magma upward or forms volcanic upthrust.
Depth-charge trash can (Harpp et. al., 2005)	chemical expansion, eruption column, larger scope, excitement, safe, noisy, useful for upper level physics and chemistry calculations	No heat involved; focus on physics of eruption column, not earth systems; not hands-on
Lava Lamp observation (Tolley, 2003)	convection currents, thermal expansion, density and buoyancy	Not hands-on

Table 1: Volcanic and tectonic analogues in the classroom

Jello plate tectonics and volcanoes activities

The Jello plate tectonics and volcano activity is a hands-on concrete experience that allows students themselves to manipulate simulated tectonic plates, letting them create fold mountains, subduction zones, fault lines, and even a volcanic eruption, all from gelatin, perhaps best known under the brand name of Jello. This is a concrete experience (CE) which with opportunities for reflection (RE) and abstract conceptualization (AC) provides good conditions for deep learning. Jello is an ideal material for simulating tectonic plates and their movements. Like soft craft foam and clay, it deforms in response to pressure; but unlike them it also melts at relatively low temperatures, which gives a better show of rock layers melting under conditions of heat and pressure that can be reproduced in the classroom. The best sort of gelatin to use is keratin-based, which solidifies to a transparent solid; agar-agar is not transparent enough for students to see the tectonic processes at work; and while the starch-based konyaku jelly is transparent, it is too stiff to deform properly and requires very intense heat to melt, disqualifying it for use as a magma simulacrum. Using Jello slabs in contrasting colors, one dark and one light helps the learners observe and articulate discussion of their movements (collision, faulting, folding, melting, etc.). Jello provides a good condition for connecting the underlying processes.

Our approach added pre-abstract conceptualization to make the concrete experience more meaningful. The procedure itself is simple: 1) explain to students that the Jello represents tectonic crustal plates, moving about on top

[10] http://www.youtube.com/watch?v=bgRnVhbfIKQ Accessed 13 October, 2010.
[11] http://www.youtube.com/watch?v=1JflCYXl3kY&feature=related Accessed 12 October, 2010.

of the earth's mantle, pushed together by the expansion of the oceanic plates elsewhere; 2) place two flat slabs of Jello in contrasting colors next to each other on a metal tray; 3) have students gently but firmly push them together and see what happens; 4) have students describe what is happening to the two Jello slabs (reflection, RE); 5) with the teacher as facilitator, connect the action of the Jello with land formation (abstract conceptualization, AC). For magma formation, set the tray over a candle - that will melt the bottom layer of Jello and let students see the change in state for themselves. It is important to emphasize that this is rock melting into magma, and that the process of tectonic collision happens constantly, over millions of years. One cannot predict exactly what the Jello will do - whether it will form a subduction zone, a series of fold mountains, or a collision zone riddled with faults, uplifted slabs and valleys - so it is best to go over the basics of land formation with the students before the hands-on experience, so they will know what they're looking for. Afterwards teachers can debrief them and see what geological phenomena they observed.[12]

The most important affordance of the Jello activity is that it demonstrates earth systems explicitly, as opposed to the other simulations. Rather than a teacher running a demonstration, the students themselves manipulate the material and observe its deformation, so in effect they play the roles of both the earth's convection currents and of geologists observing them. Their manipulations, their reflections and their participation in the social construction of knowledge through the conversations that arise can promote situative, epistemic learning. The Jello's properties grab students' attention and provides scaffolding for their understanding; it allows them to build their understanding of earth systems concepts on their experience with its behavior; they can see its wobbly and squelchy properties, and can start to make mental equivalences between the way this material behaves and the way rocky crustal plates do. Students can observe for themselves the processes of tectonic collision and subduction, of fold mountain formation, fault generation, and of rocky layers melting into the magma reservoir on the surface of the tray. Since they themselves apply the pressure that makes these things happen, they know the role of the horizontal forces acting on tectonic plates.

We have used the Jello tectonics activity in several learning contexts over the last two years, modifying it each time. The following section describes how the activity was used in an revised secondary geography curriculum, and ideas for improving the activity so that more of its potential affordances are maximized in the classroom. We observed all class lessons, made observation notes and videotapes, collected student artifacts including reflections and geography journals, and interviewed the students in the weeks after the final exam. Our observation notes and transcripts of class videos are the sources for this section.

