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David Haws
Boise State University

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PERSONAL REFLECTIONS ON PSI IN ENGINEERING MECHANICS

David R. Haws
Civil Engineering
Boise State University
Boise, Idaho 83725

Abstract - *There seems to be little argument that our students need to be encouraged toward educational self-directedness. Yet self-direction must be based on past learning success and present learning readiness. There is at least a potential conflict here: students needs to assume responsibility for their own education, directing it to topics of their own choosing, but their learning must also at least occasionally be directed along a hierarchical path of sequentially dependent learning objectives (which path may not be so obvious to the uninitiated). The Personalized System of Instruction (PSI) seems to enable both of these not-always-compatible goals. PSI allows the instructor to specify not only content but absolute mastery of that content. At the same time, PSI allows the student to control the tempo of mastery. This paper is a qualitative discussion of the evolving PSI instructional design used to teach courses in engineering mechanics and structural analysis over a period of six semesters at the University of Southern Mississippi, and at Boise State University.*

INTRODUCTION

By the beginning of 1994 I had completed my graduate research and was beginning to write a dissertation. I had just accepted an opportunity to teach my 5th undergraduate course in Civil Engineering, and was contemplating a job search and the possibility of finding a place to teach professionally. All of these events seemed to come together in a way that led me to question the effectiveness of my teaching; why did some students succeed and others fail; was I exercising too much (not enough) control over the learning process? Why did some students defer a complete reading of the text, and were they missing something critical, or was it okay to rely on the kind of one-time, auditory learning transfer associated with lectures? I was teaching the way all of my professors had taught, but it seemed, somehow, that few of my students were reaching their true potential. Those who did might arguably have achieved the same result working on their own.

Because all of my engineering degrees were completed after the age of 40, my educational philosophy was fairly well defined. I wanted to be a facilitator rather than a gatekeeper. I wanted my teaching to be process rather than content driven. I had rejected the concept of general intelligence as anything close to a static measure of individual potential. I believed that anyone, including the lower quartile of students, could understand engineering topics if they would only devote sufficient time and effort. I had come to realize that the differential performance of A and C students in any particular course was more a function of self-efficacy beliefs and how well they understood fundamental prerequisite concepts (learning readiness), rather than how bright they were or how much time they spent studying the currently assigned topics. Finally, I believed that the individual is ultimately responsible for his or her own education, and that self-actualization through personal effort is not just a goal, but a responsibility.

As I began to review some of the pedagogy literature, I became aware of the concepts of Mastery Learning (ML) and the Personalized System of Instruction (PSI). While I had never taken a mastery-based or student-paced course (in engineering or any other subject), these general methods appeared to be natural ways to not only insure learning readiness, but to promote the attitudes of self-directedness that I felt so important to the learning process. However, although I was enthusiastic, there seemed to be many competing points of view in the literature—marshaled along epistemological battle lines and suffering from ideological rigidity.

In reality, teaching systems are very personal, and become refined in a natural way as they are applied repetitively by the individual instructor. Because I feel that my formative experiences developing a personal approach to PSI might be relevant for instructors who are unfamiliar with these procedures, I would like to explain why my PSI methods have evolved the way they have over a period of six semesters, what demands these methods have placed on my work schedule, and what evidence I see as to their appropriateness. I have not devoted space here to a literature review, largely because the body of literature is both extensive, and generally more than 20 years old. However, I would be glad to send a copy of my literature review to anyone interested.

EVOLVING PSI METHODS

USE OF CLASS TIME

When you reject the lock-step method of group learning you have to give up a lot of teaching conveniences, like giving a single lecture to the entire class or writing a single exam. When I began offering personalized instruction, I initially tried to carry over some of these conveniences by using lectures to transfer information (to at least a portion of the class), and by having scheduled test days. However, even with a limited number of scheduled test dates, students quickly sought their own pace and spread out over the course content. Because members of the class were working on so many different learning objectives, the class period evolved from a lecture format with testing on specific dates, to a studio format that would allow for testing at anytime during any of the class periods.

Having experienced the studio format, it's easy to see why the historic one-room-schoolhouse evolved into grade-segregated classrooms in lock-step promotion. The studio format is noisy and sometimes chaotic (hardly consistent with the covert curriculum), but it does seem to optimize the involvement of everyone in attendance. While I was still clinging to lectures as a primary means of learning transfer, I would sometimes lecture to a group of students who were all working on the same learning objective. I noticed that students who had already mastered the learning objective would occasionally look up and listen (distracting themselves from the task at hand) to verify what they had already learned. More frequently, students who had not yet mastered prerequisite learning objectives would also be distracted trying to understand material they were not prepared to appreciate.

