Perfect Circles

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One of the greatest pleasures of working in UBC's Science One and Integrated Sciences programs (Benbasat and Gass 2002) is to observe and interact with colleagues from other science disciplines in the classroom. For the one who is "up", colleagues' active participation brings an element of surprise, uncertainty, enrichment, and very often it brings challenge. For the rest of us, observing our colleagues' teaching can provide seeds for our own, and this is one of many advantages of real-time team teaching. Here I will describe one example.

Luis Sobrino was the first physicist to work in Science One, and he spent two years there before retiring in 1995. Many things about his teaching were superb and wonderful to observe. His incredibly articulate English prose, delivered in the thick accent of his birthplace in Cadiz, Spain, inspired me to use my own language more mindfully. His stories about his hero, Galileo, always captivated me, which encouraged me to inject more of the history of my own discipline into the mix. His nearly perfect perspective drawings on the blackboard amazed me, especially since so many drawings that teachers make in the heat of the moment are horrid. Yet Luis appeared to sketch them casually with no thought or planning, and no student ever misunderstood anything about any of his drawings.

And if you don't know it already, physicists and mathematicians draw a lot of circles. Most of them must simply ***call*** their drawings circles, because they are not that at all, just as most biologists must label their drawings of fish or rats before their students can know what to see in them. But Luis' circles were perfect. They had no corners or any other irregularities (their radii were constant), and it was impossible to see where their ends met. Over the months, I marveled at Luis' circles. As I biologist, I wondered how he produced them, and how he came to produce them so well.

Gradually I realized something important about Luis' circle-drawing behaviour. From my perspective, it appeared to be stereotypic. That is, Luis always drew them at the same speed, in the same direction, starting at the same position, and more or less in the same fairly large size that engaged his entire torso in the drawing. That told me that, each time he drew a circle, he engaged the same muscles, in the same way, and in the same sequence, and it gave me an idea of something to do in class.

One day at the beginning of class, I asked the students to tell me the difference between *ballistic* and *guided* missiles. After a few minutes of discussing it among themselves, they realized that ballistic missiles are classical Newtonian particles in motion; once moving, their mass, speed, and direction of motion determine where they will land. Guided missiles, on the other hand, tune their direction during flight, usually using information about where they are to guide the adjustment. We talked for a while about what physicists would have to know to aim ballistic missiles accurately, and about what kinds of information they could use to tune the trajectories of guided missiles and how they could get it.

When I was sure the distinction between types of missiles was clear, I gave a short lecture about the organization of behaviour. Ernst Mayr (1974) argued that it is unlikely that animals control complex behaviour patterns by controlling each of their component actions independently, which would require vast processing power, be far too slow, and make coordination difficult. Instead, they package the component actions into complete sequences that he called "behaviour programs" and control those as coordinated wholes. Further, he argued that behaviour programs should be expected to vary in their openness to modification during execution, and suggested two kinds of factors that should affect that

plasticity. First, he expected short-lived animals, who have little opportunity to learn from their experience, to exhibit relatively closed behaviour programs that may even be specified genetically. Similarly, communicative behaviours such as courtship, which must be interpreted and responded to unambiguously by other individuals, should also be relatively stereotyped and closed to real-time modification. In contrast, because foraging for food and avoiding predators must be performed under widely varying conditions, it must be open to modification; especially in long-lived animals who can learn from repeated experience of the consequences of executing the same basic program.

We discussed a few examples of open and closed behaviour programs, and then I asked the class whether any of them had noticed anything interesting about Luis' circle-drawing behaviour. They lit up, and all agreed that he drew the most perfect circles anyone had ever seen. Luis beamed proudly. When I asked them to predict whether his circle-drawing was guided or ballistic, everyone including Luis agreed that it must be guided to be so good.

It was more difficult for them to agree on how to test their hypothesis. Someone noted that, by Mayr's definition, guided circle-drawing programs must be open, and suggested that we could probe them experimentally with various kinds of perturbations. When a student asked Luis to draw a perfect circle slowly and deliberately, he failed, and was surprised and visibly embarrassed by that. That gave the class the sense that they knew what to do as scientists, so I turned them loose in teams to devise and perform tests of their own circle-drawing behaviour. They tried slow circles, fast circles, backwards circles, and upside down circles, and overwhelmingly they concluded that their own circle-drawing behaviour, and Luis's, was ballistic.

In a short concluding discussion, we wondered about the structure of our ballistic circle-drawing programs, and wondered how they came to be ballistic and not guided. We tried to remember what it had been like as children to learn to draw circles, and some students remarked on the head-drawing behaviour of their younger siblings, which seemed guided. That led us to the notion that programs could become progressively more ballistic with practice, and to wonder how that happens without conscious control or awareness. The discussion continued informally for weeks outside of class, and I gave interested students copies of a paper I had published on a related topic (Gass 1985). Luis was not pleased that for the next several weeks he was too self-conscious to draw perfect circles, but eventually he returned to his former perfect style and forgave me.

Literature Cited

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