Communities of Practice in Brazil: An Ethnographic Study of Changes to University Physics Instruction[1]

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Abstract

This study examines the impact of bringing instructional methods developed in the U.S. to an Introductory Physics course at a Brazilian university. Using participant observation, interviews, and questionnaires, we investigate the influence of cultural context on the effectiveness of the imported teaching approaches. We describe student responses to instructional approaches that were designed to change their epistemologies, interactions, and sense of responsibility for learning.

> I couldn't see how anyone could be educated by this self-propagating system in which people pass exams, and teach others to pass exams, but nobody knows anything.
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> —R. P. Feynman (1998)

In Brazil, university admissions are determined by entrance examinations focusing on superficial knowledge and problem solving in a broad range of subjects. These college entrance requirements have influenced secondary education, to the point that much of

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secondary schooling is geared toward preparation for entrance exams at nearby colleges. This is the case in the communities surrounding the Federal University at Juiz de Fora (UFJF), where first year students in the sciences, engineering, and science teaching begin their college level Introductory Physics studies after completing at least three years of test-preparation style physics instruction.

Introductory Physics students at UFJF traditionally have suffered from an extremely high failure rate. In previous semesters 70 to 90 percent of students failed the course, and many took Introductory Physics three or more times. This led to increases in class sizes to accomodate repeaters, held students back from progress toward their degrees, caused many students to drop out, and meant that the physics department was, in large part, failing to provide the community with much needed secondary physics teachers. Students who did pass demonstrated a weak conceptual understanding measured by the Force Concept Inventory, a test developed by Halloun & Hestenes (1992) for comparing different instrutional methods in Phyics classrooms. This weak conceptual understanding caused problems in the second semester physics course.

The Introductory Physics failure rate at UFJF was considered unusual, even in Brazil, where repetition is common at all levels and students repeat an average of 2.7 years of primary and secondary school (Instituto Brasileiro de Geografia e Estatística 2003). Consistent with high levels of social inequality in Brazil, the country has failed to match high-level research programs conducted by a small elite with quality universal education (Sorj & Remold 2005). Brazilian educator Paulo Freire attributed some of these problems to the "banking" concept of education, which views teaching and learning as "an act of depositing in which students are the depositories and the teacher is the depositor" (Freire 1997). It is ironic that, despite the great popularity of Freire's ideas in Brazil, banking analogies are widely used to describe teaching and learning. While students aim to accumulate facts, there is little attention to higher order thinking skills.

In an effort to address high failure rates in Introductory Physics, members of the physics department at UFJF began discussions on innovations in science education, forming a Physics Education research group involving Physics faculty, outside researchers, and advanced pre-service teachers. The group investigates student approaches to science and considers alternative instructional methods appropriate for UFJF. We questioned how student approaches to learning have been shaped by years of test preparation that required memorization of isolated facts, discouraged interaction between students, and lacked explicit connections between the physics curriculum and the physical world.

Our physics education group were influenced by the learning theories proposed by Lave & Wenger (1991), and we began with the premise that the differences between being a student and being a scientist were obstacles to learning. For Lave and Wenger, learning is a matter of becoming an effective participant in a community of practice. Newcomers are introduced to the community through legitimate peripheral participation, gradually becoming capable of full participation. The gap between what is expected of students and what scientists actually do makes it difficult for even the best students to approach full participation in the community of scientists.

We believed that an Introductory Physics course that models the work of newcomers after that of old-timers would address many of the most common student problems. We also knew that a better understanding of how interactions among students differs from productive scientists would be an important step to identifying areas for work.

To modify the Introductory Physics course, we drew from the situative learning line of research, seeking approaches that supported Lave and Wenger's idea of legitimate peripheral participation. We chose student activities that followed a course of scientific inquiry and dialog. We preferred curriculum material that could be easily adapted to the UFJF context, with particular interest in methods with low material costs that had been successful elsewhere. The methods we selected to form the new Introductory Physics course were drawn from various sources, and many had never been combined in a single course before.

Several characteristics distinguished the new course from the prior experiences of the UFJF student population. In contrast to previous work, in which textbooks and teachers were the ultimate authority, we asked students to test their thinking against nature. Unlike their previous experience, trying to passively absorb material, we asked students to play an active role in their own learning. Students who were accustomed to having products of their work constantly evaluated by teachers were asked to focus on their work process rather than the product, and were occasionally asked to evaluate their own work. Finally, we asked students, who had never worked in groups, to work together and participate in scientific dialogue.

After a pilot class in 2001, all five sections of Introductory Physics have been conducted with the new teaching methods. The results of the change are initially promising, with reductions in failure and dropout rates coupled with evidence that students have a better understanding of the material (Remold et al. 2004). But test performance is limited as a means of evaluating instruction that aims to introduce students to scientific approaches and practices. We were also interested in learning if student learning habits, interactions, and thinking about learning had changed. In this study, we ask how students changed their approaches to learning science while participating in the new Introductory Physics class.

