PROJECT SUMMARY

The problem: There is a need for increased conceptual and mathematical understanding when teaching intermediate mechanics courses in physics. Future scientists, future secondary science teachers, and future engineers who take these courses must create an effective bridge between the mathematical reasoning emphasized in most physics classes and the physical sense-making that will guide their future work and life-long-learning. Although much work in PER has been done at the introductory level, little has occurred in the context of upper division courses.

Objective: Using past success as a template, the collaborating PI's will develop *Intermediate Mechanics Tutorials*, a set of at least 23 tutorials, including pencil-and-paper conceptual tutorials (15), mathematical tutorials (4), and computer-based tutorials (4), for the purpose of enhancing instruction in intermediate mechanics. Each tutorial will be accompanied by a pretest (ungraded quiz), homework problems, and post-tests (exam questions). Tutorials will be designed to allow flexible implementation in lecture, studio, laboratory, or seminar courses.

Intellectual Merit: The collaborating PI's have experience in curriculum development based on research into student reasoning, the promotion of learning in light of student difficulties, and the dissemination of curriculum materials to instructors throughout the country. The lead PI, Michael C. Wittmann, is primary author of *Activity-Based Tutorials (ABT),* published by John Wiley & Sons as part of the *Physics Suite* that accompanies the Cummings, Laws, Redish, and Cooney text, *Understanding Physics.* The *ABT* are proven, education research-based curricular materials for introductory and modern (quantum) physics that promote mathematical reasoning and use computer-based tools to enhance conceptual understanding of the physics. The collaborating PI, Bradley S. Ambrose, is a proven author of segments of the *Tutorials in Introductory Physics,* published by Prentice Hall and used nationwide by thousands of students. Both these projects have been supported by extensive NSF support. Ambrose will focus on conceptual tutorials, while Wittmann will focus on the others.

Tutorial materials will act as supplements to (rather than replacements of) regular lecture instruction. Such materials have not been developed for the intermediate (or advanced) mechanics courses. Materials will address specific difficulties students have when learning the physics. Having the materials in place will allow for greater understanding of what student difficulties in intermediate mechanics are; PER data will not only enhance future versions of these materials but help instructors unable to use the materials in their classes.

Evaluation: The effectiveness of the instructional materials will be evaluated through the analysis of data gathered using typical methods in physics education research (PER). These include pretest and post-test data and the use of standardized tests of conceptual understanding and attitudes toward science learning. Results will be compared to data gathered in previous years of instruction.

Outcomes: Materials, once proven successful at the collaborating two institutions, will be disseminated to additional users. Successful completion of the proposed project will result in:

1. a set of deliverable small-group teaching materials, "tunable" to many instructional settings,
2. documented improvements in student learning when compared to instruction that did not utilize the tutorials, and
3. documented improvements in student attitudes toward science, the endeavor of learning science, and the roles of conceptual and mathematical understanding in learning science.

There is a plan for publication and dissemination to make the curriculum (and the evidence supporting its effectiveness) nationally available.

Broader impact: A coherent set of materials can be created for teaching intermediate mechanics more effectively. These materials will reach future scientists, teachers, and future university faculty. The research-based development work will inform other ongoing PER investigations, including those in introductory courses, thus impacting a much broader audience than just physics majors. Furthermore, dissemination to interested (non-PER) physics faculty members will help them learn about and utilize innovative teaching methods without the logistical burdens involved with introductory courses.