FORUM ARTICLE

THINKING LIKE A FISH: CURRICULUM ENHANCEMENTS FOR INCREASED ENVIRONMENTAL LEARNING IN HYDRAULICS AND HYDROLOGY

Introduction

Engineering students usually learn hydraulics and hydrology through the lens of mathematics, learning to quantify the physical characteristics of flow. But what if they could learn about the whole concept of the waterway—the mountains, rain, trees, and floodplain—through the eyes of a fish?

In 1997, the writers began testing enhancements to an introductory hydraulics/hydrology course in the Civil Engineering Department at the University of Toronto. The purpose of the enhancements was to help engineering students understand the implications of engineering decisions on life forms in the watershed, and particularly for fish (Fig. 1). We emphasized the dependence of fish on intact migration paths, floodplain breeding, and adequate baseflows. The process included cognitive learning goals, but it also had potential for affective learning by students as they learned to identify with the needs of fish. In student responses to carefully designed assignment and exam questions, the writers looked for evidence that the enhancements to the course had made students more aware of the life context of engineering.

Environmental Caring

This curriculum enhancement project was part of an investigation into educating engineers for environmentally sensitive practice. To meet the expectations placed upon practicing engineers, engineering students need to achieve environmental learning goals that are both cognitive (knowledge-related) and affective (attitude-related). They are expected to understand how their engineering work affects the environment, and they are expected to be committed to environmental protection, even to the extent of acting as environmental advocates (*Guideline* 1998).

Similar goals, for non-engineering students, have been pursued in environmental education for several decades. There is still no consensus either on what skills environmental professionals should have or on what philosophical direction they should take (Lemons 1994). A bifurcation exists between ''knowing'' about the environment and ''caring'' about the environment. It has been argued that ''knowing''—especially knowledge based on scientific interpretations of phenomena—is not sufficient for an environmental professional, who needs to go further and develop an ''ethic of caring'' (Booth 1998). In research on the effectiveness of environmental education, the sort of behavioral pattern that demonstrates environmental caring has been called ''environmental citizenship.'' Two major variables in the development of environmental citizenship behavior have been shown by research to be ''environmental sensitivity'' and ''in-depth knowledge about issues'' (Hungerford and Volk 1990).

Accordingly, the writers looked at curriculum enhancements that could increase students' environmental sensitivity and in-depth knowledge about issues. Environmental sensitivity may be defined as ''a predisposition to take an interest in learning about the environment, feeling concern for it, and acting to conserve it, on the basis of formative experience'' (Chawla 1998). A review of the literature on environmental sensitivity indicates that this seems to be developed in childhood. The implication is that, for engineering education to produce environmentally sensitive engineers, there would need to be either recruitment and selection of students who were already environmentally sensitive, or there would need to be more understanding of, and interventions to promote, the transformation of existing attitudes during the engineering education process.

Finding no research on the development of environmental attitudes in engineering education, the writers decided to test types of curriculum enhancement that would increase engineering students' in-depth knowledge of environmental issues without limiting their response to one of knowledge acquisition. We looked for ways to present accurate environmental information while at the same time giving students an opportunity to empathize with impacted lifeforms. We chose to start with a second-year hydraulics/hydrology course in the Civil Engineering program.

The Life Context of Hydrology

Unlike many other engineering subjects, neither hydraulics nor hydrology is used solely to describe behavior within a human-made system. They can also be applied to pristine natural systems. Many professional analyses deal with systems that are at least partly ''wild.'' The wild waters are shared by humans with many other lifeforms. The writers reasoned that, if engineering students understood the needs and experience of even one of these life forms, they would have a better insight into the environmental impact of engineering work that alters hydrological and hydraulic systems.

Fish seemed like an accessible lifeform for humans to identify with. For commercial and recreational reasons, humans have a long history of observing fish behavior and preferences. Fish are somewhat similar to humans in that they reproduce sexually and can in some cases live more than a human life span. That humans empathize to some extent with fishes has been demonstrated by centuries of building fishways to help fish struggling to ascend waterways. A further indication of the value placed upon fish is that they have been the subject of numerous works of art and literature.

