

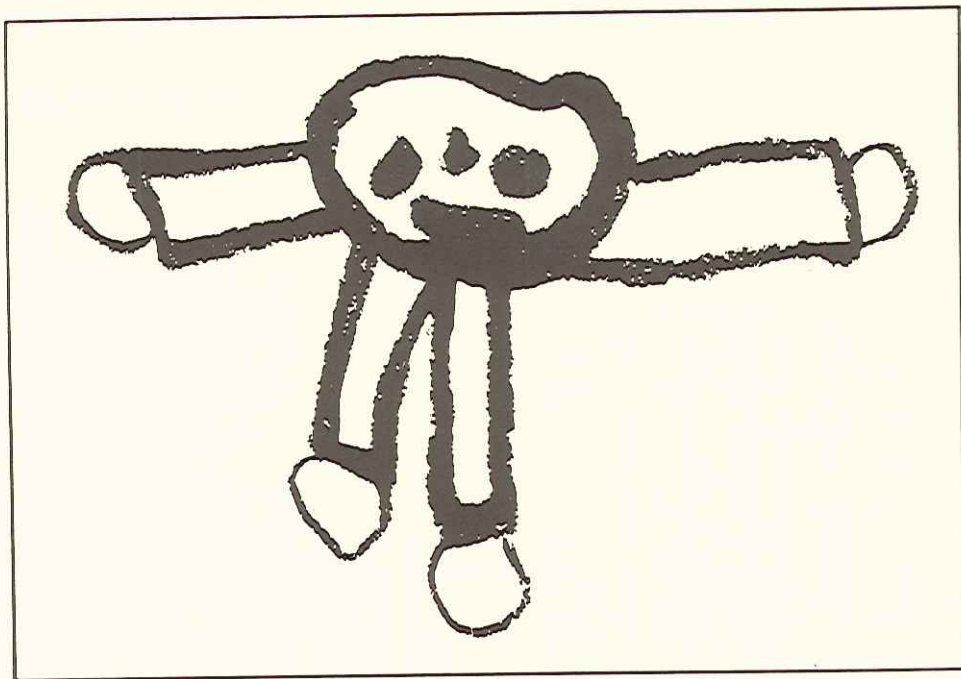
Eleanor Duckworth

INVENTING DENSITY

In November 1972, educators from several parts of the United States met at the University of North Dakota to discuss some common concerns about the narrow accountability ethos that had begun to dominate schools and to share what many believed to be more sensible means of both documenting and assessing children's learning. Subsequent meetings, much sharing of evaluation information, and financial and moral support from the Rockefeller Brothers Fund have all contributed to keeping together what is now called the North Dakota Study Group on Evaluation. A major goal of the Study Group, beyond support for individual participants and programs, is to provide materials for teachers, parents, school administrators and governmental decision-makers (within State Education Agencies and the U.S. Office of Education) that might encourage re-examination of a range of evaluation issues and perspectives about schools and schooling.

Towards this end, the Study Group has initiated a continuing series of monographs, of which this paper is one. Over time, the series will include material on, among other things, children's thinking, children's language, teacher support systems, inservice training, the school's relationship to the larger community. The intent is that these papers be taken not as final statements--a new ideology, but as working papers, written by people who are acting on, not just thinking about, these problems, whose implications need an active and considered response.

Vito Perrone



Eleanor Duckworth

INVENTING DENSITY

Center for Teaching and Learning
University of North Dakota
November 1986

Inventing Density

This monograph is for Claire, Colette, Danielle, Evelyne, Henri, Ingrid, Jacques, Jeanne, Lise, and Pierre, and for the scores of other teachers who have put themselves on the line as learners in the search for greater understanding of learning and teaching.

This is a story about the collective creation of knowledge: its multiple beginnings; its movement forwards, backwards, sideways; its intertwining pathways. The setting is a course in the educational psychology of science teaching, at the University of Geneva.

My approach to teaching this course is to engage the students in finding out something for themselves, through their own investigations of everyday phenomena; and then to draw psychological and pedagogical themes from this joint engagement. What it is that becomes the major subject of study varies from group to group; we try two or three kinds of activities until something catches on. In this group, the first one happened to catch on: why some things float and not others. It caught on partly because of some tantalizing phenomena that occurred in the very first session, and partly because the members of the group (with one exception) were willing to acknowledge that they didn't know, or couldn't remember what they ever might have been taught about, what makes things float. It was their willingness to be perplexed, and to struggle publicly with their own perplexities, that created the story.

The story covers eight weekly sessions. In addition to the work on floating and sinking, which took one or two of the three hours per session, we also watched the apparent motions of the moon, trying to fit observations with theory; and we discussed assignments that class members carried out in their own classrooms.

My interest in this class was twofold, but I am including only one aspect of it here. In my work, I am interested primarily in how to help teachers think about their teaching, but I am also interested in how adults think and learn about experiences of the physical world. It is my good fortune to have found a way to do the first through the second. (See "Teachers as Learners"* and "Teaching as Research"* for further development at this point.) In many of my classes, the most interesting developments are those which concern the students as teachers. (See, for example, "Understanding Children's Understanding."*) In this class, while the students' development as teachers was also

*Eleanor Duckworth, "Teachers as Learners," *The Genetic Epistemologist*, 13, 2, 1984.

_____, "Teaching as Research," *Harvard Educational Review*, 56, 4, 1986.

_____, "Understanding Children's Understanding," in V. Windley, M. Dorn, and L. Weber, eds., *Building on the Strengths of Children*, City College of the City of New York, 1981.

*David Hawkins, "Critical Barriers to Science Learning," *Outlook*, Vol. 29, 1978.

interesting, the story of their coming to understand more about floating and sinking is the more cohesive and dramatic. It is a story on its own, and on its own it sheds light on the capacities of a group of serious, playful adults to come to their own understanding, and on the deep complexities of an idea which is often taken to be simple (see David Hawkins, "Critical Barriers for Science Teaching").* I hope it raises questions about the teaching of science in high school and college.

The class sessions were not tape-recorded. I was able to spend as many hours as it took to write down everything I remembered. I have recreated the story from those notes.

The characters are the following:

Regular participants: Claire, Danielle, and Lise, kindergarten teachers, an inseparable trio; Colette, teacher of high-school-aged girls in their last year of a nonacademic, not-even-vocational, program; Evelyne and Henri, a married couple; she taught nursery school, he usually taught fourth grade, but this year, as part of a special project, was working in Evelyne's classroom; Ingrid, a Dutch student, doing a master's degree in education; having no class of her own, she did the weekly assignments with Jacques; Jacques, teacher of fifth-grade children in a poor neighborhood; Jeanne, second-grade teacher; Pierre, fifth-grade teacher, the one member of the group who considered himself experienced and knowledgeable in science.

Irregular participants: Anna, South American doctoral student in education; Bertrand, African master's student in education; Helen, Canadian doctoral student in education; Stuart, American doctoral student in psychology, who carried out assignments in the International School; Robert, French physicist, visitor to one session; myself, teacher of the course.

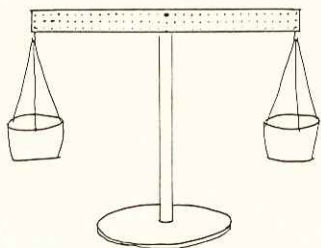
FIRST WEEK:

Early Ideas, Imaginative Explorations, Rubber Bands, and the First Reference to the Air Hypothesis

I asked the students to do what interested them with the following materials: plastic dishpans and pails; water; glass, plastic, and metal containers, with and without covers; escargot shells; nuts and bolts; odd pieces of wood, some hard, some soft; straight pins; corks; scrap metal; styrofoam; rubber bands; plastic bags; toothpicks; aluminum foil; a balance, consisting of a piece of pegboard with a plastic pan hung from each end.

They were game, this group. It's not easy to create something respectable to do with such a nondescript collection of materials; and it is very easy to feel foolish.

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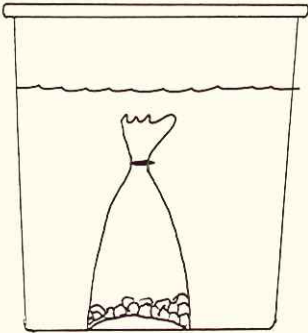
The kindergarten group, Claire, Danielle, and Lise, started by putting things in containers and floating them (I overheard one of them say she was going to put some corks in a tin to make it lighter) before settling on seeing how many bolts they could place on a small raft. Starting with a square plastic cover, they examined whether it mattered if the bolts were placed in the middle or around the edges; whether the size of the raft mattered; whether the material it was made of mattered; whether it mattered that it had a rim or not. This group also screwed cup hooks into corks to see how many metal washers a floating cork could carry.

Colette, Pierre, and Henri were, by the time I saw them, holding pieces of wood by the corner, just barely, so as to hold them upright without affecting the depth of their floating, and trying to determine why some of them floated deeper than others. The pieces of wood were of highly irregular shapes, but they were not asking about the volume of wood that was underwater--just the linear depth. They used the balance to compare their weights, examined them for whether they were the same kind of wood, and compared their volumes by pushing them down in a clear plastic bag of water, noting the height of the displaced water. When later they gave an account of this work to the assembled group, they said that they had concluded it was the volume of a piece of wood (as assessed by the water rise in the plastic bag) which determined how deep it floated. Among the evidence they presented were two pieces of wood which they said had the same volume, when it was clear to the eye that the wood in fact had different volumes. The three were nonplussed when I mentioned that; realized that their final conclusion was undermined; became dismayed over the difficulties of doing anything dependable; cast aspersions on the homemade balance as an example of everything that made the situation impossible (though when I stoutly defended my balance, Colette acknowledged that they were only looking for excuses); but did not think to question the wisdom of measuring volume by water rise in a deformable container.

Another group blew a plastic bag full of air, and added metal weights inside it, to see how many it would take before it would sink in a pail of water. They reached the point where it sat on the bottom of the pail, and stuck out above the surface of the water. I asked them if it was then sinking or floating. There were differences of opinion. The idea occurred (though not at all easily, and perhaps it came from me) to put more water in the pail. They managed to cover it with water, but then could not decide whether or not it was touching the bottom. It moved when they

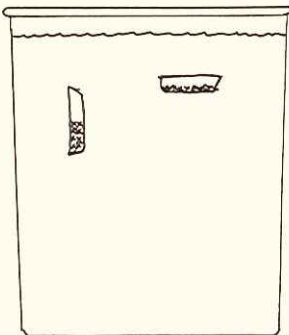
stirred the water, but that was not convincing evidence.

After the break the whole class took up this group's problem: how to tell whether the plastic bag was touching the bottom of the pail, or hovering just off it. There was no consideration of the relative likelihood of one or the other, or of whether an object ever stays put under the water, without going either up or down. They wanted to determine what this bag was actually doing; and, after stirring the water, they couldn't think of how to tell. As a temporizing measure, until someone came up with a better idea, I suggested using a mirror. Somewhat to my surprise, it turned out to be helpful: holding the mirror on the bottom of the pail and looking down through the water, they could see, first, that the middle of the bag was not touching, and then that the points of it were. ("Because of the distribution of the density," explained Pierre.)



