Engineering Thinking: Using Benjamin Bloom and William Perry to Design Assignments

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Abstract

This paper shows how William Perry's Scheme of Intellectual Development and Benjamin Bloom's Taxonomy of Cognitive Objectives can inform the design of writing assignments in engineering. After describing Perry's and Bloom's models, the article examines the cognitive tasks involved in two assignments from mechanical and electrical engineering and demonstrates how these schemes can be applied to enhance the role of writing as a mode of learning. The priciples of assignment design illustrated here can guide WID consultants and engineering faculty as they create assignments in the disciplines and in technical communication courses.

Introduction

While communication has long been part of engineering curricula, a new and greater emphasis on it seems to be emerging. Such priority is driven in part by industry, where weak communication skills are a major liability, but also by a growing recognition that the one or two communication courses students do are insufficient to develop these essential skills.[1] To develop communication, many engineering schools are trying various strategies of Writing-in-the-Discipline (WID). A significant benefit — one that proponents of writing have been arguing for many years (Emig, 1977; Elbow, 1986; Fulwiler, 1987; Rosenthal, 1987; Zinsser, 1988; Stout, 1997 and others) — is that writing deepens thinking. However, a prerequisite for successful use of writing is careful assignment design, whether a microtheme or a large graded assignment.

Careless use of writing may be destructive if only because it encourages understanding writing as afterthought rather than place-of-thought.

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In a traditional engineering curriculum, the “lab write-up” typifies this attitude: “thought” is done in the lab; writing is the grunt work of putting results in presentable form. Oddly, this mentality persists despite a consensus — at least among Engineering faculty at the University of Toronto — that “discussion” sections are badly handled both in lab and design reports.

By contrast, careful use of writing — what may be called *writing to learn* — not only encourages a healthier attitude toward writing, but also seems to encourage a healthier process of thinking. The question, then, is how to cultivate careful use of writing in an engineering curriculum? It has to begin with carefully crafted assignments. As a WID consultant, I have found my engineering colleagues are often more thoughtful craftspeople than humanities faculty. They are conscious of what their students can do and do not want to encourage them to make generalizations that might be considered irresponsible engineering. However, these same faculty struggle to make assignments appropriately challenging for their students. Providing tools for designing assignments is a first step in making writing a useful learning tool in engineering. Two tools that I have used with faculty are William Perry’s “Scheme of Intellectual and Ethical Development” (1970) and Benjamin Bloom’s “Taxonomy of Cognitive Objectives” (1956). This paper first presents the two schemes then analyzes two assignments and some of their results in student writing. The goal is to evaluate the usefulness of these tools for WID consultants and engineering faculty as we collaborate toward making writing-intensive — and thinking-intensive — engineering programs.

Bloom’s Taxonomy of Cognitive Objectives (1956)

Bloom’s taxonomy probably needs little introduction. To evaluate thinking, Benjamin Bloom and others developed a tool usually called “Bloom’s Taxonomy” that posits six levels to represent increasingly sophisticated thought, from simple knowledge at the bottom to complex evaluation at the top. Each level is briefly explained in Figure 1 on page 66.

Each level subsumes those below such that analysis also entails comprehension and application. Only the higher three levels are “open”, that is only at these levels are new ideas generated. Thus, *applying* the second law of thermodynamics in a problem set does not lead to new thought in the field, whereas *synthesizing* lab experience with theory, as might occur in a discussion section of a lab, could generate new ideas. Ideally, engineers need to function at all levels; however, in designing assignments for engineering students, and in shaping a curriculum, we need to be aware that students will likely not be advanced thinkers at the outset of their university careers. In fact, “American college students falter at the medium cognitive level. Students are familiar with these very common assignments but have not mastered them. As a result, much work is needed at this level" (Rosenthal, 997).

Figure 1
Taxonomy of Cognitive Objectives, adapted from Bloom et al. (1956).

6. Evaluation: judgment based on internal evidence such as logical accuracy or consistency, judgment based on external criteria
5. Synthesis: putting together of elements and parts into a whole, arranging and combining to constitute a pattern or structure not clear before
4. Analysis: breaking down into constituent elements, understanding of relations between ideas

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3. Application: use of abstractions(such as laws or technical procedure) in particular and concrete situations
2. Comprehension: use of information for tasks such as translation,summary, extrapolation
1. Knowledge: recall of specifics, of universals and abstractions, of methods and processes, of patterns structures, or setting.