Fish are good ecosystem indicators. They are sensitive to a wide range of environmental conditions, including the velocity, temperature, pH, turbidity, chemical concentrations, and even the smell of the water they live in. They are also influenced by light and darkness, local populations of plants and animals, noise, water level fluctuations, and electrical discharges. They respond to unfavorable transformations in their environment by displaying distress, becoming lost, losing reproductive capacity, being displaced from a habitat, or dying.

Engineers have a responsibility to understand and protect fish because the fish have nowhere to live other than the river systems, which are vulnerable to anthropogenic degradation. However, in the past, open-channel flow in particular and hydrology in general have typically been taught and studied without reference, or with only glancing reference, to life forms such as fish. For example, a survey of seventeen hydrology and hydraulics textbooks published before 1996 found a total of only six mentions (Chow 1964; Linsley and Franzini 1978; Linsley et al. 1982; Viessman and Welty 1985; Novak et al. 1989; Dingman 1994) of the word ''fish.''

This shortcoming in the hydrology literature might have been considered unimportant if we could have assumed students would have learned about the life context of hydrology from other sources. However, a decade's experience with the course had shown that we could not make such an assumption. In fact, the writers had determined that students are markedly unfamiliar with the ''real-world'' context of hydrology, let alone the more intricate life context. Through informal classroom polls, we learned that typically less than half the class had had the experience of camping out in a rainstorm, a direct

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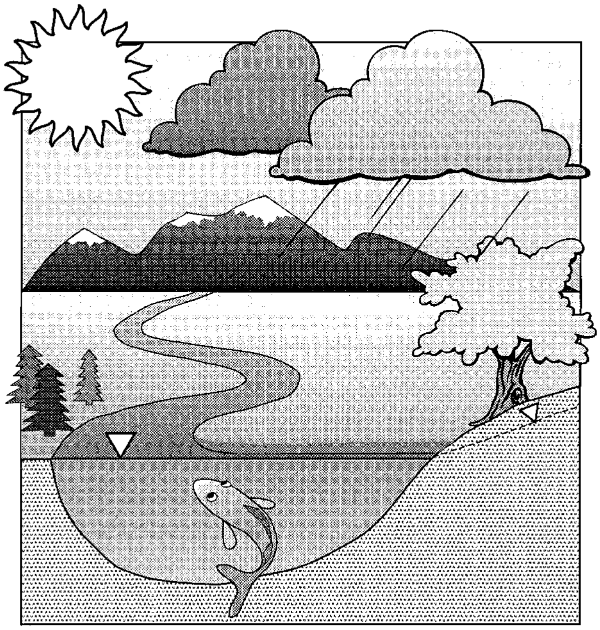

FIG. 1. A Fish's Perspective of Its Surroundings Also Is an Important Perspective for Hydraulic Engineers

learning experience that might erroneously be assumed universal by an outdoors-oriented instructor. By administering a pretest in one session of the hydrology course, the writers learned that more than one-third of the group felt most familiar with a place significantly outside their area of habitation—in this case, Canada. In some cases, the place named had a hydrological regime very different from the local area—for example, a desert. Thus, any assumption of familiarity with the local area context, or of significant direct experience with local hydrological phenomena, would be misleading.

Curriculum Enhancements

Our challenge was to develop curriculum enhancements that would help students understand the experience of fish in the context of hydraulics or hydrology. The course which was the focus of our study included three lecture hours a week, a set of photocopied course notes with explanations of basin concepts, and a set of solved problems covering the range of types of problems that students may be expected to solve on examinations. The writers tested two types of curriculum enhancement.

Study Problems about Fish

The first type of enhancement was based on the assumption that engineering students derive satisfaction from mathematical explorations of situations and would therefore be receptive to the use of analytical techniques to increase understanding of the experience of other lifeforms. We called this approach ''empathetic analysis.'' It can go beyond mathematical analysis by giving students enough information to imagine themselves in the situation of the impacted lifeform; it can go beyond qualitative descriptions of ecosystem impacts by giving students enough information to directly relate the life form's experience to the quantitative environmental description with which the student is accustomed to working. In these two ways, empathetic analysis should be able to help scientifically oriented people like engineering students develop their sense of interconnectedness with all life.