Many of the learning objectives in engineering mechanics are sequentially dependent and their simultaneous mastery is beyond even some of our better students. When struggling students attempt to tackle these learning objectives out of sequence, their appreciation for the complexity of the problems (not to mention the requisite schemata) is just not there. Nothing is more potentially frustrating for struggling students than to give something their best effort and fail. Unfortunately, a student in this position doesn't always recognize that certain material just *seems* to be imperceivable from lack of learning readiness. Fortunately for these students, the studio format helps to keep everyone active and focused on the appropriate learning objectives.

During the class period I circulate among the students. Sometimes they work on the assigned homework problems; sometimes I give them special problems; sometimes they're working on mastery exams; sometimes they're reviewing their completed homework problems. Sometimes they have questions on theory that may not have been adequately explained in the text, and so we discuss their concerns individually with a piece of scratch paper. Other times qualitative topics are discussed in class, but only after the class is prepared to appreciate them. While the classroom is noisy and I am open to the accusation that I am not teaching because I am not lecturing, I've been very pleased with the studio format as a means of learning transfer.

ORGANIZATION OF CONTENT

Both ML and PSI require that the course content be broken into smaller units. Since each learning objective has to be tested, the size of the module is limited by the number of learning objectives that can be tested in a single exam. This might vary from 50 minutes, if the exams are done in class, to three hours, if the exams are done in a testing center. Also, if testing occurs at the individual learning objective level, the complexity of learning objectives has to be such that a test problem on a single learning objective can be completed in a reasonable amount of time. I began by breaking the Statics course into six modules, each containing three to four terminal learning objectives. With this format, each of the learning objectives in a module could be addressed in a 90-minute exam (one class period). As the learning objectives became more complex in Strength of Materials and Structural Analysis, the exams on individual learning objectives would sometimes take an hour. Since module exams containing every learning objective might be excessively long, I began to limit the number of learning objectives that would appear on the module exams to two or three, and kept all module exam testing in the testing center (where time was basically unlimited). Since, with these more complex topics I was testing each learning objective in class, with immediate feedback, the module exams were used primarily to integrate the related but separate learning objectives.

When I began testing at the individual learning objective level, the course content and many of the exam questions remained the same. However, because I was focused on the evaluation of learning, the identified learning objectives were all behavioral. In reflection, it became obvious that I was ignoring qualitative topics, which were difficult to address with clear behavioral objectives. However, in spite of the fact that these learning opportunities are difficult to verify, there are several concepts in engineering mechanics that should be addressed in a qualitative sense at the introductory level. These qualitative topics (such as gaining an appreciation for Saint Venant's Principle) were introduced in the fourth semester as expressive [1] learning objectives. They were dealt with in short lectures and reading assignments, but were not tested at the learning objective level.

TESTING

Since most behaviorists acknowledge the general superiority of positive reinforcement (in contrast to punishment), I began to feel that too many students were failing mastery exams. Frequent failure destroys self-efficacy belief [2] in a way that seems to be desensitizing. This became obvious during the second semester, and so I decided to test for mastery at the level of the individual learning objective in all subsequent classes. This made the exam periods much shorter (10 to 20 minutes for simpler learning objectives) and allowed them to fit much more easily into the studio format. However, while the students were much more focused, and did reasonably well on the exams, I felt that there was a lack of integration in regard to the learning objectives. Consequently, beginning with the fourth semester, I kept the individual learning objective exams, but used them to grant admission to the module exams (which were in turn used to determine grading). While it's too early to tell, I believe that the individual learning objective exams allow the students to maintain a narrow focus, while the integrating effect of the module exam enhances the depth of understanding.

While the scope and breadth of exams have evolved as described above, there are other aspects of testing which have also become important. Since the learning objective exams are short, and taken individually, I am able to provide each student with immediate feedback. Where errors have been made, this enables an oral review and an opportunity for me to point out some of the general areas where errors may have been made (sometimes this is as simple as circling a quadrant of the exam sheet). I then allow the student to return to his or her desk and make corrections. This, together with the frequency of examination, takes a lot of anxiety away from the testing process, and produces a more accurate picture of student understanding.