When they saw its points just barely touching, they added more water, thinking that might float it off; it didn't. They wished they could add a *lot* more water, a poolful, to see if that would float it. I proposed making a very tiny object that just barely sank in a cup of water, for which a pail of water would then be a lot--close to the equivalent of a poolful for the bag. They thought that was a good idea. I made some tiny object of cork and clay, which sank very slowly in a cup of water, and rested on the bottom. Predictions then were half and half that it would float in the pail. It did not float in the pail.

This idea that more water might support more weight then was modified--though nobody made this connection explicit--to the idea that more horizontal surface contact between water and object (later referred to as "the bearing surface") might support more weight. They found two identical small, flat containers and weighted them with equal weights, distributed so that one floated upright and one floated flat. Both sank, but the flat one sank slower. Everyone felt that was inconclusive.



At one point during these experiments (which took some time to accomplish, given the nature of our materials), Pierre said that things floated if they had air in them, and sank if they did not. I had expected this hypothesis at some point, since it always comes up. I knew also that there was no very direct way of countering it. I cut a small piece off a plastic bag, and put it under the water: it floated up. I couldn't tell what most of the group thought, but Pierre said, rather weakly, that there were teeny invisible pockets of air in the plastic, which accounted for its floating.

The year before, I had discovered with my students a remarkable feature of our collection of rubber bands, to which I now turned. I tossed in a green one, and it floated. "Capillarity," said Pierre (a word which is commonly used in French when we would say "surface tension"), "like a needle." I teased him, for seeking refuge behind a word, and also pushed the rubber band underwater to show that it rose. (It did not occur to me, however, to show the contrast with a needle, which can be made to sit on the surface of water, but sinks once you push it under.) I then tossed in a blue rubber band, which sank. They were intrigued, and produced a color hypothesis, as a joke. (I said I liked that better than "capillarity" and they seemed to get my point.) They pursued the color hypothesis, and saw that indeed, the red, green, and yellow bands systematically floated, and the blue and white bands systematically sank. Very intrigued. Someone tied together two of different colors, to see which won. They also tried a plain brown one: it floated.

In the midst of this Claire, quietly by herself, tied a knot in a yellow band, as a better way to find out whether floating was influenced by the amount of bearing surface. The yellow band still floated, and she was distinctly pleased with this neat test. She caught my eye at that point, to share her pleasure.

SECOND WEEK:
Investigations Become
More Systematic, and
Explanations Seem
Elusive

During the early talk of moon observations and work in classrooms Colette said that her adolescent girls had not much patience for playing around. Above all, they wanted to know *the answer*. That took me aback; I didn't know to what question they wanted to know the answer. To all the students in this course, it was obvious: why some things float and some sink? What had I had in mind?

Well, for one thing, not some single nugget-like answer. Rather that, whatever people in the class thought about floating, it would be fleshed out, called upon to account for some surprises, attached to real-world complexities. I hoped they would come to agree that this part of the world is more interesting and less simple than they had thought. And I hoped they would be able to see what it is like to figure out some of the complexities for themselves.

I asked whether there was anything from last week that they would like to pursue. They said rubber bands. Without elaborating, Colette said that a colleague of hers had said that the dyes must have different specific weights. What she said seemed plausible to some, and nobody had any other idea. But it did not seem like an answer to anyone.

I then proposed three problems as possible activities for the session, in order to develop some surer familiarity with floating and sinking phenomena:

1) For rubber bands, I asked them to try to quantify the various degrees to which the different colors sank or floated;

2) I posed the same problem more generally: do two sinking objects of the same weight need the same amount of some floating material to make them float?

3) I proposed taking some object that sinks, modifying it so it floats, and specifying ahead of time which point on it will be on the uppermost side as it rises to the surface.

Claire, Danielle, and Lise worked on the third problem, but started with a floating object rather than a sinking one. To arrange for a given point to be highest, while the object sinks, they found they had to add a weight underneath, "in continuation" of the point.

I encouraged them to do the problem as originally posed, and they tried the reverse procedure. Taking a stone, they specified the point on it that they wanted to rise, and they tied a piece of styrofoam on the opposite side. They found that the styrofoam turned the stone over, so their point rose last rather than first. They eventually placed the styrofoam directly on the point that they wanted to rise first, but were not satisfied with this solution, since the point was not the first point on the total object (stone plus styrofoam) to get to the surface. Later, in discussion with the whole group, I asked if it would be possible to make an object such that the floater would not be the top-most part. They thought then of putting some floater on both sides, but wondered whether it would float up sideways. We were all interested in going further with this, but put it off.

The rubber band group put their efforts into ordering the five colors. By racing them, ascending and descending through water, and by putting them in salt water, they were able to tell that the whites were greater sinkers than the blues, and the yellows were greater floaters than the greens and reds. But they could not yet distinguish between the reds and the greens. The colors were size-coded, as it were: there were five different sizes, one size per color. But the sizes did not coincide with the floatability: the best sinkers (the whites) were the smallest, but the best floaters (the yellows) were not the biggest. To distinguish between the greens and the reds, their next idea was to tie one of each of them to a white one--one red tied to one white, one green tied to another white. When both now sank, they tied *two* of

each of them to a white one. The green now sank, and the red still floated. They concluded that red was a better floater.

The fact that the reds were bigger didn't seem to enter into consideration--and yet people in the class still felt puzzled. I think it was because they had established that the size of these rubber bands was not responsible for their floatability, and yet they were vaguely aware that in this case the size of the red might affect how much white it could lift. They felt they needed to know something about the nature of the material itself. I had already been suggesting that they cut equal-sized pieces from the green and red bands, and use them in their experiments. Now I said that it was precisely in order to understand better the nature of the material that I had been suggesting that. They seemed then to find sense in my suggestion, and carried it out. (The green carried more white than the red.) Of course that investigation did not tell them much about the nature of the different colored rubbers. But it did establish neatly the order of the colors, and they then felt quite satisfied with what they knew--the nature of the material was not, after all, what had been bothering them.

In the group discussion, I raised the question of how they might go further, and quantify the relationships among the colors. Several of them were particularly sharp, as together they thought through what they would have to do. They could, for example, use the tie-together-one-that-floats-with-one-that-sinks technique, provided they established equal-sized pieces. Or they could time the ascents and descents, as they had started to do, but through greater depth; or through the relatively shallow depths available here, but a hundred times over, taking averages.

Three different groups worked on the third problem. They all found, with some surprise, that different sinking objects of the same weight might need different amounts of floating material to float. The most striking instance was a small weighted plastic container which needed 15 times its weight in styrofoam to float it. Pierre, *le scientifique*, was in this group, and he was again maintaining that an object floated or not according to the "volume of air" it contained. I tried to support any skepticism that Henri and Jeanne might be tending to feel by exclaiming that surely the styrofoam did not have 15 times the amount of air. (Pierre had not claimed it did, but I wanted to push the matter.) Pierre's first reaction was that it could have maybe not 15 times the volume, but 15 times the quantity. (The 15 factor, in fact, applied to *weight*.)

Later in group discussion, he said maybe five times was taken up by air; the rest was something else. I was trying to be harsh on the air hypothesis, expecting that we could see through it by now. I asked about the role of air in the rubber bands. Colette suggested that perhaps one dye had more air in it. They talked about how to know whether there's air in something. Someone asked whether there was air in water, and Pierre said that of course there is; how else do you think fish breathe. Jacques countered, asking how we know it's air: maybe we should talk of a vacuum, or maybe it's oxygen. Maybe, he said, it's just how much space there is between the molecules. It's not molecular, Pierre said.

The bearing surface was again considered. Claire said that couldn't be a factor because of her experiment the week before, tying a knot in a rubber band. Jacques agreed with her, but saw that he wanted to contradict himself: What about those water bugs that can stand on top of water because of their broad feet? Stuart said that his kids had found that aluminum foil floats in a sheet, but sinks in a small packet. Some thought that they themselves floated more easily flat than in a ball, but there was disagreement on this.

I tried to summarize the factors they seemed to be considering: surface, air, volume. All three times that I tried this summary, Pierre broke in whenever I said "air" to specify "volume of air." I finally paid attention, and asked why he thought that should be specified. He did not manage to say what he was thinking, and ended up saying the "quantity of air."

We came back to the question of whether there was air in styrofoam. Danielle pointed out that you can crush styrofoam, and proceeded to do so. She managed to flatten it dramatically and it still floated. She said it was still a bit spongy, by way of saying that there was still some air in it. They compared its speed of rise from the bottom of a pail of water with a noncrushed piece and found no difference. Pierre, among others, said, "Of course," or words to that effect. I said to him that I thought he would have expected the opposite--that with less air, the crushed piece should be less of a floater. He saw what I meant, and responded (as the week before with respect to the balance) by saying that you really couldn't count on these makeshift materials for any dependable experimental findings.

At the very end of the class it occurred to me that if the styrofoam was crushed underwater, bubbles should come out. About half of us were together to try it. Oddly enough, it was not clear whether any

came out or not. We then squeezed with a vice. Bubbles were obvious this time. (But not, it seemed to me, with the volume one would have expected. This remains a question for me.)

THIRD WEEK:

We Encounter Mysterious
Pill Bottles, Statistical
Rubber Bands,
Floating Balloons,
and Sinking Wood,
and We Make a
Detour

Colette had brought in two plastic pill bottles which one of her girls had brought in to her. With no water in them, they floated. Full of water, they still floated! Only Pierre refrained from being surprised. He said that of course there's air in the water. Henri balked at this; he wasn't convinced it was due to air.

Jacques then upstaged even this mystification, with a collection of colored rubber bands which he had bought and experimented with. Apart from the white, which systematically sank, the other four colors had a statistical tendency to sink or float, but you couldn't count on any one to do either. Moreover, out of a population of 10 blue bands say, all 10 might be floating after half an hour, only four after an hour and a half, but seven after four hours! Total mystification. I borrowed them to study at length myself.

We needed a change by then. That things that are lighter than (the same amount of) water go up and things that are heavier than (the same amount of) water go down did not seem to be an idea that was establishing itself easily through the collection of phenomena we had been studying. So far, my students were tantalized and intrigued; enough to keep pondering and to try to make sense of what they saw. That was the best possible position from which to proceed; but it seemed to me we needed to proceed down a different path in order to see similar questions from different angles. I proposed that we stop a frontal attack for a while, and go around the edges. They agreed to that, though they were clearly impatient to know *the answer*.

