"[University professors] saw physics as a highly logical structure, based on a set of uniformly applicable generalizations... The purpose of teaching physics was to lay out this structure and, in the process, prepare first year university students for research in physics. The structure of physics was so important for most of the university teachers, it was the overwhelmingly dominant criterion for deciding curriculum and pedagogy. (...) Linking physics with the "real" world had no cognitive value..." (Gunstone and White, 1998)

The Need for Transformative Materials in Post-Secondary Introductory Physics Courses

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The Problem

In his presentation as part of the physics colloquium series at the Universiy of Pittsburgh in 2004, Eric Mazur presented a staggering statistic: only about 1% of all students in introductory physics classes[1] eventually receive bachelor's degrees in physics, and only 28% of those students earn PhDs in physics (AIP Report R-151.39 2003). Not surprisingly, student performance on standard exams such as the Force Concept Inventory and the Mechanics Diagnostic Test (Halloun & Hestenes 1985) is consistently quite poor (generally 10-20% gain over a semester) in traditional (by which I mean didactic, lecture-based) classrooms. Those who succeed in this environment are the exceptions; they represent the fewer than 1 in 300 students who will become a university professor. They will overwhelmingly teach their classes as they have been taught (Mazur 2004). The prominent attitude of university physics professors is that the structure of physics and preparation for research in the subject is what should drive the course (Gunstone and White, 1998). It is no wonder that students find themselves discouraged and frustrated.

Many clever, innovative, and successful teaching materials have been designed to address this problem[2]. Nonetheless, many professors are still wary of using them, and some who have used them report either degradation in their students' performance or increased student dissatisfaction (leading to poor reviews of the professor). This perceived failure might come about when the teacher perceives that his[3] role is merely to enact the curricular materials, rather than participating with them in a dynamic relationship. Within such a relationship, the teacher allows his content understanding and pedagogical and philosophical beliefs to be *transformed* by the materials, and he modifies the materials as appropriate for his classroom culture. Achieving this relationship requires more than simply handing a professor the materials that have been developed; rather, it may involve developing and packaging them in such a way that a *transformative* approach is required.

A New Framework

A framework is presented here as an overview of many of the relationships that make up a classroom, along with an oversimplified "traditional" framework.

Fig. 1 "Traditional" Framework

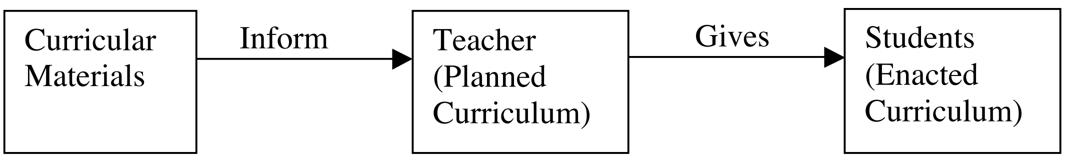
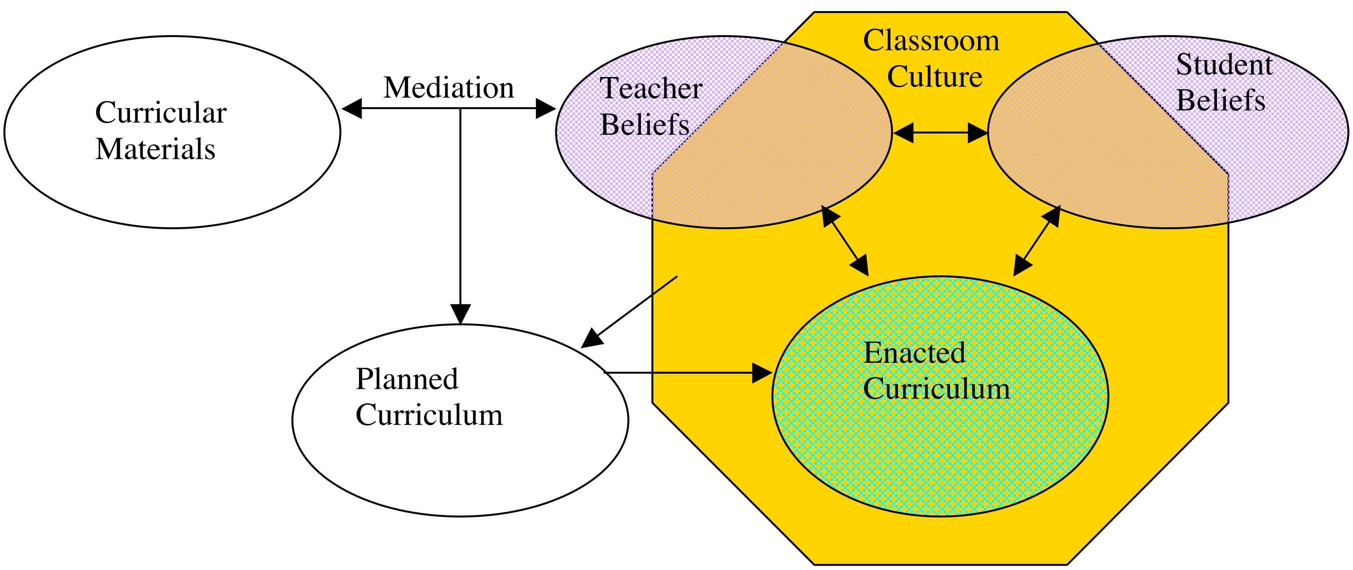