To learn about the impact of the new Introductory Physics course, we used participant observation, interviews, video recordings of group activities, and surveys to find out about characteristics of the student experience that help or hinder effective learning in the new Introductory Physics course, and to find out how students were responding to the changes. We wanted to know to what degree students believed that their physics learning reflected on nature, how they were responding to the expectations that they participate more actively in their learning, and how the interactions between students had been influenced by the new instructional methods. We hope to use this information to understand the impact of course changes on student approaches to learning and to fine tune the course to be more appropriate for the UFJF and Brazilian context.

We begin this paper by introducing what we see as the main problems with Brazilian science education, with particular emphasis on the UFJF student population. Then we describe the changes to instruction. Finally, after explaining our methodology, we present our main observations. We found that students continue to have difficulty making connections between physics class and the physical world, but that when groups of students learned to depend on one another, they increasingly tested their ideas against nature. Students assumed greater responsibility for learning and became more active in their studies during class time, but outside of the classroom few were able to evaluate their own learning and develop independent learning strategies. We found that students adapted themselves easily to working in groups, and that scientific discussion between peers increased outside of the classroom. Nespor (1994) reports that group work outside of classroom was an important factor for academic success among physics students. Our conclusion is that the instructional methods are an improvement, but that work should continue to meet the specific needs of the UFJF population, specifically helping students gain greater independence in unstructured study situations and addressing the problems of simultaneous and contradictory worldviews.

"No science is being taught"

In the 1950's, American physicist and Nobel laureate Richard P. Feynman spent an academic semester teaching at a top university in Brazil. In a talk at the Brazilian Academy of Sciences, he described his impressions of science education in Brazil and claimed that "no science is being taught in Brazil" (Feynman 1998). Feynman saw Brazilian science education as a complete failure. He was alarmed that his Brazilian students memorized facts from textbooks without any understanding of their meaning. He described one student who was able to respond to complicated questions in front of an examining board, but gave the opposite response when he was later asked to answer the same question in different words.

Lemke (1990) believes that students learn science by learning to communicate in the language of science. Feynmann's example, and many similar cases that we'll describe later, show that some students can be quite proficient in the language of science without an understanding of the relationship between this language and nature, especially when they come from an educational system where students are conditioned to think of academic subject matters idependent of the real world. A widespread complaint of UFJF faculty is that even advanced students can follow complex scientific arguments but are unable to apply their knowledge to novel situations. Feynman remarked that even though scientific facts were present in the lectures and exams, the process of scientific questioning, using evidence to support ideas, was not part of the students academic experience. Students rarely questioned their professors and noted facts that they didn't really understand or believe. Feynmann's observations call for student work more closely modeled after the work of scientists.

Feynmann reported that he asked students why questioning wasn't part of their approach to science leaning in class. One student explained to Feynman that "If I ask you a question during the lecture, afterward, everybody will be telling me, 'What are you wasting our time for in the class? We're trying to learn something. And you're stopping him by asking a question'." Feynman found students reluctant to work and discuss physics together, and claimed that students were fearful of revealing their own doubts in front of their peers. He described a situation much like that in the story of the Emperor's New Clothes: professors believed they were making sense because all students were afraid to admit they did not understand.

Over 50 years later, many of the problems that Feynman described continue. Despite Brazil's impressive level of overall productivity in the sciences, Brazilian science education indicators are among the lowest internationally (UNESCO Institute for Statistics 2004). The Brazilian government has been successful in increasing the availability of secondary education in Brazil but problems of educational quality caused by teacher shortages, decreasing classroom time, and increasing teacher workloads are growing. At the undergraduate level, these problem are reflected by underprepared students who are not able to take full advantage of their higher education opportunity. The undergraduate Physics and Physics Teaching programs at UFJF, are extreme examples: 50 students are accepted to the physics majors each year, only an average of 10 students have graduated each year, and these students usually take much longer than the recommended four years to complete the program.

A number of students who actually attend classes and put substantial effort into their Introductory Physics studies fail courses, repeat them, and eventually drop out, in a weeding out process similar to that described by Nespor (1994). Having reached the limitations of memorization of formulas and end-of-chapter problems, they are unable to meet course requirements using the strategies that were successful in high school. But without any experience in alternative approaches to learning, they continue to try to memorize the overwhelming amount of material in their textbooks. Those who succeed enter higher level physics classes and, eventually, professions that require an understanding of physics and scientific approaches. In many cases, however, they do so without a real understanding of the concepts, without believing what they have learned, and without any experience engaging in scientific dialogue. When they become teachers, the cycle is likely to repeat.

Among students of introductory physics, the way students view learning goals, physics knowledge, and their roles and responsibilities, contributes to high failure rates. The lack of questioning that Feynman described continues. Students lack experience evaluating or planning their own learning, and have little idea about how to approach study other than by repetition. Many students are content to maintain parallel understandings of how the world works, providing answers on exams according to what they know their instructors believe without changing the way they see the world. They reported little discussion of science among peers. As a sign of how distant their physics study is from scientific work, several groups of UFJF students were unable to imagine how some of the basic concepts they had studied could be tested experimentally.

The Instructional Method

The goal of experimenting with instructional methods was to provide students with an introduction to scientific approaches, to learn about the physical world through a process of inquiry and interaction, and to evaluate their own work by testing solutions in the physical world. As newcomers engaging in legitimate peripheral participation, students participate in less complex activity that takes place on the periphery of scientific work. Gradually, it is hoped that they will participate in activities of increasing complexity and move toward the center of the sphere of work through activities, such as participation in research projects, presentations of their work in conferences, and practice teaching. We hoped that the course would provide structure for students as they make this transition, helping them become more effective participants in communities of practice.