The end run that I took was not, I think the best approach, although a number of fruitful developments took place in spite of it. It consisted of focusing on air and water (and perhaps it came partly from my wanting to catch the bubbles squeezed out of the styrofoam). I knew that there were surprises in the interactions of air and water, tubes and containers, and that most of the surprises were explained if one only kept in mind that when put together, air goes up and water goes down. It seemed to me that this useful, simple principle might then be helpful in thinking about more complicated objects. For some reason, it did not occur to me that I was highlighting the air hypothesis.

The surprises did occur, and the simple principle did emerge, but this work in general did not contribute, as far as I could tell, to the ideas my students were developing about floating. I shall mention only one main pursuit that related quite explicitly to the problem that was on their minds.

Among the materials available that day were balloons. I did not usually have a specific purpose in mind for materials which were available, but the balloons had been intended to make bubbles underwater, or to fill with air, or somehow to relate to what I had intended as the work of the day. Jacques, Ingrid, and Anna, however, classically turned the materials to their purposes--filling them with water to see whether they would float! Colette's pill bottles must have been the inspiration for this enterprise, the only thing that would have suggested the question. It was as if they set out to astonish themselves, and astonish themselves they did. The balloons did float. Half full of water, almost full of water, and completely full of water, feeling very heavy indeed, they did float. Ingrid thought to try a balloon by itself, working hard to get every bit of air out of it, although she didn't think to empty the air underwater: it floated. She hadn't predicted that, nor the opposite. She took the outcome with interest, and pondered it. Most of the others didn't take much interest in it, but Claire went on to tie it in knots, and noted that it still floated.

Later, when reporting to the rest, Anna said that the balloons floated more or less high according to whether there was more or less water in them. Almost everyone was astonished that they floated at all, especially Colette: "It feels so heavy!" Pierre, once again, was not surprised. Of course, he said again, there's air in the water. It seemed to me that others besides Henri were left unsatisfied by that refrain.

At the break, I brought out a gallon jar in which there had been a piece of wood in water since the year before. The wood was resting on the bottom. There was great interest in this. The group wanted to know how much it had weighed when it was dry: I didn't know. They thought that it must have soaked up water, but did not understand why this water-filled wood sank while a water-filled balloon floated. As for what should be done with it, Claire suggested taking the wood out and letting it dry. Pierre asked that it be kept as it was for a while, so he could try to float it, with air.

A couple of other remarks that evening bear reporting. In the face of our most dramatic instance of the reality and intractability of air, Ingrid wondered what happens when a boat turns over and sinks. For

water to go in, the air has to go somewhere else. Where does it go? No one knew.

At another point I heard Jacques and another wondering together whether an object which sinks in a dishpan would do the same in a huge amount of water. Of course, I thought we had dealt with that the first week, with the tiny object that still sank in a bucket, having barely sunk in a cup.

At the end, I asked if they were still willing to pursue side-tracks, or were they too impatient. They were impatient, but they said they'd stick with me.

FOURTH WEEK:
We Look for "Proper
Places" of Differ-
ent Liquids, and
Try to Refloat
the Wood

Two major activities took place in this session. I introduced a variety of different liquids, and most people worked with them. Henri and Pierre, however, preferred to try to float the old piece of wood. I shall describe their work first.

They believed the water that the wood had been in for a year must by now be airless, so they started by blowing bubbles into the water through straws. When this did not float it, they removed the wood to some fresh tap water, and again blew bubbles into the tap water. When the whole group gathered to hear about their progress, they made a third try--replacing fresh tap water with a solution of salt water. Henri and Pierre's idea seemed to be the following: although the wood was placed in new water, the old water was still what saturated it; since the old water was airless, they would have to get it out of the wood before new, aerated water could enter it and make it float again. Recalling some version of osmosis, they reasoned that the salt water would draw out the old water from the wood, and it would then be replaced by the new water, which would be aerated.

Most of the other class members, especially Danielle, seemed to think this was pretty crazy--although Pierre's *scientific* talk of the osmosis phenomenon made some of them take it somewhat seriously.

Jacques said a kid had told him that a clothespin had floated and then sunk because water had gone in and taken the place of the air that was there. He proposed this as a plausible hypothesis in the present case, but was not sure it applied. Ingrid wondered (again!) if a whole lot of water to float it in would make a difference. There was no strong reaction to this thought; nobody took it as a suggestion for an experiment. Ingrid also observed that entire logs are sometimes found sunk in lakes in water not airless. Pierre and Henri agreed, but argued that those logs were rotten. Someone said that ours was, too, and I pointed out the stink. The discussion was left inconclusive.

Pierre also said in this discussion that oxygen is what matters, not air. He asked if the top of the jar had any oxygen when I opened it. I was not sure, but thought not. And I pointed out that I didn't know whether what might have been there would have been oxygen or air or carbon dioxide or nitrogen or what. Pierre was sure that only oxygen would make a difference in floating.

The wood was left in salt water so that the osmosis procedure would have the time it needed. Ingrid asked how long it had taken to sink. Since it had taken two or three weeks, she thought one week too brief for this experiment. I pointed out that wasn't necessarily the case, since this procedure was not the reverse of the one that had brought about its sinking. The class tended to agree.

Meanwhile, I had brought salad oil, mineral oil, salt, liquid detergent, alcohol, molasses, and a heavy syrup. I had also brought as coloring agents, ink, red food coloring, and iodine; and (for economy's sake) very skinny test tubes in which to work. In addition to various liquids, there were various solids, in tiny bits--plastics, toothpicks, styrofoam, seeds, rice, rubber, hard wood; and two large containers, one of salad oil and one of heavy syrup, in which the class could try floating the solid bits.

The class made a variety of intriguing or lovely effects with the liquids, most of which I shall not try to describe. At the beginning, at least, none of the work was directed toward answering any specific question. They tried to get to know the materials.

They shook liquids together, and watched them separate from each other. They watched drops from one liquid rise or sink in another. Ingrid tried to dissolve each liquid in molasses. Alcohol was the one with which she did not experiment: all the other liquids were similar to molasses in *thickness* or *heaviness*, and since none of them had dissolved, she thought it unnecessary to try alcohol.

In the general discussion, we looked at Evelyne's six-layered bottle. When she had made it earlier, she had not known what each of the layers was, so I had asked her to try liquids two at a time. Now, redoing some of her pairs during the discussion, we found that alcohol tended to stay under salad oil; but when we used a very skinny tube (nobody mentioned this necessary condition) and put salad oil in first, alcohol stayed on top. The Claire-Danielle-Lise group said the oil was "a barrier," and this was generally accepted, along with the observation that other liquids show that characteristic--liquids went right through them to their proper places. (I do not recall who introduced the terminology of "proper places," but chances are

that I did, since it is probably an anglicism.) After this evening's work, the class did have a general idea of which liquid went where.

In spite of this notion of proper places some wondered whether one could make alternating bands of alcohol and oil. Some wondered whether, if one used a great deal of a liquid, it would sink down underneath a liquid that it otherwise floated on. Some thought this would not happen. I did not make note of their reasoning.

At the end of the discussion, Evelynne said she did not see why weight mattered with liquids and not with objects. This was the first time I was aware of anyone (with the possible exception of Ingrid in her molasses work) thinking in terms of weight. Not thinking to ask what she meant by that--what made her think the weight mattered, since nobody had weighed anything--I said, instead, that hers was just the question to leave on, and we did. Nobody, all evening, had tried to float any solid objects.

FIFTH WEEK:
We Become More Familiar
with the Liquids, and
We Dry the Wood

The waterlogged wood remained submerged--floating neither in its salt water nor in new water. Most of the group--especially Danielle--expressed a good bit of skepticism about why on earth it would. It seemed to me that Pierre was confused about whether he thought it was the water *in* the wood or the water *around* the wood that had to be changed. Danielle said that it didn't matter what kind of water was in it, there was water in it, and that's why it sank. Someone else, again, compared it to wood on the bottom of rivers and lakes. Pierre again observed that that wood is rotten; and said it *does* matter what kind of water is in the wood. If the water was oxygenated, he said, our piece of nonrotten wood would float. Then, Lise said, this piece of wood, once dried out and floating again, would stay afloat provided its water was changed every day, or stirred, or had air blown into it. Pierre and many others agreed that this would be a test of his ideas. So they set out, now, to dry it, after first weighing it wet, out of general interest in the comparison of its wet and dry weights. Claire and Henri did the weighing.

In the interests of having the class develop a yet more solid feeling for the buoyancy of different liquids, I directed their attention to eight different questions:

- Confirm the proper places of these liquids with respect to each other
- What is the lowest possible place for salt water--that is, when it is as salty as it can get?

- Which liquids form barriers and in what conditions?
- Which liquids mix with each other?
- Which liquids do the various solid bits float on?
- Does the amount of a liquid influence its proper place?
- Can you make alternating stripes with two liquids?
- Evelyne's question: how come we talk about weight with liquids, when we ruled it out with solids?

Other questions arose, of course, both in individual work and in the discussion. These involved the difficulty in separating certain liquids from oil, if they had been thoroughly shaken; characteristic ways different liquids move; curving interfaces; whether colors leave one liquid and enter another; whether molasses is after all a liquid or not. What about jam? What about sugar? What remains of various of the liquids after evaporation?

At one point, Evelyne had a container in which some drops went up and some went down, through a middle liquid. She thought that what went up were air bubbles surrounded by alcohol and what went down were air bubbles surrounded by syrup. Pierre, working beside her, was maintaining that they were solid drops--without air in the middle. His major reason was that if it's air, it can't go down.

Henri reported that he had worked on trying to alternate layers, working with syrup and salad oil. While on the whole the syrup settled under the salad oil, a slim amount of syrup stayed on top. He had tried to thicken that layer, but it never got thicker; as he added syrup, it went down through the oil, leaving the small amount on top. It was unclear to inspection whether this was a thin layer, or simply a ring around the edge of the tube. He had concluded that it was a layer, because when he posed a grain of rice in the middle, it was braked, before it went rushing down through the oil. In a tube of oil alone, the rice grain went immediately rushing down.

According to Henri, the grain of rice went through the oil and came to rest on the syrup. As we passed the tube around, however, it went on down through the syrup to the bottom; Colette spent some effort trying to get it back to rest on the top of the syrup.

Claire, Danielle, and Lise tried floating different objects in different liquids. They prepared a set of plastic cups, each with about an inch of one liquid. They were disappointed, in general, not to find more differences from one liquid to another. Perhaps due to

this dull outcome of their well-planned investigation they began, after a while, to use grains of salt as objects, and drops of liquid, also. They seemed to acknowledge at the end that they were changing the liquid when salt or other liquids dissolved in them, but as they worked they were giving no thought to that fact.

Ingrid reported that salt water could be made to be heavier than liquid detergent, but not heavier than syrup. In her tube which contained, from bottom to top, syrup, salt water, detergent, and fresh water, she dropped grains of salt, attempting to make the top layer slightly salty. It failed to work; the grains went right down through all the layers.