I have found Bloom's scheme useful because it makes obvious sense to me and my engineering colleagues. We know engineers need to evaluate, but that students often cannot do so. We want to design stepwise assignments that nudge students from a level of cognitive comfort to a new level.

William Perry's Scheme of Ethical and Intellectual Development (1970)

William Perry's scheme has also been applied — not without some criticism[2] — in both composition studies (see for example, Burnham; Van Hecke; Capossela) and engineering education (Culver, et al.; Pavelich and Moore). Perry traces intellectual development through nine positions. The positions, unlike Bloom's objectives, are not cumulative but each replaces the former representing a kind of paradigm shift in psychological development — the capacity to hold in the mind, to work with and through, conflicting areas of grey or contradiction. Figure 2 presents a much simplified outline of Perry's Positions. Like any summary, it loses the nuance of Perry's work, but it does provide a working understanding of the scheme. Although anyone seriously interested in using his scheme needs to un-

Figure 2
Adapted from Perry (1970).

derstand each of the nine positions, the stages can be grouped roughly into four larger categories: duality, multiplicity, relativism, committed relativism.[3] "Relativism" often has negative connotations, but for Perry, it is the ability to think critically or reflectively, the basis of mature thought. He describes relativism as a quiet, but drastic revolution in thinking that brought the student a new sense of power. Not only had he "caught on" in his studies, he could now think about thought: he could spot a false dichotomy, talk about assumptions and frames of reference, and argue about the degree of coherence of interpretations or their congruence with data (111).

Relativism is reached when this way of thinking becomes habitual. While it first occurs in specific cases (Position 4b), it eventually becomes the norm and "ceases to demand self-conscious attention. Attention is freed from 'method' to 'the matter at hand'" (Perry, 112).

Fundamentally, this is the difference between novice and expert. Geisler notes that "the literacy practices of experts in the academy are organized around the creation and transformation of academic knowledge; the literacy practices of novices, on the other hand, are organized around the getting and displaying of that knowledge" (81). Students who make the shift to relativistic thinking are moving toward expertise; they are beginning to think like experts aiming to create knowledge, rather than novices trying to display what the Authority wants.

Perry notes that development can be rapid or slow through the various stages, that individuals may "escape," "retreat," or "temporize" particularly as they confront the revolutionary entrance to relativism at Position 5. Either escape or retreat will lead back to a fundamentally dualistic view of the world. Temporizing is pausing in the growth process which may involve consolidation and deepening or may just precede drifting into escape (178). Perry suggested that few students enter university at Position 1, and in his study, 75% of the seniors had attained degrees of Commitment characterized by Positions 7 and 8 (155). Pavelich and Moore, on the other hand, note that their students averaged only an increase of one position through an entire undergraduate program, and that only one quarter of their seniors tested above Position 5 (290-291).[5]

Whereas Bloom's taxonomy outlines the nature of a cognitive task, Perry's scheme deals with epistemology, the nature of knowledge. Any cognitive task can be addressed from any of the nine positions, but the results might vary widely. For instance, in an engineering assignment which asks students to propose several alternative solutions and then recommend one, a student who approaches the problem from Position 2 will look for the "answer" assumed to be held by the professor and will be unable to weigh alternatives honestly because she "knows" only one answer is true. On the other hand, the student at Position 7 will look for a "best fit" or criteria by which to make a decision knowing that different frames of reference might lead to different conclusions. She will weigh alternatives, recognizing that options not chosen also have merit. While both students will analyze alternatives (Bloom's fourth level), and while the first student may well "get the right answer" — a workable solution — only the second is beginning to think like an engineer. Both commit themselves to a solution, but the thinking from which they do so differs profoundly. If the solution is contained in a report where students justify their choices, the instructor can begin to see how a student is developing as an engineer, not just whether she is getting it right. Thus, writing can offer a rich opportunity to promote student growth.

The remainder of this paper applies these two schemes to assignment design and student writing. A careful analysis of sample assignments will illustrate how assignments can be aimed to challenge students from their initial positions and encouraging them to grow by using Bloom and Perry's schemes.