The influence of test anxiety for some students should not be ignored. I noted with my first PSI offering that there was often a large discrepancy between the ability of a student (particularly students from the lowest quartile) to solve a problem in the relative calm of my office, as opposed to solving the same problem in a highly structured testing situation. The explicit time constraints during a formal test were often enough to panic the student. The results were fractured solutions and rigid seizures upon inappropriate algorithms. Since my concern is to evaluate learning, not necessarily the ability to apply learning in a pressure cooker, the oral component of testing has proved significant.

HOMEWORK

For my first PSI offering, homework problems were assigned, but they were not reviewed unless a mastery exam was failed. If a mastery exam was failed, additional homework problems were assigned, and these would have to be completed and reviewed before a retake exam for the module would be allowed. Two problems were observed here. First, several students had managed to purchase a copy of the solutions manual and were getting very little from the homework assignments. Secondly, other students had trouble developing coherent, linear solutions, and so had very little presentation value in their homework. To compensate for this, I made up special homework problems in class for the students to complete, and I began making them orally review all of their homework before they would be allowed to take a mastery exam. During this review process, I sit down with each student individually and ask for an explanation of the solutions. If I feel satisfied that they understand the underlying concepts, then they are cleared to take the mastery exam.

To improve the presentation value of their solutions, I began to require that the homework assignments be completed in a quad-ruled lab book. This did have a tendency to improve the quality of their homework presentations, and kept a running record of their achievements that could be easily consulted during office visits or during class, and may have also improved their self-efficacy beliefs. Individually reviewing each homework set did a lot to insure learning readiness before the mastery exams were taken, but was very time consuming. To reduce this time commitment I introduced an option at the beginning of the second year, using "Internal" Student Proctors to review homework assignments.

STUDENT PROCTORS

Keller's method of incorporating undergraduate Student Proctors added a social stimulus to the learning process for his students. His Student Proctors would generally have taken the course within the previous year, would be more familiar with much of the material, and would have a *feel* for the PSI teaching methods. In addition, they would be able to relate with their fellow undergraduates more easily. A significant drawback, however, is that funding typically needs to be developed to contribute a stipend for the proctors.

In the absence of funding, Keller suggests using "Internal" Student Proctors (students who are currently taking the class and functioning at an accelerated level). Beginning with the first semester of the second year, I was able to identify the top students in the class, and they expressed a willingness to function in this capacity. Since there was no funding available to pay for their services, they were given extra credit. The only stipulation was that they sit for a minimum of 4 office hours per week, and come to class. Since it usually takes about a month for the top few students to demonstrate their self-directedness, I review the homework assignments myself during this period. Also, since the Student Proctors generally finish course content early (assuring themselves of A letter grades), they seem to have more time toward the end of the semester and approach their duties with a lot of joy and willingness (not always evident with graduate students).

Although the Internal Student Proctors never benefited from the extra-credit points they were given (which was announced in the syllabus), there was some resentment toward what was perceived as a preferential treatment. To adjust for this, I went from a Student Proctor to a collaborative learning model in the spring of 1998. I developed a collaborative learning log where students recorded their study time (both individually and collaboratively) and extra-credit points were awarded for completing the log and showing a minimum of 30 hours of collaborative learning during the semester. This in effect gave Internal Student Proctor extra-credit points to everyone, dependent upon their exerting effort to learn collaboratively and to help the learning of their fellow students.

The literature on collaborative learning is extensive, but I feel that perhaps the primary benefit is to broaden the context of all learners. Since learning concepts are perceived differently at different stages in our educational development, being exposed to the perceptions of someone else at a different stage (explaining a concept to them or having them explain a concept to us) gives us a deeper understanding of the concept. In a very basic way, this is the Constructivist paradigm of socially negotiated learning—we perceive things based on our past experience, and our experience expands as we are able to understand how others with different experiences perceive the same concept. This is why the apprenticeship model worked well for so many centuries, because it combined novice apprentices, advanced apprentices, journeymen and masters--each with their own set of developmentally based experiences and perceptions—in a common environment where their perceptions were truly shared [3]. Clearly, PSI is not incompatible with this model.

GRADING

Grading is understandably one of the more difficult aspects of personalized instruction. If the student masters the material, he or she should probably receive an A letter grade. If mastery isn't achieved and the student gives up, he or she should probably receive an F letter grade. However, grading for students who cannot completely master the course content within the time constraints of the academic semester is a little more subject to personal values. It would obviously be better to extend the semester giving an incomplete, but this isn't always politically feasible. For example, Boise State charges a flat tuition fee for all full-time students, creating a financial incentive for students to self-overload. This would perhaps exacerbate if the granting of incompletes were to become a liberal process. Additionally, there is a fine distinction between students who simply need more than one semester to master the content, and students who fail to master all of the material because they fail to apply themselves, or because they encumber themselves with other activities. Since procrastination is a significant problem with all student-paced teaching systems, I try to give my students frequent reminders of where they should be in terms of the course content, and intimations on the fleeting nature of time in general. However, the "scallop" patterned procrastination curve associated with PSI is a natural artifact of fixed interval reinforcement (basically only the final grade is perceived as a reinforcer) and procrastination in general is a "student-chosen" pacing and needs to be accepted.