Colette, working to establish the liquids' proper places, first poured alcohol followed by mineral oil, and then poured mineral oil followed by alcohol. She convinced herself that alcohol stays on top. She then poured equal quantities of six liquids--syrup, ink, water, alcohol, salad oil, and mineral oil. She didn't give an explicit reason for comparing equal quantities, but it was a first, even if tiny, step in a direction that led to important consequences later. There was a visual elegance to the array, even though three of the liquids mixed with each other. She had, from bottom up, a layer of syrup, an obviously triple layer containing a mixture of ink, water, and alcohol, a layer of mineral oil and a layer of salad oil. Its orderliness was very appealing.

Just before leaving for the night, Pierre tried to float the waterlogged wood, which seemed dry. It sank, in tap water, but slower than it did when they first tried it, he said. Claire had weighed it part-way through the session. It seemed dry then also, but there had been no difference in the weight.

As we left, Jacques said we should get a physicist some day, to answer all this. I said--with considerable hubris, considering that I have no physics training--that I thought we could answer most of it ourselves.



SIXTH WEEK:

We Get a Physicist and
Narrowly Escape
Disaster

"Zut, alors! Robert a tout fichu en l'air tout ce que j'essayais de faire avec Pierre." (Translation: *"Zut, alors! Robert totally wrecked everything I was trying to do with Pierre."*)

Robert was a physicist friend and colleague from a French university who was himself interested and engaged in working with teachers on the teaching of science from a Piaget perspective. We had often talked about our pedagogy. Specifically, I had been telling him about the investigations of this group, week by week. I knew our pedagogical approaches were different, but I had not realized how little he understood of what I tried to do. It did not occur to me to give

him special instructions about how to behave this evening, especially since I had told him about it each week. As I introduced him to the group, I said I was asking him to promise not to *explain* anything, but that was the extent of my instructions.

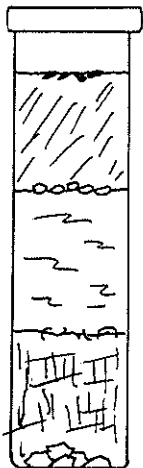
Pierre spent the whole of the experimental period glued to the side of Robert. I do not know what he asked nor what Robert said, but there was a lot of questioning and explaining taking place. My attempts to break them up became rather comic. Once I said: Don't sit here next to Robert, he'll lead you into conversation. Robert said, "I didn't say a word, it was him." I said, "I know, but he's my student. I want to be polite to him." Jacques found that very funny. I think it was he who most appreciated the comedy of the evening.

In this session I wanted them to work more systematically with solid objects. I had prepared a tube with liquid detergent, mineral oil, and alcohol--three liquid layers, with solid bits at both interfaces, as well as on the top and on the bottom. They liked it a lot. Rather than asking them to try to do something similar, I gave them much more focused instructions. Most of them had not yet paid attention to the fact that a given solid object might float in one liquid and sink in another. I knew what complications arise with more than one liquid at a time, and judged that the previous two sessions had been amply characterized by such complications. Now I wanted the activity to be simple enough to provide some regularities. I asked them each, or in each group, to take one liquid, and classify the solids as to whether they floated or sank in their liquid. Halfway through, I asked them to do the same with a second liquid.

I had told them to use yogurt containers and everyone did but Pierre. He used a test tube--I presume because it seemed more scientific. As a result, the small objects had no room to pass each other; everything stuck together in the oil and his findings turned out useless.

Right at the beginning of the experimenting, he put a piece of chalk into his liquid, and while it sunk a trail of bubbles rose to the surface. I asked him where he thought they came from and with a characteristic little smile, which indicated his unhappiness with not knowing for sure, and addressing his words to Robert alone, not to me, he said, "It's a chemical reaction of some sort, isn't it?"

Near the beginning of our summarizing discussion Robert intervened to ask what I meant by *proper places*. Was it Aristotelian? I said it was our terminology. He said, yes, but for what? I produced an account which satisfied him, but I was rather short with him, which I did not feel good about in the context of the



class. In general, instead of trying to explain to him what we were about while we were about it, I tried to proceed, cutting him short in order to minimize the damage, intent on telling him afterwards what a nuisance he had been and why.

A number of kinds of solid bits had behaved inconsistently, and we had difficulty deciding where they belonged--matches, straws, wood, aluminum foil. The best discussion concerned the question of what might make an object not go to its proper place: it might be pushed by another object on its way to a different place, and then caught there; there might be bubbles attached to it; it might have a coating--*une carapace*--around it of some other liquid it had traveled through; sometimes they stopped at the surface of a liquid, unless you pushed them through it.

I asked them to go back to working out the four troublesome kinds of solids, with these factors in mind. They worked for some time, but without conclusiveness. Many of them worked with aluminum foil, and it is the hardest material of all to understand. A sheet is so thin, it does not break through the surface of the water, and a ball is full of airpockets--so in both these forms it stays on top of water, though the proper place of aluminum is on the bottom. Some class members were led to speak again of the bearing surface.

Nobody ever drew a connection between the aluminum foil, floating needles, water bugs walking on water, and their observation that sometimes solid bits stayed at the surface of a liquid unless you pushed them through. With hindsight, I now wish I had drawn more attention and thought to that phenomenon right there. We never came back this close to surface tension.

This part of the evening's work then did manage to establish, in spite of a few confusing contradictions, the idea that both liquids and solids have their proper places in the floating order.

We then moved on to the now-dried piece of wood. Henri and Claire weighed it, as we all watched, putting the dry wood on one side and its wet weight (measured in unit pieces of steel) on the other. The equal arm balance thudded down on the side of the wet weight. Whereupon Robert said that he had changed the hole in which the balance arm was suspended--just to give us pause about taking a balance for granted! I put it back, saying curtly that we would study balances another time. (In a parallel class, in fact, during these same weeks, balances were the subject of an equally lengthy and perplexing study.) The corrected balance still showed a clear difference in weight between the wet and dry states of the wood. Henri had the nice idea of finding the amount of water that cor-

responded to the weight of the steel; it amounted to about half a yogurt container. Some had thought it would be a great deal more than that.

It was my suggestion then to attach the weights to the wood, to see if it would sink. It did, but not with a thump, as one of the class pointed out. Someone said that that was how it had sunk when they first took it out of the water, but I am not sure that was true.

I had the idea of floating a fresh piece of wood in the old water, which we had kept. Everyone, including Pierre, agreed that that would be a test of Pierre's hypothesis that the wood had sunk because the water that it was in lacked air. We found a piece of the same kind of wood, and it floated. Nonetheless, great lengthy discussion ensued about various kinds of water and their role in floating wood! And that became the very worst part of the evening, from my point of view.

If there is any basic principle in my teaching this way, it is that people are to feel free to express their thoughts about what is going on and why, and that those thoughts are to be taken seriously. Now a number of the ideas that had been put forth throughout these weeks were quite fanciful, but we had always given them due attention, and tried collectively to devise experiments that would check them out. Robert, on the other hand, referred to several ideas as harebrained--*de la fouthèse*. At the same time, Pierre's ideas, which were the most muddled but the most couched in scientific-sounding words, he reinterpreted until they made sense; and then he gave them his support. I was too distressed to follow, let alone remember, what was said.

I did make some efforts to redirect the discussion, which included asking the group what they thought of as the proper place of this wood--floating or sinking. This approach, however, led to no great insight. They compared the situation, quite properly, with chalk, which floats for a while and then sinks, and said that one would have to know the time scale involved to answer the question. When they reached this point, Pierre seized the occasion to say that time was working against his hypothesis; no failures could be taken as conclusive because they were being carried out in a short time scale.

Near the end, Robert asked to say two things. Hoping that by then he had seen enough of my approach to be judicious in his remarks, I gave him the floor: I was wrong. First he lectured the group on how it was all very well to do experiments, but not good enough if that's all one did. The point of experiments, he went on, is to check a hypothesis; Pierre

has hypotheses, which makes the experiments they give rise to worth doing; but most of the rest of the class . . . Again, I wished he would go away. I did not try to develop my view that before you can form a hypothesis you have to explore, developing the familiarity out of which hypotheses can grow; that the trouble with the science most of us have learned is that it is made far too neat--neat hypotheses, neat formulas, neat answers--before we have any sense of what the questions and perplexities are, so the science we learn never touches what we think about the world around us. Nor did I point out that Pierre's hypothesis was his greatest liability! In contrast to the other members of this group (but in common with large numbers of people), Pierre didn't want to acknowledge that he didn't know, and he had a hypothesis wonderfully suited to that purpose: if an object floats it is because it has enough air in it; if an object sinks it is because it doesn't have enough air in it. He could explain anything. And, at the same time, he could hold himself back from any perplexities that might lead him to figure out something new. My hardest job of the year was to move Pierre beyond that hypothesis. I wished Robert would go away.

He didn't, however. As his second point, he described a procedure for finding the density of flour. Now nobody had mentioned density all evening--neither the word nor the notion figured yet in our talking about the issues. But he hadn't noticed this. *He* understood that a key to our questions was the notion of density, and he wanted to tell about a neat technique that involved that idea--whether or not it had any relation to floating and sinking. (It didn't.)

I was, again, beside myself at this intrusion. This group of intelligent and willing adults had spent six evenings working towards an understanding of floating and sinking. It would make all the difference in their feelings about the accessibility of science if it were their *own* ideas and explorations that took them to this understanding. If Robert, discussing his fancy technique for establishing the density of flour, took that possibility from them, convinced them that they should have known all along that it was a simple matter of *density*, they would lose most of the benefit of their struggle.

I was also beside myself when, in the course of his account, he described how wood, with its fibers and open tubes, differed in structure from styrofoam, with its closed air pockets. (I had told him, in week-to-week discussions, about the attempts to squeeze the air out of the styrofoam.) "*Merde, merde, merde,*" is the close of this paragraph in my notes. And I would not know until the next session what the effects of these lectures had been.

But a better moment arrived even before the evening ended. Robert based part of his explanation on the formula $plvl=p2v2$. All of the class (I expect Pierre was an exception, but I did not make note of this) had the confidence--which I like to think came at least in part from their experience in this course--to admit good naturedly, if with some small embarrassment, that the formula meant nothing to them. Robert was astonished. Hadn't they taken physics? Of course they had! The formula nonetheless meant nothing to them. Robert explained it and continued his account, but it was not clear that any of them followed it.

Later in the evening, during the part of the class that dealt with their work with children, Henri gave a long statement on the virtues of "this method" compared with "the other method," and he referred to Robert's formula as something which they had all learned at some time by lecture and memory.

At some other point in the evening Jacques made a comment to the effect that experimenting was better than lectures, and Robert responded sympathetically to this criticism of lecturing, saying that what one remembered, in spoken discourse, was not what one heard but what one said. We all liked that. To me it seemed it could have led Robert directly away from the kind of explaining he was doing all evening.