Principles of Application to Engineering Assignment Design

Both Perry's Scheme and Bloom's Taxonomy can be useful for designing writing assignments in engineering, even if one applies them only loosely (in fact this might be best since all psychological models have limitations), because they encourage us as faculty to think about students' cognitive abilities. At their simplest, Bloom's levels address the question, "What will I ask for?" Perry's scheme addresses the question: "What can I expect from a range of students at a particular level?" As Rosenthal puts it: "According to composition pedagogy, it is essential for the instructor to be aware of the cognitive level called for in any writing assignment. Such awareness makes it easy to articulate the source of error in student work" (997). For engineering writing assignments, such awareness also enables us to aim our assignments at a level appropriate to our students and "construct questions to determine how thoroughly a student understands a concept" (Stout, 13).

In using both schemes, the instructor aims to challenge students with a level just above where the students are comfortable — what Perry calls "the pleasure zone" between too challenging and boring. The professor needs to "select tasks that will challenge and build skills, yet will not be impossibly difficult" (Walvoord, 22). Ideally, the instructor would know the student's ability, and would pose a problem that allows the student to reinforce what he knows through a lower level cognitive task, but also to work at a level of task just outside his comfort zone, such that a student comfortable with analysis would be called on to synthesize after having her ability to apply knowledge reinforced. If the task is too complex, students will not only fail, but will fail to learn along the way. If the task is too easy, students will perceive it as "busy work" and become resentful. As Pavelich and Moore put it, "the idea is to help students develop these complex thinking skills by repeatedly putting them in situations where those skills are called for and then mentoring them through the experience" (287).

Mentoring students through open-ended processes encourages them to face (rather than retreat from) challenges that do not fit their thinking paradigms. Such situations can be points of growth because the students experience disequilibrium when they can not account for anomalies. Assuming that most students enter university at Position 2 or 3 (Culver et al., 534), the instructor can appropriately play the role of Authority described by Position 4b: a guide to help the student discover the "coherence and congruence in reasoning in the indeterminate" (Perry, 102). By playing a mentoring rather than a truth-giving role, the instructor can validate the students' initial forays into open-ended thinking and can encourage further forays through questioning, and raising contingencies. Certainly, not all professors are prepared to play mentoring roles with students; some prefer to act as truth-dispensing authorities despite the evidence that such instruction does "little to promote growth toward intellectual maturity" (Culver et al., 534). Even those prepared to mentor face logistical obstacles: class size being the most significant.

Chet Meyers insists that, in addition to open-ended problems — or what he calls "real world" problems — assignments that foster critical thinking must also involve stepwise development of skills, meaning that students need to be led through thinking skills step by step (70-74).[6] Therefore, assignments at the middle cognitive objectives (especially Analysis and Synthesis) and nudging toward relativistic thinking (Position 5) are important to a curriculum that aims to enable students to start developing critical thinking skills. In developing assignments, we have to be mindful that Bloom's taxonomy outlines cognitive objectives, not writing objectives (though Rosenthal and Kiniry and Strenski note the strong correlation), and while writing and thinking correspond, the correspondence may not be exact, especially if English is a foreign language.

When using these schemes with engineering faculty, I keep them as simple as possible, so we can apply them quickly. Thus, I like the four-part simplification for Perry's scheme. As a WID consultant, I have found that faculty appreciate a schematic approach because, although they know engineers need to write (something freshmen do not acknowledge [Freeman, 1998]), they often do not consider how writing can contribute to the students' learning. The two schemes help them see this, and as they do, the writing assignments become more relevant and more careful.

Analyzing Writing Assignments

At the University of Toronto, we began a Language Across the Curriculum program based wholly in an Engineering School in late 1995. This situation allows, perhaps, more significant involvement than WID consultants parachuted in from other departments. In January 1996, the program began working with nine courses. As of January 1999, we are working with nineteen per term as well as teaching new graduate and undergraduate communication courses. The newness of this program means that every course is an experiment, every professor a guinea pig, every group of students a test case. The program attempts to address some of the limitations faced by faculty looking to implement writing. Some of the desired mentoring role is handled by staff from a writing center based in the School of Engineering (mostly graduate teaching assistants trained in tutoring writing). The writing tutors frequently lead small-group workshops in classes where students are working on projects. They are trained to ask questions that encourage students to probe their thinking. From the beginning, the goal of the program has been to engage thinking as well as writing. Because the program is relatively new, but also ambitious, the observations of assignments here are more like field notes than conclusions. Much changes from one term to the next, as the two iterations of the Electrical Fundamentals course assignment illustrate.