To help students change their approach to the material, we were interested in instructional methods and materials that students could work through in groups, engaging in scientific dialogue. We looked for materials that gave students a more active role and greater independence in learning and discouraged compartmentalization of school knowledge. We asked students to test concepts they had learned and to consider their meanings in terms of the physical world. We began with the use of ConcepTests, a technique developed by Eric Mazur at Harvard, which allows students to resolve inconsistencies through short discussions during class (Mazur 1997). Students were also asked to complete Minute Reports (Angelo & Cross 1993), short writing assignments designed to develop metacognitive skills, and help students start to think about possible questions.

Half of each class period is devoted to structured group activities in which students work with the same group of peers each week, using the Tutorials in Introductory Physics developed by the University of Washington Physics Education Group (McDermott et al. 1998). These activities are designed to help students confront inconsistencies between what they think and what they learn in class. Based on the work of Heller and Hollabaugh (1992)**,** our groups were given instructions on how to approach problems and were assigned roles so their interactions would most closely approximate scientific work. Students alternate between being the leader, the note taker, and, most importantly, the group skeptic, as they work on the Tutorials. Using an idea developed by Wells & Hestenes (1995) each group is offered a whiteboard for use during the group activity. This tool is intended to help groups communicate ideas visually and mathematically, but serves a secondary function as well: the temporary nature of the whiteboard media discourages students from focusing on the product and spending too much effort on presenting solutions. To help students make that transition, groups were asked wipe the whiteboards clean before returning them to instructors.

Each week, students were given homework assignments with context-rich problems to help develop the connection to nature (Heller & Hollabaugh 1992). Homework assignments were corrected by either the professor or an assistant. Students could re-submit homework assignments after receiving feedback. Students were also occasionally asked to complete anonymous questionnaires asking them to think about their own learning and how it has changed. In the questionnaires, students are asked to reflect on what is most difficult for them and what they could do to improve their success in the course. Questionnaires provided professors with much needed information about student progress but also gave students experience with thinking about their own learning in ways that were new to them.

We were aware that since students face a real threat of failure, evaluation would be an important component of the course and would guide student priorities. In Brazil, there is a widespread belief that it is possible to rank and score students objectively and accurately. Thus, professors are discouraged from using vague evaluation standards like "participation required" and must resort to more countable criteria such as "students must ask a minimum of two questions per semester." Grading at UFJF is regulated, calculations must be transparent, and formulas for grading must include at least three written exams. Grading methods for Introductory Physics must be presented in detail and approved by the entire department. The grading system for the Introductory Physics course was therefore a compromise between educational goals and university rules.

Due to the importance of class participation, attendance was required and absences penalized. Groups were not graded for their solutions to problems, and could receive full credit without completing the activities. Groups were graded on the degree to which they approached questions scientifically, and included all members as equal participants. This led some students to take grading personally, especially when groups who had reached correct conclusions were penalized for leaving members out. Gradually, as they learned that changes to their work led to changes in their grades, the grading approach gained acceptance, especially as it became clear that working together did not require agreement of all group members. Homework assignments were graded and, since each homework assignment was intended as preparation for the following activity, lateness was penalized. Exams, which had previously been the only graded component of the course, made up only about 30% of the grade.

Grading details have varied from one semester to the next and among professors with substantial impact on student behavior. In one semester, students began their exams solving problems in groups, with each individual writing up separate explanations later. To encourage collaboration outside of class, students of several other sections were offered grade rewards if all members of their regular group passed an exam. We see a substantial difference in how group discussions develop and the degree to which students focus on scientific inquiry depending on whether or not professors request a written report on the results of group activities.

The instructional methods adopted for the course were based on methods developed for Universities and High Schools with much more resources available. At Harvard, Eric Mazur uses simple electronic devices to administer on the spot ConceptTests with multiple choice responses. At UFJF we were limited to hand raising. At the University of Washington, pretests for the Tutorials in Introductory physics are administered online before class giving instructors statistical data on what their students think before they begin supervising group activities. Wells and Hestenes had success using whiteboards to encourage interaction between group members but after the first two semesters of working with homemade whiteboards at UFJF (white cardboard covered with plastic film), the cost of replacement markers became prohibitive and the department switched to small chalkboards which meant diagrams were slower to read, write, and modify.

Budget and infrastructure limitations placed a number of other constraints on the day to day details of the course. Classes were scheduled in rooms that easily fit 50 students in rows facing a chalkboard in front. But when the same space was used to organize students in small groups, the space became a limiting factor causing problems with noise levels. Classroom conditions that were less than ideal for lecture format classrooms and class sizes became much more problematic when students tried to work in groups. In sections where enrollment was full, acoustics were a major problem with students huddling together, cupping their ears, shouting, and struggling to communicate in the space.