Fig. 2 "Alternative" Framework



The traditional framework, wherein the original curricular materials (such as textbooks or specially designed units) direct the teacher's choices as to what information is to be presented to the students, is very limited in scope. The underlying assumptions that the teacher holds are that 1) knowledge is a thing which can be given, 2) students have essentially blank slates, and thus 3) what the teacher says (or demonstrates) is what the student learns. These assumptions leave little room for explicit consideration of many features that are present in the alternative framework.

In contrast, this alternative framework, which incorporates aspects of Remillard's framework of the components of the teacher-curriculum relationship (in press), enumerates many of the fundamental relationships that exist between the curricular materials and the enacted curriculum.

On the right side of the framework schematic is the classroom culture; this influences the enacted curriculum and is strongly influenced by teacher and student beliefs. It also reinforces or challenges those beliefs in a dynamic relationship that evolves throughout the course. Also, feedback from the classroom culture will affect the teacher's planned curriculum (and vice-versa)[4]. Within the classroom culture, the students' beliefs will interact with the teacher's, and each with interact with the enacted curriculum.

The left side of the schematic illustrates the ways in which the teacher and curricular materials interact to produce the planned, and eventually the enacted, curricula. What is called "mediation" above is similar to Remillard's "Participatory Relationship" (Remillard in press). Mediation encompasses the dynamic relationship that the teacher and curricular materials must develop; this relationship is more than simply the influence of the teachers' prior knowledge and beliefs on the enacted curriculum. However, it is true (and well-documented) (for example, Souza Barros & Elia 1998) that the teacher's beliefs have a tremendous impact on the curriculum.

Teachers' Beliefs

In many regimes, the relationship between the teacher and the curriculum materials is impaired because the teacher has a limited amount of content knowledge. However, in this situation, the instructors are physicists – or at least advanced graduate students in physics – and are presumably among the experts in the content knowledge covered in an introductory physics course. Hence, curriculum materials can in principle hold any degree of rigor in physics content and the relationship between the instructor and the materials will not suffer on its behalf.

Unfortunately, the instructors' expertise in the content also carries some negative implications. Studies have shown that experts and novices view subjects differently. For example, Chi, Feltovich & Glaser (1981) showed that experts classify physics problems based on a "deep structure," while novices tended to focus on "surface features." The "node-link" structure of the discipline is thus quite different for experts than for novices. That is, experts tend to understand physics through an organizational pattern that allows for seamless transitions from big ideas to specific concepts, whereas novices tend to focus on surface details of problems rather than the underlying physical concepts. Because of this, it is quite likely that an expert would emphasize the elegant structure of physics as a whole – a sort of "crystal palace[5]" that is robust, powerful, and beautiful in abstract space. However, the student is unable to see that structure because, for her, it has not yet been built. This leads to frustration and confusion: what is important for the student may not be what resonates with the instructor. Therefore, if curricular materials are aimed at relating physics concepts with the real world or otherwise de-emphasizing the abstract structure of physics, the abundant content expertise can lead the instructors to misinterpret the curricular materials. Specifically, this can lead to spending far too much time in "abstract space" and not enough time in "real space" for students to make connections with previously learned chunks of information.