SEVENTH WEEK:
I Start My Journal;
"Super Class, Super
Great Class (In My
Opinion)"

I started by telling the class how troubled I had been by Robert's visit. They were very sympathetic. Jacques said Robert was very like a Frenchman, having to show what he knew. Henri and Evelyne said something to the effect that he was always explaining, and why couldn't he not explain. Ingrid, who had left early, asked: Oh, did he finally get a chance to talk; I thought he must have been very frustrated.

I said that I felt especially bad about having, essentially, withheld from them the chance to talk to a physicist--as Jacques in particular had said he would like to be able to do. Jacques, however, hardly seemed to remember; he more or less shrugged it off. I also said that I had gotten angry at Robert afterwards for a few things; they laughed and said they weren't surprised. I said we had often talked about our pedagogy, and I had not realized that I should have explained more to him before his visit; they said it's hard to understand. Pierre unfortunately was absent this evening. (So were Danielle and Lise.)

After this discussion, I felt much better. My students seemed above all amused by the clash of fundamental views of how to help people learn science. I never would know for sure how Robert's interventions influenced their ideas about floating and sinking, but

it seems to me the net result was more confusion than clarity. He certainly hadn't made them feel they had nothing more to do.

This evening everyone worked together, standing around one high table. Colette said she wanted to do a final class with her students this week on floating and sinking, and she wanted to be ready. So we rolled up our sleeves. Henri said quite firmly, to start us off, that he believed it was air that made things float. Ingrid demurred right away; she did not think there was air in the plastic pill bottles that Colette floated. She spoke of "specific weight" (the French equivalent of specific gravity), but could not quite say what that meant.

I asked about the liquids: did they think there was more air in alcohol than in syrup. Led by Henri, they thought not. Henri said he thought that for liquids it was weight that mattered. I took a large amount of oil and a small amount of water, and pointed out that this oil would weigh more than the water. Henri then said he meant the weight for the same quantity. Colette had mentioned weighing liquids in class with her students. We never had done that in our class (she had layered equal quantities, but not weighed them), so she brought out their results. The girls had weighed one decilitre of each liquid. The order of the weights was the same as the order in which they floated on one another (with one exception). Colette was surprised; she had not noticed when her students had done this that there had been a correlation between these two orderings. The group as a whole took the girls' work as convincing evidence that weight-for-a-given-amount was the relevant factor for liquids.

I went back to whether air was a necessary hypothesis for objects. Bertrand thought that for objects it was a question of the material they were made of. I asked what it was about the material that mattered; someone suggested the amount of air it contained.

Colette very tentatively and very quietly wondered if it was the same for objects as for liquids--an object would float on a liquid if it was lighter. I asked her (since no one had heard it) to say that again. She did, but nobody took it up.

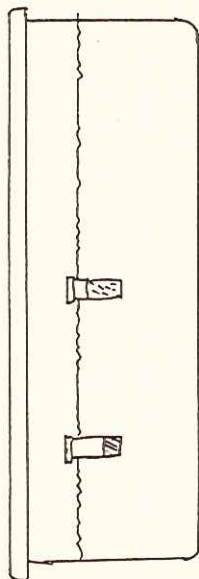
A short while later, Claire said she thought Colette was right, and I tried to pursue the idea. I brought out a balloon full of water, floated it, and asked with what they would compare its weight. This proved more confusing than helpful. Colette suggested making the comparison with the weight of the water in the pan. Others said the amount of water in the pan didn't matter.

My idea with the balloons had been vague. I was as much groping to make a connection with my students' thoughts as they were, and I moved as stumbingly toward the helpful questions as they moved stumbingly toward the helpful ideas. In any event, what I thought we needed next were two objects of the same volume and different weights. The objects I came up with were two identical and capped bottles. I left one filled with air, and put enough water in the other until it just barely floated.

I was now thinking of these two bottles as objects themselves, with equal volumes and different weights. The water in one of them was meant to make it heavier than the other, but it just *happened* to be a liquid. I hadn't meant to draw attention to the contents in their own right. However, when I asked again, as with the water-filled balloons, with what we should compare the bottle that just barely floated, it was soon clear that nobody thought of it as bottle-with-contents-as-object. It did serve a different purpose though. Evelyn picked it up and looked at it closely--clearly looking at the water, not at the bottle-with-contents-as-object. She started to say that we should now fill this bottle with the various different liquids, one after the other--and then she stopped in confusion. It was a germ of an idea, but not clear to her. Claire took it the next step. She said they should now try to see how much syrup they would have to put in the other bottle to make it also just barely float, and then how much alcohol, in yet another identical bottle. A few were about to try that, when some others said they already knew it would take less syrup than alcohol. They were about to let that drop, when I said--offhand, and really as a joke--that there would be more air in the one with the syrup. They laughed at my devilry, found this thought totally perplexing, and decided they had better do it. Lo and behold, when they did it, they both just barely floated, but one had more air! That was the single greatest blow to the air hypothesis!

Someone suggested weighing the two liquids, which led Claire to point out that this was already a balance. They had taken great pains to see that they floated at the same level (namely--just barely), and since the bottles were identical, that meant the amounts of liquid weighed the same.

While this work was going on, it became clear to me that to pursue Colette's idea that maybe it's the same for objects as for liquids, what we needed was not a just-barely-floating object, but a sinking object, an object whose weight-volume characteristics would be different from the water around it. I tossed a rubber stopper into the water, and it sank. To fol-

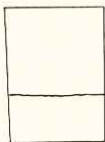


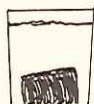
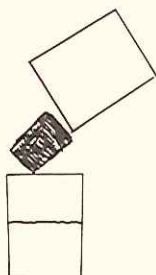
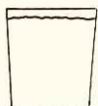
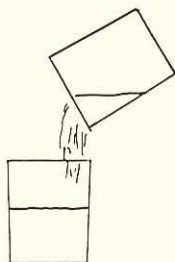
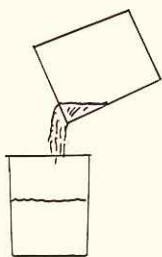
low up on Colette's idea, I asked what should we compare it with? Once again, their ideas first took off in a quite different direction from what I had had in mind. Claire remarked, as she looked at the stopper, that objects don't weigh the same in water. There was considerable discussion of this phenomenon, the nicest comment being Stuart's explanation of why a pail of water is easier to lift under water: Under water you're only lifting the pail, while out of the water, you're lifting the water, too. Jacques, during this discussion, lifted the stopper from the bottom of the pail, into the air, and said he could feel a slight difference, though he said you would need to do it with something bigger (or did he say heavier?) to be sure.

Evelyne and Colette, during this time, had been struggling together to remember what they had once learned of Archimedes' principle. Jointly, haltingly, they produced it: a body in water loses in weight the weight of the amount of water it displaces. I said to myself: Well, there it is, they've done it by remembering. But it led absolutely nowhere! Everyone heard it, laughed, and went back to work on their problem.

Claire made the first suggestion about what to compare the rubber stopper with, building on her interest in weight, and ways of weighing things. She suggested finding its equivalent weight of water, then seeing whether it floated in syrup, and, if so, finding its equivalent weight of syrup. Although I was privately thrilled by this suggestion, it was not received with much interest by the group. Some said they knew it would take less syrup than water. Others recalled that Colette had reported that her students had done something similar with three rolls of scotch tape (admittedly an unusual unit of weight): they had found out how much of each liquid it took to make the weight of these three rolls. Though Claire was hesitant about her idea, she stuck with it. Her one response to the girls' experiment was: We don't know whether the three rolls floated. It turned out that the stopper did float in syrup, and a couple of other people became interested in Claire's suggestion. Without being clear why, but, I think, with some sense it might be a good thing to do, they decided to do it. Claire did the weighing, and we ended up with syrup in one plastic cup, water in another, and the rubber stopper in a third, all weighing the same thing. People seemed to recognize that it was a neat little setup but nobody knew what to do with it.

As they were talking about it, my attention was caught by Jacques, fingering some materials hidden from most of us behind a bucket on the table, and muttering to himself. After some time, he described a





plan. In three identical goblets, put equal amounts of alcohol, and put these equal weights of syrup, rubber stopper and water into these three equal amounts of alcohol. All three will sink in the alcohol, we know, and then we can see how high the alcohol will rise in each case. Few, if any, followed Jacques's thinking. They asked: Why alcohol? Someone said: They'll mix anyway. They said: We already can see that the water will make it go higher than the syrup. What will that tell us; we already know they all have the same weight. Jacques finally convinced most of them that it was true we knew the water would push the alcohol level higher than the syrup would, but we didn't know about the rubber stopper; he thought that since it sinks in one and floats in the other, it would push the alcohol to a level somewhere between the levels of the other two. He barely mentioned volume, and nobody ever talked about a relationship between weight and volume. But he certainly knew what he wanted to do and why.

It came out very close--especially between the rubber stopper and the water--but they read it as confirming Jacques's prediction. It was a good moment.

I noted that Evelyne was still very perplexed. I did not quite follow her, but it concerned trying to keep straight the idea that, of weight and volume, one was kept constant across these three items (syrup, rubber stopper, water), and the other went in an ordered series, from less to more.

After much time given to considering the significance of what Jacques had done, someone (it might have been myself, but perhaps it was Claire) wondered about another object, which would float on water: Would it make the alcohol rise higher? We decided to make such an object--weighing the same as the rubber stopper--and proceeded to make it from cork and plasticene. It took some time, of course, assembling it and checking until it weighed just what the stopper weighed, and then checking to see that it floated on water. A fourth goblet with the same amount of alcohol was readied. Jacques knew that this object, made to float on water, could not be counted on to sink in alcohol, and was prepared to hold it down with the point of a needle, if necessary. The moment was even more intense than Jacques's original experiment, because by now almost everybody at least knew what they were looking for, if not why. It did sink. And when the alcohol level this time was the highest of all, the pleasure was great.

After it was done, Anna said that they hadn't needed to put the last object in the alcohol, because they knew its volume was bigger. How did they know, I asked. By looking, she replied. We took them out

then, the rubber stopper and the invented object, to compare them, and few thought it obvious. I had actually asked them, before they put it in the alcohol, whether it looked larger, and nobody had paid any attention, including Anna. I believe she had become so convinced of the idea that she simply convinced herself you could see it.

Ingrid remained perplexed: The prediction worked for that object, but why should we assume it would work for another? We should make another object the same weight as the stopper, that floats in water, but that is smaller than the stopper. That idea bore considerable interest for the group. But we had worked hard, and it was time for a break.

I noted that nobody ever spelled out what these experiments meant. There was hardly a mention of different volumes for the same weight, and certainly no mention of trying different weights of the same volume. There was just a greatly satisfying sense for most of them that they could produce something systematic and, to that extent, comprehensible. A couple mentioned that they still didn't know why the experiments turned out that way. It took another whole week before most of them could relate this elegant experiment to the other phenomena they had been trying to understand.