I struggled with grading issues over the first year. During the first semester, I gave two incompletes to students who were very close to completing the required modules. I gave A's to students who had mastered all of the modules (required and optional) and B's to students who had mastered all of the required modules. Everyone else received either W (withdrawal) or X (inappropriate withdrawal) grades. The grading was very similar during the second and third year, except that F letter grades were given to all students who failed to master the required learning objectives. During the fourth semester, the mastery tests at the learning objective level were used to justify admittance to the module exams, and then the module exams were scored like regular test with the test results used to determine the final letter grade. My first two semesters of PSI at a School of Engineering Technology experienced failure/withdrawal rates of 30 and 50% (comparable to non-PSI engineering mechanics courses at that institution). In two years at BSU College of Engineering, I have had less than 5% failure/withdrawal.

DEMANDS ON WORK SCHEDULE

SELECTION OF CONTENT

The time requirement for the selection and referencing of content is much the same for PSI courses as for any other class. Generally, however, the testing of each individual learning objective, requires (at some point) that the learning objectives be formalized. The writing of formal (or informal) learning objectives is one step further than that taken by most course outlines, and so requires a little more time. However, it is arguable that formal behavioral and expressive learning objectives should be written for all courses.

Since the content for PSI courses must be highly modularized, it can be easily adapted by instructors who might choose to introduce a different content emphasis. Since students are working on different learning objectives anyway, different majors could take the same class, master a slightly different set of learning objectives, and emerge with a more specialized set of skills. Alternately, engineering and engineering technology students could be combined in the same class [4]. In addition, the courses could be team-taught by a selection of faculty members each concentrating on the learning objectives they feel to be more important/interesting. Given some of these options, the selection and referencing of content might eventually prove easier for some PSI courses.

CREATION OF TEST BANK

PSI courses require a significant amount of testing, much more so than with a typical lecture course. In addition, several different tests have to be created for each learning objective/module, to accommodate students taking tests on the same module at different times. I typically begin by creating a bank of five test questions for each learning objective, and then expand this as needed. Since the creation of test questions only has to keep pace with the most accelerated student in the class, you can begin the term with an incomplete bank of questions, creating test questions for later learning objectives as the need arises. I try to start the semester with exams for at least five learning objectives, and will then make an effort to stay at least three learning objectives ahead of the most advanced student.

This can be very time consuming, but there is an advantage to creating multiple test questions. By creating test questions for a given learning objective in sequence, the questions tend to become progressively more difficult, with more integration of previously mastered concepts. Because the learning objective test questions cover a graduated range of difficulty, students with shaky confidence can be nursed along with simpler problems, allowing them to increase self-efficacy beliefs through an enactive mastery experience [2], while other students can be appropriately challenged with more difficult problems. In this way, instruction becomes more individualized (in addition to student-paced). Also, since I track which learning objective mastery tests have been taken, I can make sure that no one student is given consistently hard or easy problems to solve.

ONE-ON-ONE LEARNING TRANSFER

The amount of student consultation after the first couple weeks of instruction, is particularly high. The amount of consultation decreases with the selection of Student Proctors, or the introduction of the collaborative learning requirement, and then increases toward the end of the semester, as the majority of students try to complete the required learning objectives during the remaining period of instruction. Since more self-directed students are usually able to finish the course a little early, more time is naturally freed up to work with those students who are struggling. I post six to ten office hours per week, and will accept student consultation at virtually any hour that I am not in class or in committee meetings. For the most part, consultation sessions are short, and dovetail into my other assignments. Typically, a student will come to my office, we will talk about the material for a minute or two, and then I will send him or her off to work a problem. When the problem is complete, the student will return and discuss it.