Additionally, while physicists are experts in content, they have not, in general, had any exposure to formal training in education[6]. Because of this, their held beliefs are not challenged, and they are likely to view students as "blank slates" capable of being written on or given knowledge. However, cognitive research shows that there are misconceptions (or prior conceptions[7]) that students have from naïve explanations of the way in which the world works (for example, McDermott 1990, Halloun & Hestenes 1985, Mestre & Touger 1989). These conceptions are durable; casual communication of new information in a lecture fails because students will adapt what they hear in terms of their prior conceptions (Mestre and Trouger 1989). Many of the newer curricular materials in physics, such as McDermott's physics tutorials (1998), are designed with constructivist assumptions. Hence, they naturally seek to dig beneath the student's surface to create cognitive dissonance within him. When faced with the dissonance, the student will be compelled to change his beliefs if he is convinced that the new ideas being presented are superior.

If the course instructor is not familiar (or at odds) with this philosophy, he will not be able to interact properly with the curricular materials: what seems like a repetitive waste of time to him might be a cleverly designed pattern of deepening spirals that have the potential to elucidate deep understandings. Thus, if the instructor decides to modify a module prior to implementation and maintains a philosophy at odds with the designer's, the results can be disastrous: the student is likely be confused, if not misled. The choices the instructor makes will be guided by his beliefs about the ways students learn. If these beliefs are not concomitant with the designer's, he may assign the activities and present the material in such a way that simply *tells* the students what misconceptions they are likely to have, or what the lesson's "big ideas" are (Cartier and Huang 2005). Therefore, if we expect instructors to be able to implement curricular materials, they need to be familiar with the philosophies behind them.

Furthermore, if we are to take seriously the results of cognitive psychology, the misconceptions of the physics instructors with respect to instruction and learning need to be dealt with formally; we cannot simply expect them to take notice. In fact, it may be the case that while university physics instructors have a genuine interest in their classes, they are not aware of the worldview lens with which they experience it, as most of their students are unaware of the often pseudo-scientific lens they use to view natural phenomena. Somehow, these inherently held beliefs must be drawn out and challenged.

Modifying Teachers' Beliefs

The Conceptual Change Model of Posner, Strike, Hewson and Gertzog (1982) indicates that for conceptual change to occur, the individual must feel dissatisfied with the existing conception. To change this conception further requires that the new conception be intelligible, plausible, and fruitful. Because teachers' views have evolved with their experiences, the assessments that are established in many courses are quite consistent with the teacher's views on teaching and learning (Gunstone and White 1998). For example, if assessments of learning in the course are the diligent reproductions of canonical problems and proofs, one can expect to see students' notebooks full of such work. Having assessments that reward certain approaches in teaching and learning foster such values (Wildy and Wallace 1995). Therefore, one can challenge physics instructors by revealing what that instructor's evaluations claim about his current views. This might be sufficient to cause some dissatisfaction. Dissatisfaction may also arise from an instructor's class showing only a small gain over the course of the semester on a valued external assessment such as the Force Concept Inventory[8] (Mazur 1997).

Showing that new views of physics instruction are intelligible and plausible are relatively easy. Showing that they are fruitful requires more work. Before new instructional materials are released to the general public, they are deeply scrutinized and improved within the environment in which they were designed. Usually, they are further "pilot tested" in other colleges and universities. The results from such studies are usually presented in papers that are published in popular physics journals (for example, McDermott 1992). While this shows the possible fruitfulness of the materials, instructors often claim that there is one more hindrance: feasibility (Gunstone and Northfield 1996). Feasibility in this context refers to the ease with which an instructor who is completely unfamiliar with the materials (and often the philosophy within which they are based) is able to institute them in his classroom. If an instructor is unable to see the materials and the advertised views of teaching and learning contained within as feasible, he is not going to adapt them.