Mechanical Engineering : Thermodynamics I

Professor Sanjeev Chandra's assignment from his sophomore Thermodynamics course in Mechanical Engineering provides a good model of a graduated assignment (see Figure 3, next page), an assignment that asks students to work at increasingly difficult cognitive levels as the assignment proceeds.

Principally, this assignment asked students to function at the levels of knowledge and application, so even low-level students could achieve part of the assignment even if true analysis eluded them. Professor Chandra created three versions of this assignment so that students were not all working on the same project. In addition to the nuclear reactor shown here, students might have written on the potential rupture of a Liquid Nitrogen storage tank, or the design of a fuel injector for an oil furnace. The three assignments share as their basis the Leidenfrost effect, the phenomenon that occurs when a droplet of liquid hits a super-heated surface: a film of vapor forms between the surface and the droplet and insulates the droplet from the surface thereby slowing the boiling rate. Anyone can see this phenomenon by placing a droplet of water into a very hot frying pan. If the temperature were somewhat lower, the droplet would, in fact, evaporate faster.

Figure 3
Thermodynamics Assignment by S. Chandra (1996)

Energy is extracted from nuclear reactors by means of liquid coolant flowing through tubes inserted in the reactor core. If the flow of coolant is interrupted (as may happen if a pipeline ruptures) the core will overheat, and if it is not cooled immediately may melt. Emergency core cooling systems spray water on the walls of the core containment vessel. You are an engineer in a nuclear power plant where such a system is being installed. You are asked to evaluate the proposed design. The manufacturer of the system states that there is a delay of 45 s from the instant that the system is triggered to the time the water spray starts. Your calculations show that in the event of a loss-of-coolant accident, the surface temperature of the core containment vessel reaches 800 C in 45 s.

Write a report, to be read by senior managers of the power plant, explaining why you think that the proposed emergency core cooling system is inadequate. Assume that readers of your report have little technical knowledge. In a section devoted to the background of the problem, explain the physical phenomenon involved. Discuss how it is relevant to cooling of a reactor core. Offer recommendations on how the design may be modified.

The assignment's instruction to "explain the physical phenomenon involved" — to describe — would seem to demand primarily knowledge and comprehension. Admittedly, good description also involves selection and ordering, thus, evaluation, but writing tasks can be defined as low level "in terms of how much generalization, analysis or use of abstraction is called for" (Rosenthal, 996). In this case, such demands were limited. To help the students, the professor provided four aids:

1. a handout showing evaporation curves for water and N-heptane, and the temperature variation of a glass surface during the impact of a liquid nitrogen droplet,
2. an article from *American Scientist*,
3. a short explanation from the *Fundamentals of Physics* text, and
4. a multimedia lecture in which Professor Chandra introduced the class to his own research on the Leidenfrost effect. He used a combination of still pictures, video, and overhead

> projections, to explain the phenomenon, its origins, and several of its more colorful applications (fire swallowing, walking over hot coals, firing hot cannon balls across the water's surface).

From any of the sources, students could have gained an adequate understanding of the phenomenon and written an explanation of it. The two written resources also provided models for the descriptive part of the assignment. The application required here does involve some analysis: the student needs to break down the process to demonstrate an understanding of how the Leidenfrost effect will act in the given scenario.

The assignment aims precisely at the middle thinking levels that Rosenthal notes are so badly handled by most students. The uppermost levels of cognition are precluded in two ways: the conclusion is given, and the fictitious audience has limited knowledge. The students are told to explain "why you think that the proposed emergency core cooling system is inadequate." This wording preempts the need for sophisticated evaluation because the judgment has already been made. While this limitation detracts somewhat from the sense of the problem as a real issue by giving away the ending, it frees the student to focus on understanding why and to make the simpler evaluations such as those required in the description. Since the majority of our students found the application straightforward, we probably could have made the assignment more challenging. This could be done by re-tooling the numbers, by leaving evaluation open and by adding more real world variables, such as rate of spray/ flooding in the containment vessel .