Jello activity in a Singapore school

We first developed this activity as part of an informal learning workshop for 7th-grade students in Singapore, where earth science and plate tectonics are part of the secondary school curriculum. In Singapore students are usually seated in rows facing the teacher, listening to lectures and Power Point presentations, consulting and underlining textbooks, and otherwise receiving information that they must remember during high-stakes examinations. Our project emphasizes student inquiryand hands-on group activities. We hope to improve students' understanding of earth science concepts, to enhance their application and problem-solving skills rather (Kim, Pang, Kim and Lee, 2009 and Kim et. al. 2009).

In 2010 we had a chance to use the Jello tectonic activity in a classroom environment in an all-male secondary school, as part of a semester-long implementation project. Singapore education is conducted in English, although it is a second or third language for many students; some of these students had arrived from China only 2 months previously, at the start of the school year. This class was unusual for secondary school in Singapore, in that the students, were always seated in groups of 4 or 5, and in that we worked closely with the teacher to provide novel features in the pedagogical practice in this class. These 7th-grade boys were on Singapore's express track - that is, they had a history of performing well on high-stakes exams, and had shown that they could thrive within a system that emphasized rote memorization and receiving information in a top-down way, from teachers and textbooks. The classroom culture, the situative context, that tends to emerge from this practice is one in which a few star students answer questions during lessons; standard classroom culture values correct answers. It is common for students to be focused on exam preparation or the allocation of marks rather than ask a question about science, Our project's emphasis was to get students engaged with the course material itself through concrete experiences, and to change the classroom culture so that knowledge was built up by the students themselves. To this end we assigned open-ended

[12] To view a brief video demonstration of Jello tectonics, see http://tiny.cc/si2cg.

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questions to make students think, rather than answer correctly; we changed the physical and social context by seating them in groups to encourage social learning through group dynamics, and we designed hands-on projects for them. The teacher also changed her approach, from the role of guru to facilitator, helping students build a consensus about geography based on their own research and reasoned arguments (Wang, Kim, Lee and Kim 2011). This clearly changed the social learning dynamics of the class and helped the transition from the usual Singaporean classroom culture to a new one. This transition, while difficult initially, seemed to progress well after about five weeks. By the ninth week of the school year, it was time for the students to learn about plate tectonics. We designed for them a lesson that provided four separate discussions of plate tectonics, leading them from preliminary abstract conceptualization (pre-AC), followed by the CE, RE and AC.

Pre-abstract conceptualization: the first discussion

The students were primed in advance by having prepared answers to two Thinking Questions: one was to imagine what the Earth would look like cut in half, and the other was to think about what causes earthquakes. At the start of the period the teacher initiated the first of four lesson discussions of plate tectonics, going over students' input. The students were quite engaged during this discussion; in the transcript of this portion of the lesson, no fewer than nine students contributed to the class's understanding of plate tectonics. The class began by reviewing the movement of tectonic plates as the cause of earthquakes. Then they got into a discussion of what the plates actually are made of, before the following conversation:

Excerpt:

1. TEACHER : Now there is something interesting about the earth crust that you know - it is not one piece of continuous layer
2. HAROLD: Yeah it's not.
3. STEVE: It's a few pieces.
4. TEACHER : It is made of a few pieces. Steve, could you elaborate? What do you mean by a few pieces?
5. STEVE : The earth's plate is not like permanently connected.
6. TEACHER: Not permanently connected.
7. STEVE:There are gaps in between.
8. TEACHER: How did the gaps come about?
9. STEVE: Not sure.
10. ALAN : From the plates shifting
11. TEACHER : How does the plate shift, why does it shift?
12. ALAN : Miracle
13. STEVE [murmurs to Alan]: There is convection energy in there.
14. HAROLD : Because it is floating on water.
15. TEACHER : You mean it is because there is water underneath that it causes the ocean to...
16. STEVE : [Discusses with his group] It is not water. If it is water, this Earth will be frozen.
17. TEACHER: Why does it change shape?
18. BRIAN: Because it moves.
19. JEREMY: The magma is moving. It must be moving. Earth crust is above [the magma], and earth crust is moving.
20. TEACHER: Why is the magma moving in the mantle? [She gestures towards drawing of mantle.]
21. BRIAN: Is that the mantle?
22. JIM: Because the core is moving.
23. JOHN: Because of volcanoes.
24. HUGO: Because of heat [inaud].
25. TEACHER: Do you agree with Jeremy or with Hugo?
26. HAROLD : (Starts to smile and point to Steve)
27. STEVE : Because of the heat. The magma is constantly cooling and heating. Because when it heats up it rises to the surface, then after it cools it comes down again. So it's like...a movement.
28. TEACHER : Interesting... [Alan: So smart!]. Do you all agree with Steve? I want you to think about it. We are going to do a very interesting activity. We will come back to this question