There were no available classrooms with small tables or flexible setups to facilitate small group discussions. In groups, students formed circles while sitting in chairs with small individual desks attached to them. The desks inclined toward the students making it difficult for peers to share written material and white boards, even when students were grouped around the white boards, the incline of the desks meant that is was angled toward one person. Space limitations were also apparent in how students worked together outside of class. Though surveys and interviews revealed that students who worked together outside of class found the experience valuable, it was impossible to facilitate formal study groups because the department lacked a student meeting or study area. A small locker room for physics students was occasionally used by a few groups for study but its single table was usually full.

The limitations of available infrastructure, especially adequate space and appropriate seating arrangements for group work were not introduced with the new instructional method, seating space with a view to the chalkboard and acoustics were less than ideal for lecture classes as well. But these limitations were more apparent with the revised course, especially when students were asked to work in groups, discuss with neighbors, or respond to lecturer questions.

Methodology

Before implementing instructional changes, we considered student background and the kinds of interactions that the community of learners brings to the course. Later, after the initial semesters, it became clear that fine-tuning the course to the UFJF context would require a better understanding of how student approaches to science and peer interactions changed during the course and how students responded to unfamiliar approaches to learning. We hoped to understand more about the students as they entered the course, how students approached science, and how they interacted when working together, when they believed they were learning and which activities they judged as valuable. We used participant observation, interviews, and surveys to find out about characteristics of the student culture and experience that facilitate or complicate student transitions to a collaborative and interactive approach to learning.

During the first semester of 2002, one of the authors, an outside researcher, observed classes and group activities. During the second semester of 2002, a different author, at the time a graduating senior in the Physics teaching certification program, participated in the class and documented details of group interactions. Though he participated as a student, the reason for his participation in the class was explained to students. Although the period of participant observation is relatively short, 2 semesters of participant observation during class time and other activities, all three researchers were involved in full time activities in Brazilian universities in different capacities. During the semesters of participant observation, we also conducted several informal conversations and interviews with former and current students and began videotaping some group activities. Finally, an anonymous questionnaire was distributed asking students to indicate which of several resources (books, colleagues, etc.) were most useful to them during the course.

All three researchers also took advantage of informal opportunities to find out about how student approaches to science were changing through participation in the course. These opportunities were frequent and varied, from informal conversations during lunchtime to a former student who we picked up as a hitchhiker one afternoon. Though students knew that the professor was involved in course development and that the research group was optimistic about improving the course, we did not find a trend of more complimentary comments concerning the teaching methods in discussions with him. In fact, students who had objections to the course usually chose to discuss them with the professor during office hours rather than the other two apparently more neutral researchers.

In our research we were interested in having a more complete picture of the community of student learners, their interactions, and their ideas about learning science. We were specifically interested in how the instructional changes influenced three key characteristics of student approaches to physics which the research in this area indicates are important to student success. First, we were interested in how science learning changed students' epistemological views, i.e., the degree to which they either drew connections between what they learned in the course and nature or compartmentalized school knowledge separate from their actual beliefs. Second, we were interested in student responses to a course that required more active participation and new responsibilities for their own learning. Third, we wanted to know how students would engage in dialogue with one another and if, after years of isolated study, they would be interested and able to work together effectively.

Nature versus Teacher

Research in physics education shows that an epistemology in which science is seen as a collection of facts disconnected from one other and from the physical world is problematic for students (May & Etkina 2002; Lising & Elby 2005) and that students benefit from relating the content of what they learn to the real world and using their knowledge. The problem of maintaining separate worldviews, one that the student believes and the other that they maintain for school, can be addressed through activities that ask students to test their ideas. The Tutorials for Introductory Physics developed at the University of Washington help to address this problem by demonstrating that physics concepts are meaningful and can be applied to real situations. But in a setting like UFJF where concerns about grades, especially the threat of failure, have distracted students, shifting their priorities from a focus on nature to a focus on their professors. Regarding instructors as the ultimate authority, even when their ideas seem to contradict nature, limits student questioning and detracts from their development as scientists and science teachers.

One reason for maintaining alternative worldviews is that students are often not able to relate what they are studying in the classroom with natural phenomena. Many physics textbooks illustrate concepts using examples that do not exist in nature. For example, in textbooks cars are often point particles (with no width, length, and height), and students are asked to imagine frictionless inclined planes. Brown, Collins, & Duguid (1989) describe school activities like these, in which the successful student must ignore common sense when working on school problems. This encourages successful students to maintain two independent contradictory worldviews, learning to ignore what they know when working on school assignments. We found that this kind of thinking exists in Brazil as well as evidenced by several cases where students ignored not just their own common sense but even their personal experience believing instead what they remembered from formal instruction.

Working in isolation from peers may also contribute to the problem of compartmentalizing school learning. Palincsar (1998), discusses the advantage of learning from peers over learning from authority figures. He refers to the increased likelihood of new ideas changing the learner's worldview after discussion between peers. We hoped that UFJF students would convince one another of complex concepts as they worked through tutorials and other activities together.

When students test their ideas against nature, we can infer that they believe in the connection between what they learn and nature and that they are changing their worldview in response to what they learn. In contrast, when students aim to predict what the professor thinks, we conclude that they see no connection between what they are taught and nature. Students at UFJF have demonstrated both of these behaviors. One student enrolled in Introductory Physics for the third time explained that he understood the material but continued to fail exams because he was never sure if the professor wanted him to answer with what he believed or what he knew the professor believed. This remark is similar to comments reported by researchers at well known universities in the United States. Eric Mazur (1997) reported a nearly identical remark from a Harvard student. This outlook can be problematic because students who learn new material without believing it rarely apply what they learn to non-standard problems and new situations.