The second limit comes from the audience. Forcing students to aim the report at non-technical management reduced the problem of students getting lost in detailed technical analysis — though writing for a non-technical audience has perils of its own to baffle the undergraduate engineer. Students could not hide behind numerical solutions and technical jargon, but had to expose their understanding or lack of it in writing. The audience also had the effect of encouraging a better report structure, as our engineering students seem to assume that other engineers do not care about clear writing.

One point of critique of this assignment is that the request for "recommendations" is not well prepared. It sounds logical enough upon a first reading, but it actually skips a step of analysis. Before students can make recommendations, they need to consider options, something they are not asked to do. To push students more clearly into analysis, the assignment could ask them to offer alternatives (comparison being a mid-level cognitive task [Kiniry and Strenski, 194-195]) and then make a recommendation. Such a step would demand a more thorough analysis of the problem and understanding of the phenomenon.

By Perry's scheme, students whose position was essentially dualistic were able to see "what the professor wants" and derive a right answer, so these students were affirmed in their ability to handle scientific questions. For example, they calculated when the reactor's sprinkler system would need to activate to prevent a meltdown; however, they still had to explain their findings and justify them in writing. As we might expect, students who could weigh possibilities handled the problem better than those who simply presented a single answer. In other words, students who seemed to be working above Multiplicity Subordinate (Position 3) seemed more able to perform the cognitive tasks necessary for the assignment than students who saw the assignment as simply a calculation exercise plus write-up. The higher-level students began to struggle with variables such as whether weather conditions or size of the rupture were factors in the liquid nitrogen spill. These students posed alternatives and evaluated them even though that was beyond the scope of the assignment. Their evaluations suggested compromises and "best fit" choices. Clearly, these few students were thinking relativistically and critically beyond the assignment to synthesize what they know of thermodynamics and what they learned of the Leidenfrost phenomenon. Obviously, the goal of a program is to challenge all students to become relativistic thinkers, but one assignment cannot be expected to do that alone. By posing this assignment in the mid-range of the cognitive objectives and limiting the amount of evaluation necessary, we were able to affirm students' basic understanding while at the same time nudging them toward more relativistic thought.

Admittedly, even the best students did not challenge the Authority of the assignment. For example, none of those working on the rupture of the nitrogen tank assignment considered that the roughness of concrete onto which the liquid would spill might affect the Leidenfrost effect even though their examples only showed the effect on smooth surfaces. Such a point might lead to a conclusion opposite from the one in the assignment; thus, it was precluded, however worthy. So, even as better students' analyses surpassed expectations, we did not see any of the rebellion against Authority that might occur were students operating in Positions 5 or higher.

Finally, if learning involves retention, then this assignment did very well. Two years later, twenty-five of twenty-nine students could write, and often illustrate, an adequate explanation of the Leidenfrost effect, given only three minutes. This suggests that most students have good comprehension. While Bloom's taxonomy appears linear, comprehension based in experience and grounded by analysis and application is a significant advance over comprehension that is, say, based on lecture alone.

Electrical Fundamentals

This large freshman course (four hundred students) is taken by all engineering students, except the electrical and computer engineers. It has a longstanding writing component, traditionally a formal lab report or an essay. Typically, this was evaluated only for "English" by a teaching assistant from outside the School who had little or no knowledge of the field. After I consulted with the professor coordinating the course in 1998, he developed an assignment that was essentially descriptive. His goal was to reinforce the knowledge required in the course. The purpose of the report was to explain electrostatic potential and Kirchhoff's voltage law (KVL), and explain how the labs reinforced these concepts. The assignment gave very explicit instructions, such as this for the introduction: "In about one half page, clearly state the purpose of the report and give the reader a clear understanding of the report to follow" (Zukotynski).

Each section gave similarly explicit instructions. At the suggestion of a writing tutor, the professor also assigned an outline to permit an opportunity for formative grading; however, unlike the Thermodynamics assignment that moved students at least as far as application, this one had no real problem or issue. The result was a huge pile of papers that were essentially identical and rarely inspired. Many of the outlines were virtually copies of the assignment itself, an understandable fact given that the assignment provided a basic outline complete with section headings and descriptions of what should be discussed under each heading. Many of the reports were largely paraphrases of encyclopedias. Overall, we agreed that the assignment had held the students' hands so much that it negated the need to think. A dualist student could perform very well indeed here, because the Authority of published sources would confirm his understanding of what he knew to be true. The relativist student — if any — was probably frustrated by the assignment's rigidity. One writing tutor who worked with the assignment commented that the structure had "raised the floor, but lowered the ceiling" over the previous year's assignment. It was hard to fail, but equally difficult to write a really superior report.