again. Ok. I want you to keep this at the back of your head. Why? Why are the earth plates moving? Yes, that could be your new thinking question…. Ok, and how do plates move? There are three basic movements. [Class gives the answer simultaneously]

29. TEACHER : They either collide, slide apart and the last one they separate, pull apart, ok. These are the basic three basic movements.

One remarkable thing about this exchange is, as mentioned above, the sheer number of students taking part in it. Another is the risk-taking evident among the answers: when the teacher asked Steve to elaborate on why the plates are in several pieces, he could admit ignorance without being laughed at (Turn 9). He knew that there are convection currents (Turn 13), and had a private conversation with Harold over Harold's suggestion that the plates are floating on top of water (Turn 16). Steve was thinking hard, and he wasn't the only one. Jeremy, who had never before spoken voluntarily in the class, offered his reasoning that the movement of crustal plates shows that magma must be moving (Turn 19). Once Steve heard Jeremy's contribution, he made the connection, which he shared with Harold – that's why Harold was smiling and pointing to Steve (Turn 26), who finally understood why the plates move on the surface of the mantle and described the movement of magma in convection currents (Turn 27).
A third remarkable thing is that once Steve made the connection, the teacher did not congratulate him on being right with a textbook-based answer. At turn 28, unusually for a Singapore teacher, she deferred the notion of a correct answer to some future time when more of the students could follow the logic and come to a consensus. She refused to tell the students the answer and anoint Steve the reigning geological genius of the class; John, Hugo and Jim remained in the running with their contributions, and the class would remain in suspense until they reached a consensus on the matter.

The challenge of turning concrete experience into reflection: the second and third discussions

This suspense set the stage for students' further conversations and observation of tectonic plates. In their state of suspense the students watched a brief video demonstrating the tectonic Jello activity and showing them what to look for in terms of land formation, subduction zones, fault lines, fold mountains and so forth. At that point we distributed to each group a tray with two Jello slabs on it, advised them to assign the jobs of tectonic pusher to one student and observer/scribe to another, told them to wash their hands so they could eat the Jello when they were done, and watched them push the tectonic plates towards each other..

The activity itself took about 8 minutes, including cleanup. Each group had at least one student pushing the plates, and another hovering excitedly, watching over his shoulder. The activity itself afforded another opportunity for a second conversation about plate tectonics; in one group a student said "It formed ridges, then BOOM!" when their Jello formed a large crack and fell apart. But not all group discussions focused on geology. Typically they followed a pattern like this group. They began with a discussion of the hygiene of the person pushing the Jello slabs together, then moved on to coaching him: WILLIAM : "Slowly...slowly sloowly....sloowly, slowly... why you move so fast..too fast" (turn 30). They compared their progress to other groups' and stated their desire to eat the Jello, then noted what the Jello was doing: "He is making a mountain range" (turn 31). This brief observation was followed by a good deal of speculation about the Jello's flavour and methods of dividing and eating it, and was only brought back to geology when the teacher joined the conversation: TEACHER: "Ok, when it folds... Now did any part crack? You see, there is a crack here...When there is a crack what happens? When there is a crack in the Earth's surface what happens?" JOSHUA : "There is a mountain." WILLIAM : "Then the magma will come out." TEACHER: "Yeah, when there is a crack in the Earth's crust...what happens is below, the magma will rise (shows with hands motion of moving up). And when magma rises, what does it form?" (whole group simultaneously answer): "A volcano! TEACHER : Very good! Ok, enjoy your Jello" (turns 32-38).