Another example demonstrating that students fail to connect course content with nature is the behavior of students who are repeating the course. These students often sit at the back of the room, holding separate conversations during class. Though they appear to be ignoring the class, they are paying attention to the lecture and discussion, often trying to guess the next key vocabulary word the professor is going to use. For example, when the professor introduced the concept of motion and the need to describe it by using quantities that have both size and direction, students in the back began to mumble "vector, vector, vector," repeatedly, until the professor finally used the word "vector" in his explanation. The students who correctly identified the name for the idea usually show clear signs that they were satisfied to have guessed or remembered the key word.

Since definitions of key vocabulary are often required on secondary science exams, we believe that this focus on naming things and satisfaction with being able to identify vocabulary is a consequence of excessive focus on what students believe professors want. As a response to an education system that tests students frequently on a wide range of superficial knowledge, many students have shifted their focus toward identifying key vocabulary, with little attention to how the isolated facts they learn can fit together to describe their world.

After the change in instructional approach, we observed students increasingly testing their ideas through peer feedback and observations of nature. Frequently, while working in group activities, in the midst of heated discussion, groups would completely erase their whiteboards and begin working on the problem again with a different approach. This indicates a focus on scientific inquiry and independence in challenging their own ideas and approaches, something that scientists do all the time. Having recognized a contradiction in their results, the groups begin working on the problem with a different approach. We believe that this reflects a transition toward legitimate scientific inquiry with a focus on justifying and testing ideas.

Despite some improvement, separate world views continue to be an area of great difficulty. While some students quickly and happily make the epistemological transition, those who fail to change their focus toward nature during the first months of the course often wind up repeating and continue with the same difficulty in subsequent semesters. The University of Washington Tutorials have been helpful in bringing up inconsistencies between what UFJF students believe and what they learn. For example, while working on a tutorial on forces, one group of engineering students was confused about "the possibility that something can move without a force in the direction of movement." They realized that something was wrong with their reasoning and discussed the matter for several minutes before asking for help. In dialogue with the instructor, one of the students made an excited realization of one of the most difficult and unintuitive concepts in Introductory Physics: "so... there's is no need for a force for it to move. Force causes acceleration! Physics is cool."

But not every group was able to make this transition, many students preferred guidance from the professor or TA over examples from nature. In the example below, three students discuss a problem involving a person pushing a block. After struggling with identifying all action-reaction pairs, one of the students notice something wrong with their diagram, the force of friction seems to be pointing in the wrong direction. To explain his point, he gives an example from his everyday experience asking his peers which direction their feet slide when pushing a large object. With the incorrect drawing in front of her, another student claims that her feet slide toward the object she pushes. In this case, she ignores her real life experience when it is inconsistent with the diagram in front of her.

> Student A: Levanta e tenta empurrar a parede. [Get up and push the wall.]
> Student B: O que? [What?]
> Student A: Levanta e tenta empurrar a parede. [Get up and push the wall.]
> Student A: O seu pé vai estar fazendo isto. [Your fee will do this.]
> (He presses his hand against the wall, demonstrating the motion of the foot away from the wall. Nobody in the group gets to try his experiment.)
>
> [...]
>
> A: Então, se cê tá empurrando, o seu pé, a tendência dele é puxar pra trás. Então o atrito vai tar fazendo isso, ó. [So, if you're pushing, your foot, its tendency is to push toward the back. So, friction will do this, look.]
> (Draws the direction of the friction and the motion on the chalkboard.)
> C: É ué. [Yes, that is what I mean.]
> A: Quer dizer, a força do seu pé tá pra cá. [That means, the force from your foot points toward here.]
> (Shows a direction opposed to the motion.)
> C: Não, seu pé vai tá exercendo a força pra frente. Vai empurrar pra frente. [No, your foot is making a forward force. It will push forward.]

Finally, the students decide to call in the TA for help with this inconsistency. Even though Student A initially suggested that his theory could be tested by trial, standing up and presing a wall, the group eventually called in a TA to resolve the question rather than have someone stand up and push against the wall.

On several occasions, we have observed the transition from school focus to nature focus as an isolated moment. In most cases testing ideas in nature is something that students either do consistently or never. We think that if we had time for students to complete all of the activities, more students would experience this critical moment of discovery. Unfortunately the tutorials often take much longer than the available class time, even though students at UFJF have twice as much class time for tutorials than students at the University of Washington, where the tutorials were developed.

Legitimate Participation

One student described her initial reaction to the course and explained how her opinion changed throughout the semester. She said that at the beginning of the semester, she didn't like the course, but that later she came to change her opinion, and decided that what she hadn't liked initially was being forced to think. Researchers have identified a tendency for science students to view learning as a matter of passively receiving knowledge from professors. UFJF students often declare openly their efforts to "absorb" or "receive" material. Involving students more actively in their own learning is therefore a challenge. We found that the new method did successfully involve students more actively in their own learning and helped them build more independent learning skills. But in many respects this improvement was superficial. Even those students who had completely changed their approaches to learning continued to measure their success by the number of facts they had "taken in."