In the next iteration of the same course (summer 1998), another professor and I modified the previous assignment keeping the focus on electrostatic potential and KVL, but placing it into the context of a real issue in the automotive field. We set the students an open-ended problem:

> As a summer student with Ford Canada, your first assignment as a member of the electrical system design team

> is to look into the 12V battery standard. This standard is being questioned because every year consumers demand more from the power supply in their cars: powerful air conditioners, power windows, power locks, sophisticated audio systems, power antennas, plugs for cellular phones, plugs for notebook computers. (de Windt and Irish. See Appendix 1 for the entire assignment.)

The graduated assignment requires students to explain some background concepts, and then apply them to a situation. This assignment also explicitly included the need to evaluate alternatives. The task was designed to work students progressively up the full range of Bloom's taxonomy though with the emphasis at the middle level of analysis. Further, we explicitly moved the task into relativistic thinking:

> Analyze the advantages and disadvantages of a higher voltage standard for car batteries. Recommend whether or not Ford should develop a new standard. Defend your position using your knowledge of circuit analysis. (de Windt and Irish)

The results were remarkable. Ten of the sixty students in the course included in their reports current research from journals in the field (not just encyclopedias), something uncommon for engineering freshmen at University of Toronto. Numerous others conducted interviews with engineers at Ford, Chrysler or General Motors. Many seemed to acknowledge the limits of the Authorities, and recognized that even without a clear answer they still had to commit to a recommendation. This would suggest that these students were working from Position 3, Multiplicity Subordinate, or perhaps higher. They recognized the obstacle as real, not manufactured by the professor. They allowed for legitimate uncertainty, but chose answers as "best cases" based on their evidence. Students' conclusions were different because they had the latitude to establish their own criteria for evaluating. This is a significant advance over the previous assignment which merely asked students to respond to the topic by finding the appropriate authority, something that could be done easily from Position 2.

Noteworthy, too, about the students involved in the second iteration is that they were doing the course in the summer term because they were in the School's T-Program, a kind of second chance for students who fail something in the first term. Presumably then, these students represented academically weaker students than those who handled the first iteration, yet their thinking on the assignment was clearly more developed. Here is a sample from one student paper. It forms the transition from advantages of raising the battery standard, to disadvantages.

> Suppose we raise the voltage standard to 36 volts. Each loop of the circuit would have to use 36 V; however, all consumer electronics designed for automobiles are rated at 12 V. Plugging such consumer products into a 36 V plug would cause damage. This problem may be averted by installing three special plugs for every loop. Each plug would have a variable resistor that would regulate the voltage and make sure that only 12 volts are supplied. However, that is compensating for new technology not capitalizing on it, a classic case of after-the-fact engineering.
>
> Of course, consumer products would likely catch up to new technology if a company the size of Ford was to make the change, but for some such a change would not be an enhancement or an efficiency because they would likely just make the resistor go inside their product, thus wasting power, making cars inefficient, and costing more money. (Student Sample)

The sample shows a student exploring and evaluating a problem and its possible solution. Having seen his way to a solution — variable resistors on each loop — he critiques it with an awareness that, though it would work, it is weak. He then poses an alternative and a further critique. In Bloom's terminology, this student is evaluating using external criteria (level 6), the main one being that a best solution would "capitalize on" not "compensate for" improved power. In Perry's scheme, we might say this student is making forays into relativism, though in the paper as a whole, he seems to assume that an as yet undiscovered right answer exists. The assignment and the class process that accompanied it (an outline returned with extensive feedback, a webpage to guide students from the outline to the report, conferences with writing tutors) led this student and a significant number of others to begin to discover independent thought in a specific case under Authority's guidance (Position 4b). The truly open-ended assignment has encouraged them to think in ways that may expand their ability to think. Did the assignment lead these students to develop beyond the earlier class? Certainly not, but it does appear to have challenged the students to think at the critical level just beyond where they are comfortable.