The teacher changed the social dynamics of the groups by joining each one in turn and initiating a reflective discussion, asking students what they saw and helping to reflecto on their concrete experiences. According to our transcripts of all the groups, the teacher's presence in the group was the most important factor in keeping the students' discussion focused on earth processes, and yielding more productive conceptual conversations.

Reflection to abstract conceptualization: the fourth discussion

Finally the teacher helped the class as a whole to consolidate their observations with their knowledge of plate tectonics, first having them read their textbook's treatment of plate tectonics and then writing on the board a series of statements elicited from the students, which they were required to copy in their notebooks. This was the fourth discussion of plate tectonics that took place in the class during this 45-minute period.

Excerpt

39. TEACHER: (writes: "As the 2 plates collide" on the board) Do not use "Jello," use "plates" to describe. Writes: "It makes an earthquake.")

40. HENRY: The two plates climbed.

41 JOHNSON: One plate go over other plate – overlap.

42 BRIAN and many others say that one plate overlapped the other.
43. TEACHER:What happens to the top plate?
44. BRIAN: Fold – it starts to fold into mountains.
45. (TEACHER writes: "a series of")
46. BRIAN: Mountains
47. (TEACHER writes: "Was formed along the")
48. TEACHER: What do you call the place where the two plates meet?
49. THOMAS: Plate-edge.
50. (TEACHER writes: "Place where 2 plates collide.")
51. TEACHER: What happens to the plate that gets subducted? That is, sinking?
52. ELTON and JEREMY: It melts.
53. TEACHER: Why?
54. ELTON: Heat and pressure. (Others also say Heat.)
55. BRIAN: Like a blanket in a bed. When you're under the blanket it is very warm.
56. TEACHER: What happens then?
57. ELTON: It forms magma. (Others also say magma.)
58. TEACHER: Some of your plates – what happened?
59. STEVE: makes a hand gesture indicating breaking up of plates.
60. JOHNSON: It got eaten.
61. (TEACHER writes: "If there's a fault on the crust")
62. TEACHER: What happens in the collision? What will rush out?
63. HENRY: Magma.
64. (TEACHER writes: "Magma will flow out onto earth's surface")
65. TEACHER: What kind of land forms will it make?
66. OSCAR: Island. JACK: hill. ELTON and others say the same.
67. TEACHER: An island is sometimes formed by a volcano.
68. (TEACHER writes: "Forming a volcano.")
69. BRIAN: Is that how Singapore is formed?

We were able to capture the participation of 9 of the 38 students in constructing the general summary of tectonic collision that they all eventually wrote in their notebooks. These nine were the ones who spoke loudly enough to be recorded; others were feverishly talking during this conversation but did not manage to make themselves heard. Two students in this exchange had never spoken up in class before (Johnson in Turns 41 and 60, Thomas in Turn 49), so the Jello experience seems to have changed the social dynamics of the class and encouraged them to join the conversation reflecting on their experience. Or perhaps it was the compelling concept of violent disasters - volcanoes and earthquakes are, after all, exciting. And Brian was on fire – in Turn 55 he compared magma below the surface of the earth with the heat that builds up beneath a blanket, and in Turn 69 he also extended the realm of inquiry, from the general theory of plate tectonics specifically to the formation of the island of Singapore. The personal observation and engagement enabled by the hands-on Jello activity appear to have broken down some barriers to class participation and ownership of the lesson material. The activity is simple, yet creates excitement and engagement among students that can work to give them ownership of the intellectual matter at hand, as well as stimulating informal and class discussions, different social roles in learning, and ultimately a better conceptual understanding of tectonic motion, landform creation, earthquakes and volcanoes. Through this process of multiple discussions the students can reflect on their observations during their common concrete experience to the abstract concepts of plate tectonics.