Unfortunately, many factors contribute to make feasibility a serious hindrance. First, the initial energy input required in many programs, such as the University of

Minnesota's Context Rich Problems (Heller & Hollabaugh 1982, Heller, Keith, & Anderson 1992), is very imposing. Many professors, when faced with that challenge, are likely to cite their more pressing responsibilities (which usually involve grant proposals and research) as reasons for not investing in a new educational program.

This feeling is further compounded by the lack of a community. Physics instructors at the post-secondary educational level may feel isolated if they attempt to break away from the traditional educational philosophies. Without the support of a community with which to share ideas, communicate difficulties, brainstorm, and improve, it is less likely that any instituted changes will be successful and resilient. Moreover, there are incredible pressures to remain within the current social norm; these pressures have a very real effect on what actions are taken (Ajzen & Fishbein 1980) and may prevent university physics instructors from deviating from traditional methods.

Furthermore, while instructors in physics courses in post-secondary education settings are generally given autonomy, they are also under quite a few pressures: preparing majors for the physics program, preparing pre-medical students for the MCATs, and preparing other science majors for their needs while maintaining positive student reviews and not ostracizing any students who are taking the course to fulfill core arts requirements. This severely hinders the freedom that the instructor might have[9]. Combined with the complications listed above, this can lead to a feeling that, when in his teaching role, he is a laborer rather than a professional. If the teacher has a labor mentality, his agency becomes effectively diminished, making him less likely to feel capable to institute any new instructional materials within his constraints (Apple 1993). Hence, the instructor might feel overwhelmed by "labor-type" obligations and see alternative teaching approaches as simply not feasible.

There are external strategies that we may employ to combat these hurdles to feasibility; however, they are quite difficult to implement. One of the initiatives with the most potential for success involves "in-service" workshops or courses. Pre-service training programs for teachers have found that putting future teachers through a course that introduces them to curricular materials such as inquiry or computer-based modules by immersion leads to a positive shift in the teachers' beliefs about the materials (Zacharia 2003). After the course, the teachers had a more positive attitude toward physics, the inquiry activities, and the computer modules. The teachers were also more likely to institute these modules and activities in their classrooms. Using a course or a workshop aimed at immersion in new instructional materials may afford instructors at the university level the same opportunities for change. However, because the participants in the study by Zacharia were science educators, they were presumably quite familiar with the underlying philosophies, and they may have experienced more harmony with them. Unfortunately, as previously suggested, physics instructors are generally naïve about such beliefs.

Nonetheless, because of the deep parallels between the instructors' naïve beliefs about instruction and learning and the students' naïve beliefs about physics, an opportunity exists to impact the instructors in a meaningful way. If workshops educated physics instructors in *educational* materials through a method that parallels the new physics instructional materials (say, by immersion and inquiry), the affective outcome could be quite potent. Further research should be done to establish whether such workshops are actually possible. Sadly, even if such workshops are possible, it is very unlikely that they are very feasible. Without any established requirements regarding teacher training within university departments such as physics, there is no external incentive for instructors to attend. External pressures and a lack of community further complicate many teacher-development programs. While hope remains that some such programs could be developed successfully, another possibility lies in transformative curricular materials.

Participation with the Text

"Teacher-proof" materials that were developed in the late 1950s and 1960s proved themselves significantly flawed. One of the reasons for this was that they treated teachers as a "conduit for curriculum" rather than a user or designer of it (Remillard in press). In the 1970s and 1980s, researchers[10] shattered the assumptions that a teacher could merely follow a text without engaging with it.

Brown and Edelson (2001) describe the interaction between sheet music and bandleaders in comparison with the interaction between curricular materials and teachers. Bandleaders bring with them their own experiences and preferences, leading them to present a musical piece that sounds different from the same musical score presented by a different bandleader. We would have no difficulty in recognizing that the same song is being played in each situation; however, despite their similarities we could observe that they sound distinctly different. Moreover, we could explore the sources of this variation. The bulk of the creative work occurs in the performance of the piece, although they are using an "artifact" – a musical score. The mapping to teachers and curricular materials is obvious. We should be able to study the ways in which teaching performances vary and yet we are able to obtain end products that are meaningfully very similar.