The writers decided to include empathetic analysis content in the course by changing some of the study problems to emphasize their ''fishy'' implications. Small alterations to problems successfully integrated fish information without changing the substance of the original hydraulics/hydrology aspect of the question. Out of the complete set of 34 study problems, four were altered; in two cases, including the following example, the problem was restated from the fish's point of view.

> Original problem: On average, a 400 km^2 drainage basin has an annual rainfall of 75 cm and a runoff of 35 cm. A water supply reservoir of 1,100 hectares is planned at the basin outlet. The average evaporation from the reservoir is estimated to be 100 cm per year. Stating your assumptions, estimate the annual withdrawal of water that can be permitted from the reservoir.
>
> Revised problem: Imagine that you are a fish living downstream from a water supply reservoir with an area of 1,100 hectares. Your fish community requires a continuous flow that amounts to $2.00(10^7)$ m^3/yr. The reservoir is at the basin outlet for a 400 km^2 drainage basin which has an annual rainfall of 75 cm and a runoff of 35 cm. The average evaporation from the reservoir is estimated to be 100 cm per year. From your perspective as a fish, estimate the annual withdrawal that can be permitted from the reservoir. State your assumptions.

The revised problem is a drastic simplification of a problem which in real life would require, for its solution, extensive knowledge of fish biology as well as a team negotiation engaging the key local stakeholders. In an engineering classroom, a class discussion of these requirements, ideally presented by a visiting stakeholder team, could be a good way to further promote the environmental sensitivity that is the objective of the project (Odgaard, personal communication, 1999).

This curriculum enhancement was tested on the 1998 session of the hydrology course. In the previous session, the writers had included a question on the final exam that provided an open-ended opportunity for students to demonstrate their understanding of the life context of hydrology. A similar opportunity was provided on the final exam in the 1998 session. Had the enhancement been effective in the way the writers had intended, we would have expected to see a greater level of life context awareness among the students who were exposed to the enhanced curriculum. Disappointingly, the findings were inconclusive. There appeared to be a slightly greater contextual awareness among the 1998 students, but it was not possible to determine what level of difference could be deemed significant. A large part of the problem originated in the use of the final exam question as the measurement instrument; other constraints on the framing of the exam question severely limited its usefulness as a research instrument. For example, the question had to be different for each year, since students have access to the previous year's question; it could not be very extensive, because it served to test only a small proportion of the course content; and it would have been tricky to pilot due to confidentiality concerns.

Stories about Fish

The second type of enhancement was based on the assumption that narrative is a teaching technique of profound power that has tended to be neglected in engineering in favor of descriptions (such as solved examples) developed in mathematical or technical languages. Several stories, told in the second person, were written about fish living in degraded environments. For example, one story was about a fish living in the Don River, a Toronto watershed where a major habitat rehabilitation program is in place:

> Imagine you are . . . a female mottled sculpin, living in the East Don River in Thornhill, Ontario. At adulthood, you are six inches long. You like to stay near the bottom of cool

J. Hydraul. Eng. 1999.125:1114-1117.

streams with sand or gravel bottoms. If you are approached, you burrow into the bottom. You live on aquatic insects, crustaceans, and worms. To find prey hidden in the substrate, you place your lower jaw on the bottom to detect the vibrations caused by the prey, and then move to the right place and bite into the sand.

You spawn at night, attracted to a mate by the knocking sounds and drumrolls he produces by knocking and slapping his head on the substrate. When you are almost ready to lay eggs, you search for up to a week for the right mate, large enough to have built a big nest under a substantial rock, but not so large that he will eat you.

Your lifespan is six years and you breed once a year, starting when you are three years old. For fifty generations, your community has been struggling for survival. One hundred and fifty years ago, there were already a dozen mills upstream from your community, altering the flow of the river, interfering with seasonal floods, and impeding your passage upstream. By 1950, the Don watershed was 15% urbanized; now it is 80% urbanized. With urbanization has come polluted surface runoff water through stormwater drains; storms are quickly followed by choking spates of water heavy in salt and sediment. The trees and bushes have been removed from the sides of the river and its tributaries; temperatures in the summer are now uncomfortable for you, a cool-water fish. Where, generations ago, there was abundant cool ground water replenishing the refuges at the bottom of the stream, now that ground water is being diverted to dilute pollutants from the Keele Valley Landfill, a diversion planned to continue for the next fifty generations of your community.