Carefully designed writing assignments can play a significant role in enticing students into critical thinking at higher levels. Perry and Bloom provide valuable schemes to focus assignments for writing-to-learn. These schemes can even guide our entire classroom practice; for example, if we know that our students are dualists under modification we can support their maturing toward relativistic thinking by modeling the kind of decision making in writing that we value. The worldwide web provides an easy way to post model outlines, model assignments, etc. that students can follow. Better still, we can illustrate the thinking process in action as Hirsch and co-teachers do through role play in the freshman design and communication course at Northwestern University, showing that such a process intertwines thinking, communicating, design and problem solving.

Most of the foregoing has analyzed assignments, but in that analysis lie the principles of design to which my title alludes. To put these principles into action, a process of collaboration is essential. Typically, in my WID consultations, the process goes something like this: I contact a professor; we discuss the objectives of the course and WID; we decide on an area of the course where writing might prove helpful. Perhaps with models or samples of other assignments, the professor makes a first attempt at design. I provide feedback and suggestions for modification: sometimes wholesale changes, sometimes tinkering to tighten the focus or cognitive level. As we go through the process, we discuss how to obtain the cognitive as well as the writing objectives. We also plan what types of intervention the Language Across the Curriculum program might provide to support the writing/thinking exercise: lectures, workshops, models, draft classes, writing conferences. I remain involved through the writing and evaluation stages, so that we can examine the students' results to determine whether or not we have met our objectives. Not surprisingly, the assignments improve in second and third iterations. By then the professor and I understand each other's goals, and I understand the subject matter better so can offer more substantial contributions.

Applications to Technical Writing Classrooms

Thus far this paper has focused on writing happening within engineering courses; however, as staff from the Language Across the Curriculum program have begun teaching a new Written and Oral Communication course for juniors, we see the influence in the opposite direction. Often technical writing courses are taught by compositionists who do not have strong awareness of the values of engineering. Some research has been done on this difference — for example, compositionists value process and student ownership, whereas engineers value product and accuracy (Smith; Miller et al.) — but the responsibility would seem to lie with the compositionists to move into the discipline. The principal advantage we have gained by working with Bloom and Perry is an ability to imitate the kinds of thinking asked for and privileged in engineering courses. This is beginning to shape our assignment design.

In the major assignment sequence in our new course, we are working with faculty members teaching other courses in the same term to create topics that push students deeper into core material in ways the courses themselves cannot do. So, for example, one option is an evaluation of a Monte Carlo simulation designed to test a fading wireless channel. The problem is open-ended: simulations are widespread in communication and other fields, and the accuracy of those simulations is important for every researcher or designer. The assignment asks students to work at middle cognitive levels so that all students will be able to achieve some of the assignment, but the assignment also demands that the best answer will involve evaluation. In the sequence, we also intentionally work students through writing tasks we know they need; for example, we guide students through a mini-sequence leading to a formal literature review that will become part of the final report and will prime them for their capstone thesis or design courses.

By pushing the students into their core course material for their written reports in ways they do not encounter there, we are confident that the writing course will contribute to their learning. They need to synthesize material from several courses, and to evaluate and apply what they have learned from those courses as well as ours. Further, we are placing them in a situation with no set answer, where multiplicity exists, and then attempting to play that mentoring role to guide them in forays into relativistic thinking. Whether or not these students progress to higher positions in Perry's scheme or in Bloom's taxonomy, our goal is to make careful use of writing such that we are contributing to their overall engineering education, such that they will learn that one of the ways they think, and an important one, is in language.

Conclusion

Whether for the writing classroom or WID, writing consultants need to add to their quiver an understanding of cognitive development. While other models may also serve (e.g. Kolb's learning styles [Sharp et al.]), I have focused on Bloom and Perry because their schemes combine sophisticated understanding of the cognitive processes with simple useable schemes. Sometimes I do not mention Bloom or Perry; I merely use their paradigms to explain how a good assignment might work. My intention is to keep my collaborations uncluttered; however, as the two iterations of the Electrical engineering report show, when faculty understand the cognitive objectives, attitudes toward knowledge, and the process of mentoring involved in moving students along the path of intellectual development, the results can be significant. As the experiment at Toronto continues to evolve, I will become bolder in faculty workshops, providing engineering faculty the theoretical tools to enhance their assignment design, and as I do I know that we will continue to learn together the value and effects of careful assignment design.