Remillard[11] characterizes four perspectives researchers use when considering how teachers use curricula. First, one can consider the degree to which the teacher follows or subverts the text. Within this positivist context, the teacher is seen as an enactor of the planned curriculum, which is a fixed representation of the enacted curriculum. Important in this perspective is the degree to which the teacher holds true to the text; the assumption is that a successful teacher is one who is able to faithfully enact a certain set of (proven) curricular materials.

Next, the teacher may be seen in the role of a designer of the enacted curriculum by drawing on curricular materials. Rather than focusing on the degree to which the teacher is faithful to the text, this perspective concentrates on the agency of the teacher. Namely, the research is concerned with the choices that teachers make (say, for choosing to use one lesson from a curriculum but not another) and what influences those decisions. The assumption here is that teachers have the agency to make decisions about what they want to draw from a given written curriculum and what they want to find in alternative sources.

Third, research could question how teachers interpret their curriculum resources. Stake and Easley (1978) explored case studies dealing with inquiry in math and science education. They observed that rather than exhibiting the desired inquiry patterns, the teachers were re-interpreting and adapting the materials to fit within their traditional notions about the nature of teaching and learning as well as their beliefs about their subject matter. Specifically, teachers were still concerned with getting through the "inquiry" as quickly as possible in the interest of total coverage. The interpretive stance holds that it is actually impossible to be faithful to the instructional materials; rather, teachers are "meaning makers" who draw on their own beliefs and experiences.

The fourth conception of curriculum use is the least explored, although it significantly overlaps with the previous perspective. This conception holds that teachers interact collaboratively with the materials; they are designers. Based on Vygotskian notions of tool use and interaction, curriculum and the users of them both change throughout an interactive process. Teachers not only engage with the curriculum, they also change and learn from using these resources. Researchers are interested in how teachers change as a result of the use of curriculum resources and what teacher and curricular factors influence this relationship.

Brown and Edelson (2001) most closely align with the fourth perspective, and they provide further support for the view of teachers as designers. While some collaboration between teachers and curricular designers is likely to occur in what Brown calls a "Work Circle" involving researchers, developers, content experts, and teachers, collaboration can also occur asynchronously: lessons learned from classroom observations can be "re-evaluated to address alternative domains." Even though the designers are not present in the classroom, the curricular materials represent them; the teacher is able to collaborate with the designers in some sense. The curricular materials are able to communicate *to* the teacher, rather than *through* the teacher: this contrast between transmission and transformation is stark.

Within a transformative perspective, we can look meaningfully at questions such as what teachers read for when preparing and enacting a curriculum. Sherin and Drake (under review) considered such a question and found three general approaches: "reading for big ideas prior to instruction, reading for lesson details prior to instruction, and reading for big ideas prior to and for details during instruction." The teachers with the greatest success in achieving their overarching goals and specific elements of instruction were those who adopted the third strategy. Moreover, the majority of the teachers attended to their own understanding and use of the materials (Remillard in press). This implies that teachers are actively looking at curricular materials in an effort to understand them. Presumably, most of the teachers in the study were not satisfied being conduits for the instructional materials. They wanted to *understand* them. By doing so they would be able to interpret the materials in meaningful ways, not only for their students, but also for themselves as teachers.

Brown and Edelson (2001) also describe three types of resource use with respect to curricular materials. In many situations, teachers will adapt the materials in meaningful ways. This interpretation can take many forms: modifying lesson plans or improvising materials or connecting the content with a related area within the context of the unit. This most often occurs when the teacher sees value in the materials and understands them enough to have agency for modifying them. Instructional offload is another way teachers may use a resource. Here, the teacher simply follows the materials in a scripted fashion. When this is done because the teacher fails to understand the materials, the results can be disappointing. On the other hand, sometimes offloads allow students to accomplish learning that would have been impossible given the teacher's personal resources. Finally, at times the materials will simply suggest or influence a task or activity that the teacher develops. In these improvisations, the lesson stems from teacher's expertise rather than the designs. At different times, any teacher may use these three interactions with the curricular materials, as each has its own merits and challenges.