Improving affordances and future development

According to their written reflections and journals, students found the Jello plate tectonics demonstration fun; cognitively it helped expand the students' existing concepts to understand complicated processes of plate tectonics, magma movement, and vulcanicity. The fact that Jello is food was both distracting and beneficial; the novelty of using food to model scientific concepts was clearly attractive and enjoyable to the students, but their adolescent hunger tempted them to focus excessively on the Jello's edibility.[13] The activity took the students' experience with Jello's texture and properties and added to them the concepts of motion induced by convection currents in Earth's magma, of the creation of fold mountains and subduction zones between moving solids, of the crust's change of state from solid to liquid under conditions of heat and pressure, and of the formation of volcanoes when those conditions combine with a hot spot or upwelling of magma through a fault in the crust. Of course for hungry students it provided a snack. For an activity of eight minutes' duration, that was a lot to deliver.

Some elements that enhanced the affordances of the jelly activity include: the students' previous preparation for learning (pre-AC) about plate tectonics by their research of the Thinking Questions about earth's structure and the causes of earthquakes; their viewing of a demonstration video before the activity itself; the fact that they all experienced the activity (CE) simultaneously, in groups of 4 or 5 students who had been working together for nine weeks - they could compare results between groups informally (RE); the teacher's visit to each group during the activity to debrief them on what they saw (RE); the teacher's consolidation of the lesson after the demonstration by having the entire class contribute to a statement on the role of plate tectonics on mountain and volcano formation, which the students were required to write in their notebooks (AC); and of course the review of the activity during the next geography class. The skill of this teacher adumbrated throughout the activity and made it even better; for although the activity has affordances, the teacher was necessary to keep the students focused on them.

But we should not discount the differences that the overall classroom practices made to the students themselves. As mentioned previously, these were performance-oriented students who for the first time were working in groups and getting to ask questions, instead of having knowledge handed down to them from on high - having been brought up in a strict behaviorist model of education they were now experiencing a more situative approach. During the course of the semester we found that many students who originally left the job of answering questions to others - deferring to the acknowledged experts - began speaking up themselves; in their reflections, a good number of them mentioned their increased confidence in their own voices, their own opinions, and their own abilities to learn. In situated learning theory (Lave and Wegner 1990) students learn from their social and physical environment; they discourse in groups, asking questions, evaluating each other's answers and sharing the responsibility for both questions and answers (Greeno, Collins and Resnick, 1996). When we added to this situative learning context a demonstration of plate tectonics using Jello, performed not by an expert in front of the class but by the students themselves, we supplied additional affordances of the students' direct experience with the materials of the demonstration itself. We allowed them to be the experts in the demonstration, continuing the class's trajectory towards distributed meaning-making.

Of course there are limitations to the Jello tectonics demonstration. One thing we have learned is that the CE can be distracting; it proved vital to have a facilitator work with each group, to keep them focused on the earth processes. Providing enough facilitators for a class of 40 students to do the activity simultaneously is impractical, so we are trying to improve students' focus by assigning one group member responsibility for documenting the Jello's deformation with a mobile phone camera, for posting on the class's Facebook or Edmodo group. Asking the students to create a tangible product at the end of their activity may also deepen their reflections (RE), so we can ask them to create their own Jello videos or posters, hoping that this will enhance their connection of the activity with science (AC). And it may be that the colors of Jello, combined as they are with scent and flavor, are overly distracting for hungry adolescents; it may be better to work with clear unflavored gelatin and odorless food coloring, or perhaps to do the activity twice in one class period, so that they have an opportunity to get used to the novelty of the experience and focus more on the forces at work the second time through. We are currently in our second year of classroom implementation of our ideas, and are gradually refining our curriculum, reconciling innovative teaching ideas with the limitations of time, space, and an exam-dominated curriculum.

There are also limitations on the scientific accuracy of the activity itself. We haven't yet figured out how to model an expanding oceanic rift with Jello to show new land formation or why the plates are colliding, to create a convection current under the Jello plates, or to convey the sheer size of the plates or the enormity of the geological time scale. But deployed in a well-thought-out program of earth science inquiry, this simple, safe activity seems to encourage student understanding of several key concepts in plate tectonics, which is what we were after.

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[13] There are many educational scientific demonstrations that use food. For a representative sample see http://foodscience.psu.edu/public/kitchen-chemistry/youth or http://www.proteacher.net/discussions/showthread.php?t=7084

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