Since you were hatched four years ago, you have lived with these problems, but you have noticed life getting easier each year. Instead of being confined to one short stretch of the river, you have been able to journey further and further upstream without encountering unbearably polluted water. The spate of polluted water after storms has been less overwhelming. Each year, the fish in your community have found more possible places for successful spawning, and there have been larger numbers of young-of-the-year fish to be seen. You have seen more fish of other species, some that no fish in your community had encountered before. Aquatic insects are increasing, so your diet is more varied. You are even venturing downstream, looking for places to expand your range. In a dozen generations, perhaps your community will be as widespread as it was before the coming of the city.

An effort was made to find a balance between telling the story on the basis of what the fish would observe and interjecting information that the human reader could understand about the source of the environmental problems. The stories were introduced by a brief invitation to imagine being a fish, sketching the customary activities and sensory faculties of the fish for the benefit of a reader who might not know how sensitive and perceptive fish are. The other three stories focused on a lake sturgeon seeking a spawning bed, a brown trout disturbed by insensitive development of a golf course, and a sock-eye salmon migrating up the Columbia River. (The complete set of these fish stories is available from the writers.)

These stories were included as course materials in 1999 with three other readings (of a more conventional nature) about issues of hydrology, hydraulics, and society. The other three readings were on water-related political problems in the Mid-East, large dams in developing countries, and water shortage problems in sub-Saharan Africa. Study questions were provided with each reading, and the students' assignment was to summarize all four readings and write a short essay responding to the questions for one of the readings.

Out of a class of over 120 students, only eleven chose to write their essay on the fish reading. The questions were as follows:

> The fish stories introduced you to the fishes' perspective on aquatic habitat problems caused by human activities. From the human perspective, how high a priority do you assign to the fishes' needs? What short-term, limited human actions could reduce the inconvenience caused to fishes in these scenarios? What medium-term alteration in human expectations and behaviours would help the fish? What long-term major changes in human ways of living would promote a sustainable habitat for fish? From your own point of view, which of these changes are worth working toward? From your perception of political will, which changes are likely to be possible given the dynamics of national democracy?

The students who responded had a range of opinions about what appropriate short, medium, and long range strategies could improve the fishes' situations. The answers were most uncertain on the issue of political will.

Conclusions

From the first curriculum enhancement, the most important learning was that it was not a simple matter to monitor students' development of contextual awareness. Using a final exam question as an instrument had many drawbacks. A possible alternative would be to design and administer an instrument specifically for this monitoring purpose. A project of that nature could also be of value to other engineering educators, since a well-designed instrument could be used in other settings with minor alterations.

From the second curriculum enhancement, judging by the students' choice of essay, the writers learned that the students felt more comfortable with the more conventional readings and shied away from the fish stories. One possible instructor response to this kind of opting out would be to do a similar assignment in a future session of the course, but make the fish reading mandatory.

Beyond the immediate difficulties of measuring student response to the curriculum enhancement was the more general problem that the writers were making the assumption that a noticeable difference in response to a course would translate into significantly different behavior when these student engineers graduate and begin their practice. Unfortunately, little has been published about engineering students' transition to practice. Without more research in that area, it is not possible to know the ultimate impact of changes to curriculum.

In terms of environmental education in engineering education as a whole, the potential for developing environmental sensitivity in student engineers has been opened as a research area. In the course materials the writers developed, we tried to explore environmental issues in such a way as to evoke student empathy and environmental caring.

Is caring part of engineering? Some would argue that engineers can be environmentally competent without developing an ethic of caring, since professionals with other backgrounds can bring that dimension to the multidisciplinary treatment of environmental problems. By contrast, the writers' study proposes that caring is currently a missing component of what could be a more holistic engineering curriculum.

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