At the end of the class, Jacques and Colette lingered, along with Helen and Anna. I asked Colette if she was ready to put things together with her girls. She said she thought the answer was specific weight. I asked her what that meant to her. She buried her face in her hands to think; what she came up with was not clear (and I could not remember it). I asked how she now understood her pill bottles. She said something to the effect that they were light, but did not articulate light in relation to what. Jacques said: If you melted them down and made a cube, that cube would float. He said it was like the balloons--full of water or not they float, so they floated. Colette said: So the plastic floats, whether full of air or full of water. I brought out the balloons, which were still in the cupboard--one full of water, and one two-thirds full of water, but we did not get out a pan of water to float them in. Anna remembered that the amount of water in the balloons made a difference to how high they floated. Jacques said they floated at about the level of the water inside them. And when I asked Colette if she remembered how high her pill bottles floated, full and empty, she said she would have to do it again, but she thought that full of water they floated just at their caps, while full of air they sat on top. She tried now once again to say what specific weight meant to her: you have to state the weight for a cubic meter, or something. It was still

quite vague and, notably, seeking to repeat a school formula. In an attempt to turn her attention to what we had been doing, I muttered something about weight per anything, but she did not pick it up. I said that float or sink was a pretty crude measure--and also arbitrary. There was some acknowledgement of this point, but it was not a striking idea for anybody. I was annoyed with myself for not having drawn attention any earlier to how high or low an object floats.

There were two other nice insights in the course of the evening's work. They seem related, but they were separate insights coming at separate times in the discussion. At one point, in considering the ordering of liquids that float on each other, Colette said, "And air is the lightest of all."

And in the discussion of proper places, Jacques said that a balloon filled with a gas lighter than air will float up until it gets to a place where the air is not heavier than it, and then stop, having found its proper place.

This class, by the way, was the last time the word was mentioned. Colette, who had been absent last time, asked what had happened as it dried. They told her that it now floated, and that the loss of weight represented so much water. Jacques explained that they had learned about long openings in it that were initially full of air, which water replaced over time. Nobody went to look.

EIGHTH WEEK:
Lingering Confusion,
Consolidation, and
Further Questions

In this session, I was, to begin with, greatly disappointed. In spite of my knowing that structuring complex ideas is never straightforward, I had expected that last week's breakthrough would have left clear marks of excitement and understanding. Excitement and understanding did emerge as the evening went on, but things were far from clear.

Jeanne and Evelyne remarked that the last had been a tough session--exhausting. Jeanne was more confused at the end of it, she said, than before. A number of people had tried to look things up in books in the meantime, or talk to more knowledgeable friends. Colette, for example, had looked up plastic in a chemistry book, and found it contained oxygen--though she was not sure that meant it had air in it. Helen had included discussion of this problem in her weekly telephone call to Canada. She thought they were so close now that people *had* to know. (And I had gone away thinking that now for the most part they *did* know.)

Henri summarized his understanding. It had three parts: (1) one liquid floats on another when it weighs less, given the same amount; (2) for solid objects, the relationship between how big it is and how

heavy it is matters; (3) the amount of air matters.

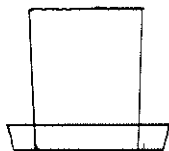
Considerable discussion followed about the role of air before Jacques said he thought he could account for everything with one hypothesis. He said it clearly--if two things weighed the same and one took up more space, it would float on the other--but he said it hesitatingly, so some did not follow him. Most did follow the second time he said it, but did not leap to agree. Colette in the meantime had also looked up specific weight in a book, and said that she saw a relationship between what she had read there and what Jacques had just said. She was able to say what she meant by specific weight this time; but of course in the standard definition, on which she based what she said, it is volume which is held constant, and weight which varies. Henri pointed that out, that it was in that way different from Jacques's hypothesis. Someone else said that it didn't matter, that it amounted to the same thing. Henri repeated his point, but agreed that it came to the same thing, and nobody disagreed.

Colette, during this discussion, said her colleague had claimed air to be important only for its effect on the specific weight of an object. She said this unclearly and nobody followed up on it.

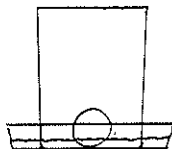
For those who had been absent the week before, I drew Jacques's experiment on the blackboard. It went slowly, but we finally arrived at Ingrid's question: Could you make an object of the same weight as the rubber stopper, which floated on water, and which was smaller than the rubber stopper? At this point everybody went to work, some on that problem, and some on more general ways they wished to check Jacques's theory.

Claire, Danielle, and Lise, with Helen watching, carried out an investigation based on one that Claire had read in a book. They had a plastic ball which they could open to fill with plasticene. This they did, then weighed the ball, put it in a container brimming with water, gathered the water it caused to overflow, and compared the weight of that water with the weight of the ball: the ball weighed more. Then they removed some of the plasticene, until the ball just barely floated, and found that it now weighed the same as the overflow water.

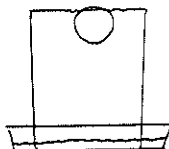
The third phase of the experiment was a little confused, I think. When they removed the rest of the plasticene, and the ball floated high on the water, it displaced less than its whole volume. The book talked of weighing the amount of water that the ball now displaced, but this had, so far, no basis in anything that they had done, nor in any of the questions that they had had. That led to some confusion on their part about what they were doing, why they were doing



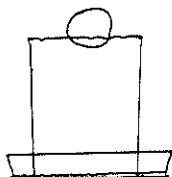
it, and what they might expect to find. I believe they were weighing the amount of water now displaced by the floating ball and expecting this water to weigh more than the ball, confounding the book experiment and Jacques's experiment. And I believe that they convinced themselves that that was the case--not hard to do with the difficulties of accuracy presented by a small high-floating object and a wide container.



Jacques chose to check his theory with a ball of aluminum foil. I was annoyed at his choosing this odd-ball item, and it was problematic. But using a vice to squeeze out enough air so it sank, and using a narrow test tube so a water rise would be most easily visible, it did confirm his predictions.



Pierre was more interested in talking out ideas than in experimenting. He also seemed to feel a bit lost. He engaged Stuart and me in a discussion of the nature of density. He said: We are 15 people in this room. That's the density of people in this room. I said: That's the number. He said: But take another room, with a different number of people, that would be a different density--the number of people for the surface, that's what density is, isn't it? So we can say the same for objects, can't we? That's why there's more weight for the surface. That's why they can have the same size and one be heavier--it's denser. At one point, when he took a hollow plastic ball and spoke of the amount of matter for the surface, I finally exclaimed, "for the volume!" He said, "Yes, surface or volume." "It's not the same thing," I said, and he replied, "Yes, volume." I was not sure what that meant to him.



Pierre was working hard here, not trying to keep uncertainty at bay by using good words. But I was extremely tired during this class, feeling neither patient nor inventive, and unable to find the ways to help him think through the ideas he was finally grappling with.

Pierre was also concerned with experimental issues. He said you can never do a proper experiment, never check on what makes it float, because all the factors are intertwined; you can't keep both weight and density constant and change only volume, for example, so you can't do a well-controlled experiment. He and Stuart kept up this discussion as I left, Stuart developing the view that you could nonetheless do a well-controlled experiment.

The most intriguing set of experiments was the work carried out by Evelyne, Henri, and Jeanne on Ingrid's question: Could we make an object which floats on water and which takes up less room than its equivalent weight of water? First they used a snail shell, stopped with plasticene, and floating. It

turned out to be bigger than its equivalent weight of water. Then they tried to make many objects smaller than the snail shell, which would also float. They tried cork with plasticene, styrofoam with coins, cork with coins. All of them, at the same weight as the snail shell, and smaller, sank. I overheard many statements that started, "What we need now is . . .," and then responses of two sorts--either no, then it would be too big, or no, then it would sink. Henri concluded that it was impossible. Jeanne and Evelyne held the opposite. Jeanne exclaimed, "Everything's possible in science." She considered that they just did not have the right materials; they needed the right kind of plastic--like Colette's pill bottles.

After this working time we assembled again, and this second discussion was rather more encouraging. At the beginning of the discussion several people said things were clearer now. Jeanne volunteered that she now understood Jacques's experiment. Ingrid said very slowly and hesitatingly approximately what Jacques had said at the beginning, adding that it depends on the liquid. Again, she had to repeat it for people to follow what she was saying, but then many indicated agreement. She herself was very surprised that it depended on the liquid. She had not seen the point of doing different liquids until last week; she seemed quite moved by the depth of her present understanding of this matter.

Lise, at this point, said that it does *not* depend on the liquid, and a very long discussion ensued in order to clear up that disagreement. It turned out that Lise was referring to the fact--which came to her group as a surprise--that the plastic ball, submerged, displaced the same amount of liquid in syrup or detergent as it did in water.

In the course of that discussion, in listening to them describe their experiment, Ingrid predicted that an object which just barely floated would weigh the same as its volume of water. She was delighted that their experiment confirmed that.

Jeanne, Evelyne, and Henri described their attempts to make an object that floated on water, and which took up less room than its weight of water. I asked the whole group who among them thought it was possible: only Jeanne and Evelyne did. They were doubtful about it, given everyone else's views, but they did not see why it couldn't be done.

I asked Henri what he thought now about his three hypotheses. He still thought they were right, and he repeated them. This time, the weight-volume relationship was stated clearly, and the air hypothesis became, "and then if there is more or less air, that makes a difference to the weight-volume." He thought, too, he

could take any object now and predict whether it would float or not: weigh it against water, then put it and the water in equal amounts of another liquid and see which takes more room . . . and so on. There was general agreement.

Jacques and Stuart both seemed clear that the air hypothesis was unnecessary. Jacques said it quite clearly: It was taken care of in the weight-volume relationship. I did not sense a universal rallying round, but a general sense that he was probably right. We kept coming back to it though.

Ingrid, who said that until now she had never understood the balloons--they were heavy, so why didn't they sink--came back to them in this final discussion. She quoted a girl in Jacques's class, who had said, "Water goes with water and the balloon floats." She had not understood at the time what the child meant, but she did now, and liked it a lot. Jeanne admitted she did not understand that, so we brought out the balloons again. Watching them float at different heights, according to the amounts of water and air in them, everybody came to understand what the child meant. They noticed again that the water levels were even, inside and outside of the balloon. They noticed also--it was the first time it was mentioned--that the air was always at the top; Stuart said, "air floats," which they liked. Ingrid said that if the balloons were filled with syrup, instead of water, they would sink. And full of oil? They would float, but higher.