I began to keep a log of my time at the beginning of the 1997 academic year, and so have been able to develop comparative figures on the amount of time required to develop and teach a PSI course in Structural Analysis. This time requirement breaks down into two general components: time for instructional development and delivery, which is fairly constant regardless of the number of students; and course maintenance time, which is a function of class size. In-class time will be slightly greater than for non-PSI courses because students (and the instructor) tend to come early and stay later (particularly if the classroom is open either before or after the class period). The Structural Analysis class was scheduled for four 50-minute blocks and I averaged 3.9 hours per week in class. The spring 1998 Strength of Materials course was scheduled for three 50-minute blocks and I averaged 4.6 hours per week in class (largely due to the fact that the classroom was not in use before or after the scheduled class time). During development of the Structural Analysis course I spent 9.6 hours per week (spreading course development/preparation over the entire semester), which was about three times my normal commitment. In the spring of 1998 Strength of Materials offering, which used materials from the previous year, course development/preparation was less than seven hours for the entire semester. Of the maintenance categories, the Structural Analysis course required .36 hours per student-week to grade (about four times what I typically spend in non-PSI courses) and .26 hours per student-week of consultation (as much as 10 times the amount of out-of-class consultation time in my non-PSI courses). Similarly, the 1998 Strength of Materials course required .37 hours of consultation per week for each student, and .27 hours per week for each student to grade their exams.

Because my PSI courses are small (as small as seven students and no more than 30), I grade all of the exams personally. Grading time per student, therefore, should be fairly constant. Student Proctors and collaborative learning can increase the amount of consultation received by students, but has less effect on the demand for my time when I happen to be available (it would appear that I am still the consultant of choice). Consultation time per student, then, seems fairly constant. After accounting for grading and consultation most of the extra time is used to develop the bank of test questions.

EVIDENCE OF SUCCESS

I don't have any unimpeachable evidence of the effectiveness of PSI, primarily because I've never taught a sufficient number of students to require simultaneous offering of a control group with random assignment (there is ample evidence in the literature, however and this is not much of an issue). The completion rate at the University of Southern Mississippi (USM) was improved (as high as 70% as opposed to 50% for earlier non-PSI offerings). There was also some indication that PSI Statics students at USM did better in Strength of Materials (100% completion for PSI students, compared with a 30% failure rate for students who hadn't taken the PSI Statics course). The first PSI Strength of Materials course at Boise State University had one early withdrawal (before the drop deadline) with everyone else successfully completing the class. I had no withdrawals and 100% completion of the course for the fourth semester, Strength of Materials. There was one failure (of 12 students) in the Structural Analysis PSI course (fifth semester), and one late withdrawal (of 13 students) in the spring 1998 Strength of Materials. While none of this is offered in way of a proof, it is supposed that PSI is at least a contributing factor.

I have noted with great satisfaction that struggling students tend to stay on task, rather than bemoaning their incipient failure in a way that precludes any possibility of success (clearly success and failure are self-feeding). This attitude appears to be reflected in their student evaluations of teaching, as well as personal comments. Most students comment on the amount of work involved (which many consider excessive). In terms of Student Perception of Teaching (SPT), my PSI courses have never given me my highest ratings, however the differences between my ratings in PSI and non-PSI courses are very minor. Testing at the learning objective level definitely inspires some students with a "brick-in-the-wall" attitude. While this may demonstrate a lack of vision, in terms of the big picture, I don't find it inappropriate in lower division engineering. In the final analysis, however, success must be measured by changed attitudes and lifetime commitment, which are indeed difficult to verify.

CONCLUSIONS

Perhaps the most frustrating aspect of PSI for someone trying to explain why he uses the method in the 1990's, is the epistemological mind-set of educators. Clearly this problem was exacerbated by Keller's declaration "I'm not 'behavioralistically inclined'; I fell all the way!" [5 p. 147] However, the significance of PSI is more obvious from a philosophical rather than an epistemological point of view. Keller used the tools he had, which were behaviorist, but his method works because he was also a humanist—as much as Malcolm Knowles or Carl Rogers. This is clearly demonstrated by his reliance on social negotiation of meaning and his emphasis on individual instruction. The narrow focus of behavioral objectives is often appropriate for courses such as engineering mechanics. And when it is inappropriate, more Constructivist activities are easily added.

At first glance, there may seem to be a conflict between achieving learning readiness and enhancing self-directedness (one seems to require control while the other seems to require a relinquishment of control). However, PSI can accomplish both of these goals. PSI allows us to stipulate both content and level of performance, while simultaneously giving our students more control over the learning process, helping them to develop commitment and moving them philosophically toward educational self-directedness. While PSI is not the whole journey, it can be a step in the right direction. As such it may help our students to become the self-directed learners they will need to be if they are to flourish in the 21st century.

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