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Appendix
Electrical Fundamentals Assignment by L. de Windt and R. Irish (1998).

ECE110 FORMAL REPORT (Summer, 1998)

As a summer student with Ford Canada, your first assignment as a member of the electrical system design team is to look into the 12V battery standard. This standard is being questioned because every year consumers demand more from the power supply in their cars: powerful air conditioners, power windows, power locks, sophisticated audio systems, power antennas, plugs for cellular phones, plugs for notebook computers. Your report needs to include the following components:

Introduction: In about one half of a page, clearly state the purpose of the report and give the reader a clear understanding of the organization of the report to follow. Remember that it is not enough to give the order, you must make explain why that order makes sense.

Principles: Electrostatic Potential and Kirchhoff's Voltage Law: Explain the theoretical principles that underlie the electrical system. To do this, provide an extended definition of electrostatic potential, so that your reader can understand this basic concept. You might use the concept of mechanical potential energy as it is used in classical mechanics, or another analogy to help make the explanation clear. Also make sure you include a clear sense of how understanding this will help your reader understand the battery question. Since Kirchhoff's voltage law (KVL) is relevant to the problem, explain it and its relationship to the concept of electrostatic potential.

Discussion of Experiments: Since the experiments this term are designed to help you develop a clearer understanding of KVL, relate the information from the laboratory to the theory discussed in the earlier sections of your report. Use relevant experiments to clarify the concept for your reader. Be as specific and quantitative as possible, including a discussion of experimental errors.

> You may want to make use of some of the following questions or suggestions:
>
> How do the experiments reinforce KVL?
>
> How do your results illustrate KVL or suggest its limitations?
>
> Use your knowledge of KVL to account for any experimental error that you encountered.
>
> How might such error be avoided in the future?
>
> How might such error be relevant to the car battery?
>
> How does a theoretical understanding of electrostatic potential help you understand the procedures in the lab?
>
> Is the power supplied by the power source equal to the power absorbed by the rest of the circuit? Can you explain any discrepancies?
>
> How can you apply that understanding to the problem statement? Use ECE 110 experiments to provide concrete examples of how these principles operate in a "real world" setting.

Discussion of Advantages and Disadvantages: Now that the reader understands the necessary concepts, analyze the advantages and disadvantages of a higher voltage standard for car batteries. Recommend whether or not Ford should develop a new standard. Defend your position by using your knowledge of circuit analysis. (Hint: This section should be about one page of the report).

Conclusion: Your conclusions should be brief but as concrete as possible. Conclusions should be logically linked to your introduction, but do not try to summarize the whole document. You may, however, state your recommendation in a revised form that considers what further work needs to be done.

Notes

[1] In an informal survey of 40 schools last year, I discovered that most U.S. engineering schools have two communication courses in the curriculum (a few have as many as four), whereas Canadian schools usually have only one because freshman composition is relatively rare in Canada.

[2] Perry's work has been criticized as gender-specific and narrow because he worked almost exclusively with male Harvard undergraduates to develop his scheme. Perry did not try to universalize its application, but others have extended it and applied it successfully, particularly in the fields of critical thinking and composition. (See Capossela, pp. 53-60, for a summary of both the objections and the extensions of Perry's scheme.)

[3] Perry himself groups the positions into three: 1-3 modifying dualism; 4-6 realizing relativism; 7-9 evolving commitments (58). Pavelich and Moore (1996) use a similar arrangement to mine.

[4] Relativistic commitment differs from the immature (black/white) commitment of a dualist because the individual is able to hold other possibilities in mind, to revise a held conviction in light of evidence, and to entertain multiplicity without being defensive or lost. Perry compares the difference to the distinction between simple belief and faith, noting that "Faith can only exist after the realization of the possibility of doubt" (34).

[5] Pavelich and Moore tested more students using a broader range of inquiry than did Perry. They note that their students' progress is actually better than that found by other researchers.

[6] Culver et al. suggest that a well-structured design program includes "a model of problem-solving strategies used by experts" (536). A well-structured writing program involves much the same thing.

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