And what if there were a void inside, Ingrid now asked. I took a capped jar, full of air, which floated, and asked what it would do if we removed the air. Most people thought it would sink. They mainly seemed to agree it would weigh less, but thought it would sink anyway. Claire gave the major clue to this reasoning: she thought that perhaps the volume would now be different. I did not find out for sure what she meant by that, but my sense is that it is some view of volume that takes into account how much of the volume is filled with matter. If a jar has air in it, then the whole system is full of matter, and each part of the system takes up space. If it doesn't, then the inside, left to its own devices, would not take up any space and the only *volume* is that of the glass itself, and of its cover. It is a notion of volume partially contaminated by a notion of density. (This interpretation seems to me consistent with the way everyone looked at the bottle I prepared in the previous class--the bottle weighted with some water, which I had intended to be seen as a single object, bottle-with-contents. Nobody thought to look at that as a single object, having a weight and a volume--the contents demanded too much attention in their own right.

Ingrid tended to think that making a void would be changing the conditions enough so that a different theory might be needed; after all, theories hold in certain conditions, and often you find that outside those conditions they must be modified.

Jacques predicted that it would still float; he fit the situation easily into his general one. But apart from him, and perhaps Stuart, there was no certainty, no way to think about this question.

At another point we had a small glass bottle which, filled with air, sank. Someone suggested filling it with styrofoam instead, but everyone agreed--I noted that Jeanne was among the most adamant--that it would not float then either; it would be still heavier.

Pierre continued to struggle with the air hypothesis: Couldn't you say that air had something to do with it, more air floated more? Jacques made a very clear statement to the effect that it simply wasn't necessary, with which I finally allied myself. Pierre turned out, however, not to have been swayed.

In one of the last points of discussion, we came back to boats. Claire asked how come plasticene sank, in a ball, but floated when posed on the water shaped like a boat. Then she answered her own question: It's now taking up more space in the water. Everyone seemed to understand and agree, and she was very pleased with herself. It seems to me now that this would have been a good time to ask her again what she thought about the volume of the vacuum jar, but I missed it at the time.

It is only now--while working on *revisions* of this account--that I have noticed that, with the exception of Robert's lecture and Pierre's solo discussion, the word *density* never appeared. *Specific weight* did. But whenever anyone referred to Jacques's experiment and the relationship between weight and volume, the term they used was *weight-volume*. I do not even know whether Pierre knew that weight-volume was density, and wanted to understand that better; or whether density represented something different for him. I have the same question about what Lise wrote in the *Postscript* that follows.

So the group "invented density," but gave it their own name! I expect that at least some of them did not know that what they had invented was the idea of density; and that the word *density* still represented for them something else, that they may or may not have thought they knew something about. I wish I had caught onto that in time to say simply, "What we've been calling weight-volume is what is ordinarily referred to as density."

Postscript

A few weeks later each of the 10 regular participants wrote a brief paper about their learning about floating and sinking. I use these to try to state where each of them now stood.

Claire, Danielle, and Lise all seemed to have internalized Jacques's experiment (to which, of course, Claire had made a major contribution) and to feel they had gone one step further with their experiments the last day.

In addition, Danielle wrote of her understanding why a small jar sank while a large jar floated:

I found that strange, and was sure that it was because there was a lot of air in the big one, and less in the little one, but I couldn't go any further. Then we left that, to work on the "proper weights" (sic) of liquids: we came to realize that the weights of the liquids, in relation to the volume they occupy are different according to the liquids, which implies that they can float on each other. So, in alcohol, the lightest of all the liquids that we saw, objects float, but less well than in water, which is heavier in relation to the volume it occupies. I thought then maybe, in spite of the air in it, the big jar would sink in alcohol, thus, that there was a parallel to make between the weight in relation to the volume of the object and the weight in relation to the volume of the liquid.

Claire wrote a wonderful account of the ups and downs of her coming, once and for all, to the conclusion that the bearing surface is *not* a factor in floating. Lise wrote of the same issue (referring to the same experiments they had done together) in slightly different terms:

In retrospect I realize . . . that in fact the shape doesn't change anything about the property of the object. If the volume is the same, the shape can be as different as can be and that doesn't change anything; it's the law of conservation of quantities. For a given volume, we can give it any shape, and that will not change anything about its property, if it floats, it will float, even with another shape, etc.

Here is what Lise wrote about density:

If syrup is heavier than water, we know that it has a greater density than water . . . but in fact why is it so and what exactly is density. It seems to me that we never talked together about what density represents.

Colette described four stages. (1) "*Fog*: what are we looking for? What is expected of me?" (2) "*Clearing*: enumeration of different factors . . . and verification of their relevance." (She wrote, "I was able . . . to assure myself that none of these factors alone was the cause. I confess, however, that for a long time I attributed a predominant role to air.") (3) "*Confusion*: the appearance of terms and principles from physics, and the impossibility of relating them to the factors we had been working on." (4) "*Comprehension*: but I must admit that I am not sure that I would have reached it without the theoretical explanations I was given."

For Evelyne, comprehension did not come. Here is part of what she wrote:

Everything went well until the second last lesson. The more I manipulated, the more I was satisfied, and the more I had the impression that all these different approaches would soon lead me to understand the problem of floating. Yes, I would have liked to consult books and good old Archimedes was in my mind. But each time I decided against it because I was afraid I would lose my ardour for manipulating, and would fall back into book knowledge. This concern was accentuated when our visitor chose to dazzle us with p1v1=p2v2.

At this time in December I felt generally that I was becoming less receptive, in the class and elsewhere. And when Jacques had a wonderful idea, it certainly was that for him and maybe for others (c.f. Henri), but for me it was the coup de grace. In an instant, everything collapsed and everything I had brought to bear in the preceding sessions was wiped out. I had the impression that all was but wind.

In the disorder, Henri tried to help me out, but no matter how much he explained to me, made me drawings, and repeated it to me in different forms, nothing was internalized. I seem to understand for the moment, but when I have to re-explain it, I get muddled, and nothing is coherent any more . . .

I will not try to analyze whether or not the situation causes me anguish. Personally, it doesn't discourage me at all. It is perhaps the best proof that I still need time to continue to manipulate, while I try to form hypotheses. Because while in the first session I was able to play without any clear goal, now I feel very deeply the need to know what I want to [know]. So now I have to begin to form hypotheses, so I can verify them. All this will make me relate my different manipulations to each other, so as to find the link among them.

Evelyne was right about Henri. He wrote:

The first time, it seems to me, that I began to feel an answer to the floating problem was when Jacques Bonnard did his experiment with the stopper, syrup, water, and alcohol, and he observed, at equal weights, the volume of the first three in alcohol. This clicked for me. From then on I only tried to confirm or invalidate what appeared to me.

He gave an extremely clear account, with no mention of air, of how to predict whether a given object will float in a given liquid.

Jeanne wrote little about what she now felt she understood of floating and sinking (she wrote more about pedagogical insights). But she did write the following:

These discussions, above all the ones before Christmas [the two last], were for me steps forward. My mind was sometimes completely muddled and then the next week glimmers appeared. For example, after Jacques's experiment I was disequibrated and the discussion the next week was helpful. My mind became clearer and it seemed to me that I took a step forward in my understanding. I have the impression of having understood . . . why one object sinks and another floats.

She also had the following interesting comment:

I have opened my eyes to a lot of notions that hadn't interested me before. For example: why in a mountain chalet does the condensation form on the outside window, while in my Geneva apartment it forms on the inside window? One question leads to another and another. You start asking about everything.

Ingrid wrote:

I think that alone I never would have taken the next step. I do not remember how we came to the idea of weighing the object and taking a quantity of liquid that has the same weight as the object and seeing whether the object has a greater or smaller volume than the quantity of liquid and thus predicting whether the object floats or sinks.

She was the only one who referred to the aluminum foil, and acknowledged not understanding phenomena which in fact, though she did not know it, depend on surface tension.

And Pierre? Here is some of what he wrote:

In the beginning I had ideas stemming from previous personal experiences and physics courses in high school. I have to say that these ideas have not changed; rather they were refined, reinforced by becoming more real as a result of the manipulations during the course.

As the sessions went by, I was more and more convinced that the phenomenon . . . results from a set of intertwined factors and that it was just about impossible to isolate some factors without bringing in others. This was also confirmed for me by our physicist-visitor.

Currently, as far as the experiments carried out in this course are concerned, it seems to me that the factors involved in floating/sinking are the material the object is made of, the air it contains, the form and the mass of the object. When I speak of the form, I am thinking of a very thin needle . . .

Thinking back on everything I've done, I note that I observed many things, but I don't have the impression of gaining understanding of fundamental aspects of the phenomenon of floating.

Jacques I have saved for the end. He wrote at length about the phenomena which particularly caught his interest (starting with the rubber bands), and how they affected him, before moving on to consider the effects of working as a group:

The experiments of the others, their discoveries, their conclusions, the discussions that we had at each session were for me the stimulus to keep going with the search, the opener of new tracks to follow, the confirmation or disconfirmation of my own findings.

His inclusion of details of time and place, as he closes this section, makes it sound like a moment of historic importance:

And I think that if, the 13th of December, 19__, in the Dacha [our small classroom building] between 7 and 8 p.m., everyone present (at least I hope so) came to grasp the principle of floating, we can attribute a part of the success to each of us.

And after considering many of the elements which went into the class and his involvement in it, his final paragraph expresses again his own excitement:

Each Tuesday evening, all propositions, good or bad, right or wrong, could be made, and never was any value judgment brought to bear on them. Everyone had the occasion to have wonderful ideas and to be proud of them. To the point (please forgive me if this appears somewhat presumptuous) that I currently have the very validating feeling of having myself discovered the principle of floating.

Commentary

This story tells how much there is to learn about knowledge from people who are in the throes of learning, developing their ideas in public and out loud.

- It is significant to me that the work was characterized as much by feeling as by ideas. Playfulness, mystification, laughter, excitement, frustration, trust, confusion, fascination, determination, aesthetic appreciation, enjoyment of each other--all of these were involved in keeping the work going.

- I was impressed that the knowledge was clearly a collective construction, extending even as far as to include some of the group members' students. It was not simply a matter of pooling results. It was far more a matter of intellectual exchange in the search for understanding--an exchange in which one person's idea stirs another's. The seventh session is the most striking example of this kind of reciprocal stirring of ideas, but it characterized each session, and Jacques's closing comments speak to it eloquently. Often the contributions are made backwards or sideways: one person's idea is not immediately taken up as such, but suggests something else to another. Piaget speaks of *tatonnement*, groping towards an understanding, with stabs in a general direction, guided on the one hand by some feeling about where things aren't quite working right, and on the other hand where there is some familiarity with something you know. Transferring back and forth among different minds, the process is more visible here, and there are more different sources of tentative ideas to try out, but I think it may be very similar to what takes place within one mind.

- I am just as interested in following an individual's particular ways of getting a handle on the ideas. Not knowing week by week what would turn out to be significant, I missed many individual continuities, I am sure. Two of which I took some note both concern Claire. There was her preoccupation with the shape of things, and whether the bearing surface played a role. With-

out comment in the first class she tied a knot in a floating rubber band. Again without comment in the third class, she tied a knot in a balloon. And in the last class, she was the one who questioned, and then figured out for herself, cases in which a change in the shape does make a difference--when a ball of plasticene is reshaped into a boat, for example.