Effective participation in communities of practice requires that students assume an active role in their learning, taking personal responsibility for the learning process. This is reflected in a range of changes to student work including making choices and developing strategies for their own learning and evaluating new information. We look for evidence that students are considering the content of the course, comparing the content with the physical world and trying to make sense of the material. A stronger sense of responsibility is evident when students continue working on their tutorials after class or meet outside class to discuss the material, we can also find cases where students draw from real life examples to support or dispute material in the course rather than deferring to textbooks or instructors.

We saw improvements in this area throughout the course but in group discussions, it was not clear that reasoning supported by evidence from the real world had more weight than other types of evidence when disagreements occurred. Sometimes students showed decreased dependence on the authority of the professor and assistants in approaching group assignments and worked among themselves to justify their ideas and conceptions. But when peers disagreed, there was a strong tendency to refer to the authority of the instructor rather than consider examples from nature.

One group was working on an activity that asked them to consider the forces at play when a person pushes on a large block. To settle a dispute about the interaction between the person and the ground, one member of the group asked his peers to draw from real world experience, he asked; "Which direction do your feet slide if you are standing and pushing something heavy?" His peers looked at their papers and answered that your feet slide toward the object you are pushing. Surely they had experienced the sensation of their feet sliding away while trying to push heavy objects but their approach to physics problems was so disconnected from the physical world that rather than refer to their own experience, they looked at their diagrams, where they had already incorrectly drawn in the force in question from memory. The group eventually waved down a TA for help resolving this disagreement. In this example we see student thinking supported by personal experience with the physical world, rules memorized from prior instruction, and instructors. Ultimately confirmation from the instructor was needed to resolve contradictions between the other two. Perhaps student levels of confidence in their real world experience could be improved if instructors provided feedback with real world evidence as well.

Another issue related to student confidence levels was evidenced by student reluctance to make mistakes. We noticed that students had some reluctance to experiment with addressing unstructured problems through trial and error, and that their concerns focused largely on not wanting to get things wrong the first time. During one activity, a student made the following remark:

> Rapaz, é melhor você não botar e falar que não fez do que botar e depois tem que ficar apagando para fazer de novo. É melhor não fazer. [It's better to not put

anything and say we didn't do it than to put (an answer) and later have to erase it and do it again. It's better not to do it.]

Students showed even more unease with the possibility of not getting things right the first time when there was disagreement between peers. In several groups working on tutorials, skeptics questioned inconsistencies in their group leader's thinking. The challenges were difficult to resolve within the group. The roles were designed exactly in the hopes that inconsistencies would be discussed within the groups, but often discussion would come to a halt if skeptics followed their role. Groups would turn to the TAs or professors to settle competing views rather than discuss inconsistencies within the group. In one case, after a very calm disagreement between members of a group in which they debated without interruption or change in tone of voice, everyone put their pencils down, stopped talking, and the entire group began energetically flagging down the TA. When the TA arrived they asked for help remarking that the conflict was getting out of control.

> Student 1: Dá uma luz para a gente, porque o negócio tá ficando feio. [Enlighten us, because things are getting ugly.]
> Student 2: Tá quase saindo porrada aqui. [It's practically a fistfight here.]

This is a phenomenon we have not seen reported by American researchers using the same materials. Perhaps students at UFJF are less comfortable with the idea of contradicting one another than U.S. students. It was for this reason that the instructor continually provided feedback on how well students were carrying out their roles, especially the role of the skeptic. He would check group work and then remark that yes, they had gotten to the right answer but he would then ask what kinds of challenges the skeptics had come up with to test the work. His focus was always on the skeptics role in helping to refine the leader's thinking.
Students in group activities also seemed to continue their focus on what the professor was looking for rather than considering nature as an authority. When they compared their opinions, rather than talk about what they think or what they believe, they would refer to what they planned to put on their answer sheets or what they would put on exams given a similar question. Much of the group discussions seemed to focus on what the professor expected of them, which often led groups to devote enormous amounts of class time to irrelevant details. After giving careful consideration and making a series of unnecessary calculations irrelevant to the group assignment one leader said:

> Se esquecer disso na prova, já era. [If you forget that on a test, it's over.]

This attention to detail often seemed to distract students from the questions they were supposed to be discussing. They voiced a great deal of concern over whether or not they had forgotten to do something that was expected of them, and often continued seeking to give more information, labels and formulas for responding to questions long after they had actually finished the assignments, as though they believed the assignment contained trick questions. These strategies are generally effective in a school setting, but proved time-consuming and appeared to distract groups from reflection on their work. In one example, students were asked to draw a free body diagram to help them identify all of the forces at play in a particular scenario. Rather than freely sketch and label arrows representing forces, groups often took painstaking care on making their diagrams appealing on the eye. One group drew illustrations of the objects and people involved in the scenario while another used rulers to carefully ensure that all arrows were drawn perfectly. Many groups drew and re-drew the same diagrams. Students clearly saw the diagrams as the product of their work rather than as tools they would develop to help them think about the problem.