If the teacher is to know which of these strategies to take for a particular unit, he must understand that he is interacting with the stack of papers in front of him. The materials do not simply dictate his actions in an attempt to reach the students. Rather, they actively transform the beliefs of the person using them to enable that person to present them in a unique and meaningful way. If the materials are also created with this in mind, potential arises for changing the beliefs of physics instructors within the materials themselves, lessening the urgency of seminars and in-services[12].

Creation of Transformative Curricular Materials

A detailed analysis of what is required to make truly transformative physics educational materials for university classes is beyond the scope of this paper. However, there is need to pursue such materials in greater detail. Research should be conducted to establish what is required within such materials, and the end product of such research should be detailed advice to curriculum designers throughout physics education research. This would lead, in turn, to studies on new transformative materials to establish their successes and failures, and to improve for future iterations. Nonetheless, some of the salient features of transformative papers should be elucidated at this point to provide concrete grounding for such analyses in the future.

Explicitness is a key to transformative material creation. Not only should the manuals and guides mention appropriate behaviors such as, "have your students make predictions and discuss them," but also explain *why* such behaviors are desired. For example, the University of Washington Physics Education Group published an incredible volume of work entitled, "Tutorials in Introductory Physics" (McDermott 1998). This collection of worksheets guides students through a number of observations and leads them to form logical conclusions and create deep understandings through cognitive dissonance. Unfortunately, the only framing that is explicitly done within the workbook itself is a one-page motivation for the worksheets. Besides this, no information is aimed at the instructor of a course. What is required to make these worksheets truly transformative are explanations and scaffolding *for the teacher* to understand why questions are asked in a certain sequence. Furthermore, the philosophy behind each unit (as well as the book as a whole) should be presented explicitly, in terms a scientist can be expected to understand. Specifically, if the goal of a certain unit is for the students to appreciate the difference between a real conductor and a real insulator in terms of their properties, discussions about the abstract constituents of such materials, if not properly framed, could be antagonistic. Without explicit scaffolding by the curriculum designers, such a conflict could arise, as the instructor will not have had the opportunity to modify either his personal goals for the unit or the materials presented to him by the curriculum designer.

Furthermore, curricular materials that are intended to be transformative with respect to the instructor's beliefs about teaching and learning cannot assume that the instructor already holds the desired philosophy. Hence, constructivist materials need to be *explicitly* constructivist. If a tutorial begins with a discussion about sharing money before leading in some way to electric potential without explaining its rationale to the teacher[13], the instructor may look at the first few pages of the tutorial and exclude them because of time concerns. This could, of course, be detrimental to the lesson.

Transformative materials also must provide support for the instructor to think about assessment. As was established earlier, assessment is one of the most direct routes to accessing the underlying assumptions of a classroom. If materials that are highly focused on conceptual understanding are used in the classroom and the teacher has not been transformed from an earlier set of beliefs, then the assessment will not be well matched to what was learned in the classroom. This would lead the instructor and students to feel that the materials had failed.

Designers of curricular materials should also avoid the trap of the 1950s, when the goal was to create materials that would work regardless of the teacher. Because the teacher inevitably lends his experience, beliefs, and expertise to the instruction, the curricular materials that sit as a stack of papers or lifeless computer disc become real and valuable only when the teacher interacts with them. The teacher must be given agency by being provided with access to interaction with the materials. Otherwise, they remain as worthless tools in a classroom, like pieces of sheet music in a concert hall.

Conclusions

Because of the unique space in which university physics instructors work, curricular materials that are transformative with respect to teaching and learning are desired. Such tools would allow the instructors to grow and understand appropriate theories for teaching physics content[14] to others. They would allow them to question their motivations and goals by challenging what the instructors assess and expect their students to know. Most importantly, transformative materials would provide one avenue for a change of framework from a very traditional, passive environment to a rich, dynamic one alive with possibilities for learning.