Her *continuity* was expressed again when she gave particular attention to ways of weighing things, and circumstances when weighing might be an important thing to do, starting, I think, with wanting to compare the weight of the wood, wet and dry.

• I am impressed that *right* ideas are so meaningless and hard to recognize before the frame has been built into which they can fit. There was Colette's "maybe it's the same for objects," to which hardly anyone paid any attention; there was the recital of Archimedes' principle which made no connection whatsoever with anything they were thinking or doing; there was Claire's idea of making equal weights of water, rubber stopper, and syrup, which nobody found interesting; there was Robert's entire lecture about density; there were the various things that they read in books, or that friends and colleagues explained to them. A special case is that of *critical* experiments that turn out not to be critical. In the first class, we conducted a critical experiment to see whether a larger container of water could float an object that sank in very little water. The object sank, but the question kept coming up for weeks. In the sixth session, everybody agreed that a certain experiment would test Pierre's hypothesis that the wood had sunk because there was no air in the water in which we tried to float it. But when the experiment was done, the results gave rise to endless interpretations.

Perhaps the most dramatic instance of a critical experiment not being critical was the supplement to Jacques's experiment, in the seventh and eighth sessions. The prediction was that an object of the same weight as the rubber stopper, that floated on water, would take up more room than the stopper, and more room than its equivalent weight of water. For those who followed the ideas, and had some way of understanding the point of his experiment, it was an exciting confirmation. For those who did not, it proved nothing: It worked for this object, why should we believe that it will work for any other? The same reasoning applies, I think, to every critical experiment for which the ideas are not ready, including the two other examples above: It worked this time, but why should it work another time? And Jeanne exclaimed, "Everything's possible in science!" This has some es-

*Barbel Inhelder and
Jean Piaget, *The Growth
of Logical Thinking*
(New York: Basic Books,
Inc., 1958).

stantial similarities with a five-year-old's search for reasons why some objects float: this one floats because it is big and strong enough; this one floats because it is small and light enough. Each instance is a case apart, when the unifying ideas are beyond you.*

Here, in these examples, is powerful evidence of the inadequacy of empiricism as a theory of knowing. The critical experiments themselves cannot impose their own meanings. One has to have done a major part of the work already, one has to have developed a network of ideas, in which to embed the experiment. Jacques himself is the best example of this--he did the major part of the work in his mind, assembling the ideas which his experiment then could confirm (and I wager that if the experiment had not confirmed it, he would have redone it until it did)--and he was the only person for whom, when he first did it, it meant anything.

• What I have described so far are some general phenomena, not specific to this topic. I am also intrigued by specific ideas about floating, sinking, and density that came up in this study. I am intrigued, for example, that Jacques's invention took the form of holding weights constant and comparing volumes. Was that largely due to the circumstances of the activities we pursued, or is the notion somehow more readily apprehensible in that form than in the standard, "measure out equal amounts and then weigh them"? For the liquids, measuring equal amounts is pretty simple, and this procedure did occur both to this group and to Colette's girls. For solid objects of random forms, measuring out equal amounts is no easy job. The liquids served as an intermediary, first for finding equal weights, and then, after one more step, for finding equal volumes.

It started when I chanced to put different liquids in identical pill bottles to make two objects of the same volume and different weights--starting from the classic way of thinking about density. The liquids in the bottles weren't meant to be the object of attention; they were there only to influence the weights of the bottles. Evelyne then had the idea of comparing liquids in some way by using them in these identical bottles. Claire had the idea of putting, in each of several different bottles, just enough liquid, a different one in each bottle, to make it float. Then another person questioned the weights of these different amounts of different liquids, and it was agreed that these different amounts weighed the same. In this way, with liquids, the idea first arose of making equal weights with different amounts. Then, later, in the presence of the rubber stopper, Claire had the idea of making *its* equal weight in different

liquids--a big step, which perhaps she was able to take because, at the beginning of the evening, she noticed Colette's wondering whether it might work the same for objects as it did for liquids.

It was after all this had been done, with the two liquids and one object of equal weight lined up in front of him, that it occurred to Jacques to look at how much room the object took up compared to the room the liquids took up.

• I am, of course, also intrigued that Jacques's experiment was so difficult to grasp, for those who had not come up with it--that is, for everyone but Jacques. What is it that is hard about putting those particular ideas together? Evelyne gives us the clue that the difficulty is in developing two systematic sets of relationships, and both separating them and integrating them at the same time. But I would like to know more about what is hard about that, and what is invoked in coordinating them together.

Reading Piaget, especially the sensorimotor books, has given me a strong sense of how coordinating ideas can be understood to be very like coordinating physical acts. Anyone who has taken a gym class or a dance class knows that getting each part of a large action going smoothly itself, and integrated with each other smoothly-going part, is no easy matter. How it all manages to come together is also rather mysterious; there does not seem to be any way to guarantee that the coordination will take place. Coordinating ideas seems to me to be just like that.

In both cases there is differentiation as well as integration. In the case of physical coordination, one of the major steps is differentiating movements from another. For example, two limbs are likely to move together, globally, when a new movement is attempted for the first time, but they move in ways they have moved before, not in the ways desired for this new movement. Elements of the original global movement must be differentiated from one another so that some of them can be integrated again in a new way.

In our case here, a global idea of *amount* must be differentiated into *weight* and *room-taken-up*. Each must be developed systematically, and each object has its rank order on each of these scales, which have no necessary relationship to each other. Then they must be integrated back together into a totally different idea from the original undifferentiated one.

• I am also intrigued with the question of the glass jar with nothing in it, not even air, and I would like to be able to check out my understanding of why they

thought the volume might now be different (see page 30), and to find out what is involved in coming to think about that situation differently.

- Something should be said about my own role. I consider that I did two main things. One was to capture the class's interest in trying to find out about something and to find ways to keep the interest going over time. The second was to encourage them to say what they thought, to express ideas in their own terms, in ways that made sense for them, to listen to each other, to take their ideas seriously and see where they led.

Capturing and maintaining the class's interest often meant taking the lead with suggestions of activities to do. I did not by any means leave to my students all decisions about what they were to do. I did not, in the first class, ask them what they wanted to learn about. I gave them materials and instructions (loose though these were) that I judged would keep them engaged (for an hour, I thought--two months was far more than I anticipated). I chose for discussion those of their activities that I thought had a chance to engage them further. In the second class, and subsequent ones, I proposed specific activities for them, of my devising, though often they were based on questions that had arisen from them. Often, the point of the activities that I devised was not at all that they *discover* anything in particular, but simply that they should keep at it, doing something, until they encountered some phenomenon that captured them again, when they would again take off on their own. Some of the activities I proposed did not work very well from this point of view; others did.

Encouraging them to say what they thought had two main purposes. One was that trying to be clear about what you think about something often helps you get clearer. The second was to encourage them to take their own ideas seriously. I have found that most adults are nervous about expressing their own ideas, especially in a realm where they are quite sure there is some appointed wisdom to which they are not privy. They think, then, that their own ideas are not worth attending to; they should drop them, and catch on to the real, authenticated knowledge. I believe, on the contrary, that one's own knowledge is all one ever has, and that the only way to develop it further is to pay attention to it, figure out what needs to be further thought about, modify it, keep striving to make it more adequate to one's experiences. But it takes work on the part of a teacher, as I was in this case, to convey that view of the importance of one's own knowledge. The best way to do it is to get to the point where they are willing to say what they think

(mainly by making it playful in the beginning), and then to make it absolutely clear that what they think is O.K. with you; that you will attend to it carefully and help them to do the same. My ways of doing this are fairly muted in this account, since what I found interesting enough to record in my notes was what they said, rather than what I said. And I do not always do it well. But it is always what I strive to do.

• I think both Pierre and Evelyne merit special mention, since in a sense one could say that this experience failed with them. To start with Pierre, he was the one member of the class who did not, at least during the first six classes, make himself vulnerable by acknowledging how much he did not know, putting forth ideas he was not sure of, asking questions which he might believe anybody else present would be able to answer, expressing his surprise. I am glad that all the other members of the class managed to resist his seeming authority, to come to their own position on his air hypothesis and the experiments he devised to support it, and to resist his use of words in lieu of explanations. I take their reactions to Robert's plv1=p2v2 lecture as evidence that they had come to realize that technical language did not necessarily represent knowledge that made sense to them. But in the process, I lost Pierre himself. I think Robert's visit probably did influence Pierre to feel that his ideas and ways of going about things were good science. Then Pierre missed the seventh class, when most of the hard thinking was done. And in the final class, where he was finally willing to struggle with ideas that he acknowledged not to be clear, I did not do a good job: on the one hand, as I have said, it did not occur to me that he (or the others) might not have made the connection between what they referred to as weight-volume, and what the rest of the world called density; on the other hand, I did not follow through with him, either in our one-to-one conversation, or in the context of the class discussion, on the ideas he was grappling with. He came a long way to get to this place, I believe, and I wish I had managed to help him realize that.

As for Evelyne, I felt very badly to read in her retrospective journal that "everything I had brought to bear in the preceding sessions was wiped out," but much relieved to read a few paragraphs later that "it doesn't discourage me at all." I am fascinated, and feel encouraged in the way I went about it, by the fact that Henri's explanations helped her not at all. I have no way of knowing what Henri put into his explanations, of course, but I imagine that they were a fairly adequate account of what he by now understood. Her own account is deeply interesting, I find. She had a wonderful time finding out about liquids and

*In fact, Evelyne's first-person account gives support to the findings of A. Karmiloff-Smith and B. Inhelder in their paper, "If You Want to Get Ahead, Get a Theory," Cognition, 1975, Vol. 3, pp. 192-212.

floating phenomena, convinced that at some point everything would fall into place. She did not herself work at how they might fall into place, developing her own hypotheses as she went, but I share her conviction that when she does, the ideas will come and the coordinations will take place.* I would have loved to be there when it happened though.

• I have one final comment. In this commentary I have pointed to some general themes which I think can be found in my story. I believe that the themes hold for teaching situations in general. But I find them far less engrossing than the specifics of the story. I do not consider such themes to be the outcome, or the results, or the findings. These are to be found in the details. General themes are easy to come by and easy to state. Specifics are far rarer. In giving this account, as detailed as my 12-hour memory allowed, I hope to make such situations, charged with learning potential, easier to recognize and to create.

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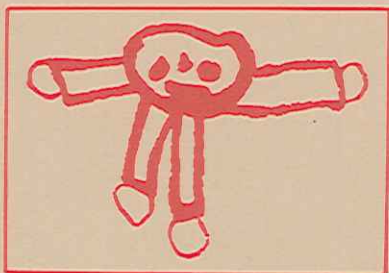
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