The group activities were successful in focusing student attention on nature while they thought about and discussed problems but not to the exclusion of the types of concerns that have distracted them from scientific thinking, principally concerns about getting things wrong and attention to what professors are looking for.

The assigned roles helped students in developing critical approaches to problems. At the beginning of each semester, students had difficulties with the role of the skeptic, possibly because openly confronting another person's ideas is so unusual in Brazilian education. With the help of the assigned role of skeptic, students gained increasing competence in raising relevant questions that moved group discussions forward. In one semester, the professor decided to experiment with not assigning roles for group activities. Several weeks into the semester, the professor noted that a group was having trouble making productive use of their discussion time. He introduced the idea of assigning roles of leader, note taker, and skeptic, and participated in the group discussion for about 15 minutes to exemplify the role of the skeptic. A week later, the group approached the professor after class to say that the use of roles had improved their group interaction. One student said the following.

> "Before having the roles, we would each work separately, and would compare our conclusions at the end. Often, when I wanted to compare my results with someone else, the other people in the group would be working on other parts of the activity, and I would just give up discussing and keep going on. With the note taker and the skeptics, everybody discussed, and we found out that we were not really understanding some concepts."

Sometimes, at the end of the classroom time, recognizing that they were running out of time to complete the activity, groups of students would suddenly abandon the process of group discussion and try to finish the activity independently, comparing their responses afterwards. This was more common in classes where responses were collected by the professor at the end, but it became less and less common throughout the semester, as students were reminded that grading would be based on the group process rather than the solution.

Students showed an increased commitment to their work and responsibility for their own learning, even when the professor was not present. On several occasions, students stayed to discuss their work long after the class was over, often staying in the classroom for as much as 45 minutes after the end of the class time, at the expense of their lunch breaks. One student who had already passed the course, returned during the subsequent semester to repeat some of the activities that she believed were not yet clear to her. Some students had been willing to continue discussions after class time had ended in previous semesters but when the activities were introduced, the number of people who chose to stay after class increased. In some cases, professors found it helpful to try to make arrangements for classrooms that would be vacant for the subsequent class period.

Helping students develop independent learning strategies is an important component to active learning. Given their educational backgrounds, we knew that UFJF students had little experience with metacognition and would need help in evaluating their own learning. Throughout the course, we presented metacognitive activities, asking students to think about which parts of the course were most difficult, what was surprising to them, and what they thought they needed to study more. Despite this effort, students continue to demonstrate much more productive use of time in structured activities, and very little ability to study effectively outside of class. Students are often surprised by the feedback they get when they receive homework assignments, often expecting that they understood the material they are taken by surprise to see the corrections to their work. When students have difficulty, they often don't know how to express their questions. We believe that independent learning strategies are new for these students, that direct attention to this area is important, and that continued difficulty in this area indicates a need for further work.

While there is no question that students changed their approaches to learning, especially in the group activities, it is not clear how much of this change has influenced their learning goals and will be carried on to other courses. When students expressed satisfaction over their accomplishments in the Tutorials, they talked about how the Tutorials helped make the material easier for them to remember. Students did not recognize their participation in the group activity as having intrinsic value and instead saw it as a vehicle for more efficient individual learning.   They also continued to evaluate their own progress in terms of improvements in fact recall. Even though students who have completed the course continue to study together in later semesters, we are unsure about the degree to which students are practicing the scientific questioning introduced to them in Introductory Physics.

In one semester, the professor attempted an experiment with the exams. Given that an important component of the course was collaborative, he decided to allow students to work in groups during the exam. He divided the exam into two parts: the first part was a context-rich problem, to be completed in group, and the second part, to be worked individually, had a series of specific questions about the solution of the problem from the first part. At the beginning of the semester, when the professor explained the scheme to the students, they were excited about it. But as soon as the first exam was over, it became clear that the idea was a complete failure. Many students reported that they did worse on the exam than they would have individually even though they thought the collaborations were helpful during regular classes. Apparently under the pressure of a grade, students abandoned the process of scientific discussion and. The result was a collection of non-sensical resposes to the questions. This experience calls into question the degree of confidence students have in their collaborative techniques when they're focused on getting the job done.

Peer Interaction

Effective legitimate peripheral participation requires that students take an active approach to their learning and group participation. From the student point of view, the presence of group work is the most obvious difference between Introductory Physics and their other courses. While many components of the course are new to them and many of the course objectives differ from other introductory physics classes, students were most aware of the group component and often referred to the instructional method as "the collaborative method." When asked for opinions of the method, students will almost always give opinions and anecdotes about working in groups. This is not surprising, since only one out of 42 students in the first class (a graduate of the University School of Education application high school) reported ever having been asked to do group work in school before.

The Tutorials, developed at the University of Washington, were designed with U.S. students in mind. Learning to work together is an explicit part of the curriculum in the U.S. as early as kindergarten. There was initial concern that students without this background, with no experience working together, might have difficulty with or object to working together. But students at UFJF were very receptive to group assignments. Educators interested in peer interaction in the U.S. have described common complaints of students who prefer individual assignments over group assignments. These complaints were rare at UFJF, few students claimed that they preferred to work alone or found their group was holding them back. Some students complained about working in groups but their primary concern was that with group activities came mandatory attendance. Those who did complain about the group activities themselves, preferred to study independently from books at home, but no students commented on the reduced lecture time. During the first classes, when students first learned that they would be divided into small groups, several students complained, but this general negative attitude toward group assignments did not continue in subsequent classes.