Unfortunately, such transformative materials will require extensive research. We need to establish how to construct deep physics instructional materials with educative scaffolding for the teachers that will help them understand not physics but the educational philosophies. Furthermore, we need to test these materials, not only in terms of the students' performance on certain standardized exams like the Force Concept Inventory, but also in terms of the development of the students' and instructors' beliefs and attitudes about science, instruction and learning within science, and the specific materials that were used in their instructions. Such research would be worthwhile; transformative materials have potential to improve the dismal amount of learning that presently occurs within university-level introductory physics classrooms.

Endnotes

1. At the University of Pittsburgh, the numbers are even worse; none of the students in the "mainstream" introductory courses enroll with the intention to pursue a physics degree; rather, those students are placed in a segregated "honors" class.
2. See, for example, the work of McDermott and the University of Washington group (tutorials), the University of Minnesota group (Context-Rich Problems), and various computerized materials such as those developed by the University of Kansas (Visual Quantum Mechanics).
3. The exclusive use of the masculine pronouns within this paper is taken as a convention. Moreover, it reflects the actual (albeit disturbing) severe predominance of men as instructors in physics (although there are plenty of students of both genders in the introductory classes).
4. For more discussion about classroom culture, see "Through Different Eyes," a paper also written by the author for I&L 3486.
5. This is a reference to Dostoyevsky's Notes from the Underground: "You believe in a palace of crystal that can never be destroyed – a palace at which one will not be able to put out one's tongue or make a long nose on the sly. And perhaps that is just why I am afraid of this edifice, that it is of crystal and can never be destroyed and that one cannot put one's tongue out at it even on the sly." I like to muse that perhaps there is some inherent antagonism by students towards the beautiful abstract science that we often try to present because it lacks a quality of humanity about it.
6. At the Universiy of Pittsburgh, the only "exposure" comes when first year physics graduate students are enrolled in a "teaching physics" course which goes over board writing, lecturing, grading, and how to properly present worked problems to a class: hardly what would be considered an "education" course.
7. Smith, DiSessa, and Roschelle (***YEAR?***) argue that we need to not use the word "misconceptions" because they imply something inherently wrong with the way students perceive the world; they may have a point, but I don't wish to get into a debate here.

8. For example, a sample of Brian Wargo's data from 2004-2005 shows only an average gain of 16%. While this is a high school class, the implications are the same: (in his words) "The results are humbling!"
9. At Bethany, for example, these students are likely to appear in the same class because they are not segregated due to Bethany's small size. Hence, there is a constant tension, (for example) between pre-medical students, who want concepts and canonical problem solving preparation for the MCATs and physics majors who *want* to see the elegant structure of the discipline and derivations. This creates a difficult, and constricting, situation (from an interview with Prof. Todd Brown, April 2005).
10. See Sarason 1982, Stake and Easley 1978, Berman & McLaughlin 1973, 1978, all cited within Remillard (in press).
11. Remillard (in press) is summarized throughout the paragraphs discussing the four conceptualizations; I only cite her once at the beginning of the discussion, but my description is essentially a lightning summary of parts of her paper. In general, when I begin a paragraph with an author, I am paraphrasing his or her work.
12. These sorts of educative experiences are still necessary, especially within a community. However, rather than expecting them to appear and that instructors will attend them, the idealized approach suggested here is that materials be created to transform the beliefs of the instructors. When they experience the power of a different worldview with regard to instruction and learning, they'll naturally crave the community and workshops.
13. It is also worth noting that instructional materials can be made to be transformative to the students as well. Informal interactions with students who have engaged with tutorials (specifically those created by C. Singh and her students) have led me to believe that often students don't understand the reasons for the tutorials and feel that they are tedious and a waste of time. However, pre- and post- testing often shows that a significant amount of learning occurred. If all instructional materials (beyond such tutorials) were made transformative to the students, hopefully their morale would improve. Some degree of meta-cognition would probably benefit students significantly.

14. Presumably, college and university instructors are not concerned with teaching students scientific procedures in introductory courses. However, this might change some day, and if materials are developed with that aim, they must explicitly defend it.

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