Some students spoke with the professor privately about concerns related to the group activities. Issues raised during office hours related to problems with individual group members whose participation level was regarded by peers as inadequate. When students talked about these problems, they revealed that they recognized the potential value of a more productive group discussion. On several occasions students reported a connection between the productivity of their group and how well they learned. One student visited the professor after a member of his group was transferred to a different group. He was concerned that the transfered member was key to the interactions, and that without him the dialogue had become less productive. He said “I know that I am not going to learn well if our group does not discuss well.” Similarly, other students have expressed interest in being placed in the groups that they regarded as more productive.

When students sit down to approach the group assignments, they often begin by using colloquial language to talk about physics concepts, perhaps not yet comfortable with the technical language that has just been introduced. As it becomes increasingly clear that their discussions require more precise terminology, they begin to use formal definitions and technical vocabulary. During several group activities student made several unsuccessful attempts to communicate a complex idea to his peers. On his fourth attempt, using the technical vocabulary from the previous lecture, his group understood what he was saying. Through the group interaction, he went one step beyond understanding a concept from the lecture to actually using the conceptual tools offered in the lecture material to communicate.

The use of whiteboards was also connected to students abilities to be productive members of their groups. During group activities, students were asked to use a small whiteboard as proposed by Wells & Hestenes (1995), so that all members of the group could see the formulas and diagrams involved in solving the problem. The whiteboard helped groups communicate and build on ideas and prevented members from splitting off to work individually. Toward the beginning of the semester, it was typical for groups to leave the whiteboard completely blank until they had finished the tutorial, and then use it to document their solutions. After several classes, the instructor asked students to wipe the board clean when they were done, making it clear that the whiteboard was a communication tool and not an answer sheet. Gradually, with more experience in the group activities, students started using the whiteboard to make visual and mathematical representations of their ideas during their discussions. The level of sophistication and standardization of these representations showed an increased proficiency in communication. The whiteboard became a tool much like the technical vocabulary they began to share, helping to build the base of knowledge within the group.

Overall we see students learning to communicate ideas, and we showed elsewhere that this resulted in lower failure and dropout rates, along with some evidence that they have gained a better understanding of the concepts (de Barros et al. 2004). Not only are students more productive in interaction with one another, but many are even aware of these advantages. We see discussion increase in richness throughout the semester, as students develop into better group participants. Students who completed the new Introductory Physics course claim that they continue to study in small groups, even when it is no longer a class requirement. Some students report more discussion of ideas among peers who have taken the new course, as opposed to graduates of the previous method.

Conclusions

Throughout the course we saw improvements in the three areas of student approaches to learning that we investigated. We found that an increasing number of students approached their learning more scientifically, clearly showing that they thought of the material within the context of the natural world, instead of maintaining separate worldviews for school and real life. Despite improvements, some students continued to maintain separate worldviews separating school knowledge from their own common sense, these students were much more likely to repeat the course. On several occasions, we witnessed moments of discovery, in which students made their first connection between physics class and the physical world, indicating that, at least for some students, this transition is a dramatic event that changes the way they view science and science learning.

Students at UFJF adapted well to a course that required that they take a more active approach to their learning, but many continued to regard their learning process as a matter of retaining information. We found that students had very little experience in questioning and critical thinking, but that most were able to approach questions critically. Students generally accepted their new responsibilities in the learning process, but continued to evaluate their own success in limited ways. Instead of viewing their improved abilities to participate in group problem solving as an achievement on its own, they continued to see their participation as a vehicle for higher test scores and better content retention. Instead of thinking about how their understanding of mechanics had changed, many students were interested in how their ability to solve standard problem sets had improved.

Students generally welcomed the opportunity to work in groups and to work on activities that allowed them to apply the concepts they had learned. They gained proficiency in using conceptual tools and communicating complex ideas. Contrary to Feynman's findings in the 1950's, UFJF students were willing to expose their doubts to peers. Their only difficulties in effective collaborative work were in criticizing peers and acting as skeptics. Because of this, the structure of the group activities and the assigned roles were a critical component to the success of the course. The fact that students continued to study together in subsequent semesters indicates that Introductory Physics helped them become both more independent and more collaborative during the course.

After the initial pilot semester and expansion to all five introductory sections, the Physics Department officially adopted the changes to the Introductory Physics course and facilitated it with co-ordinated scheduling and equipment funds. Findings from this study indicate that the course should continue to be developed each semester, and that apparently minor changes, such as changes to the grading practice, have a significant impact, and should be studied in greater detail. While these first semesters indicate that imported teaching methods can work at UFJF, ideally, attention to detail must continue as the course is adapted to the needs of UFJF students whose limited experience in non lecture-recitation format classes requires more gradual reductions in the amount of structure in interactions, and more emphasis on illustrating connections to the natural world. Finally, considerations must be made for making the course objectives more explicit to students. Teacher-certification students who participated in the course during their first semesters will soon begin teaching, and several claim that their experience in Introductory Physics will have an impact on the way they teach.

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