Undergraduate Learning Outcomes

Department of Physics

1. Students develop conceptual understanding and scientific reasoning skills

This component requires familiarity with basic concepts and physical understanding across major sub-fields, including mechanics, waves, electro-magnetism, optics, quantum mechanics, nuclear physics, and relativity. The level of understanding excludes advanced mathematical methods but includes critical and educated physical reasoning.

- Ability to solve novel (not previously seen) problems

  Students must be able to possess a robust conceptual understanding of the subject matter. They should be able to productively analyze novel situations (previously not discussed in class) and apply a chain of intellectual steps that starts from fundamental physics principles and leads to a prediction or inference.

- Ability to apply scientific reasoning skills

  Students should possess an ability to apply scientific reasoning skills that are typically referred to as a five-step pattern: (1) make a puzzling observation, (2) generate a hypothesis to explain the observation, (3) use the hypothesis to generate a test and determine predictions for the outcome of the test (deduced from the hypothesis), (4) conduct experiments to test the outcomes, and then finally (5) compare predicted and observed results to determine whether the hypothesis has been supported or rejected.

2. Students develop problem-solving abilities, which includes

- appropriate use of mathematics;
- ability to fluently connect different representation (e.g., graphs, diagrams, mathematical expressions, verbal descriptions);
- use of approximations and awareness that approximations imply ranges of validity;
- visualization skills;
- solution-checking and ability to test limiting cases.

3. Students develop rigorous quantitative understanding of core physical theories

This component employs advanced mathematical methods and targets core physical theories in classical mechanics, electromagnetism, quantum mechanics, and thermodynamics/statistical mechanics.

Example learning outcomes for thermodynamics: recognize the deductive nature of thermodynamics starting from thermodynamic theorems, recognize minimum principles of thermodynamic potentials, construct thermodynamic potentials from equations of state, transform between thermodynamic potentials, derive and apply Maxwell relations, characterize phase transitions of first and second order, understand properties of phase diagrams, develop ability to apply thermodynamic relations to specific systems such as non-ideal gases, mixtures, and chemical reactions.

4. Organized knowledge of the major branches of physics, which includes

- ability to distinguish between classical, quantum, and relativistic regimes;
- ability to make connections/links between concepts covered in different courses;
- ability to recognize physical properties of real systems on varying time and length scales;
- understanding of how physics knowledge has shaped our understanding of the world and how it may help to solve complex problems in the future.

5. Computational and Laboratory Techniques

Students should develop familiarity with:

- a range of experimental methods in order to design, perform, document, and analyze advanced experiments in physics;
- programming techniques, basic algorithms, and numerical methods.

6. Communication skills

Students should be able to justify and explain their thinking and/or approach to a problem or physical situation, in either written or oral form. Specifically, they should be able to

- give formal and informal scientific presentations to various audiences, including peers (e.g., capstone presentation)
- communicate clearly and concisely in writing (e.g., written HW solutions, lab reports, capstone reports)
- participate effectively and productively in group work and class discussions.

7. Ability to Complete a Guided Research Project

Students must acquire abilities to conduct an in-depth investigation of specific physical scenarios. Students must be able to:

- conduct an effective literature search;
- apply appropriate methods and technique to collect, analyze, document, and process data/information;
- use the scientific method;
- write at least one formal research paper and one research proposal.

8. Intellectual Maturity

Students must:

- develop an awareness of the current limitations of physics and their own knowledge (i.e., perform quality control);
- develop ability to detect pseudoscience;
- develop and demonstrate strong work ethic, which includes integrity, sense of responsibility, emphasis on quality, and team work skills;
- recognize the interdisciplinary nature of contemporary physics (i.e., biophysics, medical physics, computational physics, physical chemistry).

The set of outcomes developed by the Department of Physics is in agreement with the undergraduate learning outcomes approved by the University and, at the same time, reflects discipline-specific requirements.

The set of outcomes was synthesized by the physics department assessment committee based on the department-wide discussions with the faculty, staff, and students. At least three faculty meetings over the period of 6 months were dedicated to the in-depth discussions of the learning outcomes. Following each meeting, the faculty were encouraged to submit their contributions to this report in writing. The faculty written responses were posted on the Physics Department Blackboard page. In addition, the following sources of input were utilized, which greatly informed the development of the learning outcomes.

- ***The Physics Department laboratory committee*** provided information regarding the quality of the physics laboratory courses.

- ***The mid-semester and end-of-semester student surveys*** administered in the introductory physics courses provided student feedback related to students' experiences, views, beliefs, and expectations in these courses.

- ***An extensive chair evaluation*** provided formative feedback from faculty, staff, undergraduate and graduate students related to a wide range of department activities, including teaching, advising, and research. Two sets of surveys were developed. One survey was administered among the faculty and staff; the other was given to the physics graduate students. In both cases, responses were anonymous and an option was provided for free form text response for the evaluation of individual statements.

- ***Student surveys related to reformed formats of introductory physics courses.*** The majority of physics faculty are engaged in the implementation of elements of reformed instruction in large enrollment introductory physics courses. As part of the implementation, the faculty administer targeted surveys related to specific aspects of a course (e.g., clickers, pre-tests). Results of these surveys informed this report.

- ***The Society of Physics Students*** meets with the physics faculty regularly. Both formal and informal interactions between the students and the faculty often address Issues related to the teaching, learning, advising, and research in the department. Since the majority of our undergraduate physics majors are deeply involved in the department teaching and research activities, the students' feedback received during such conversations is particularly valuable. For example, student comment on courses (or request new courses) that are of special interest to their current and future work.

Desired learning outcomes, opportunities to achieve, and assessment strategies

Desired learning outcomes	Opportunities to achieve		Assessment strategies
	Introductory courses	Upper division courses and other opportunities	
Conceptual understanding and scientific reasoning skills • Ability to solve novel (not previously seen) problems • Ability to apply scientific reasoning skills	Phys 251, Phys 252, Phys 251R, Phys 252R Phys 251L, Phys 252L	All courses All courses	1. Performance on regular course exams (both in multiple-choice and free-response formats), standardized pre- and post-tests (in multiple-choice format), research-based pre- and post-tests (in free response formats) 2. Observations of student group work and class discussions 3. Assessment of the quality of student lab reports 4. Assessment of the outcomes of in-class projects (both individual and group-based), capstone project, and individual research projects
Problem-solving abilities	Phys 251, Phys 252, Phys 251R, Phys 252R, Phys 251L, Phys 252L	All courses	
Students develop rigorous quantitative understanding of core physical theories	*Preparation through:* Phys 251, Phys 252 and various math courses	Phys 261: E&M, Phys 455: Class. Mechanics, Phys 462&463: Thermo & Stat. Mechanics, Phys 485&486: Quantum I&II	Strategies 1-4 above and 5 5. Assessing the quality of the problem-solving techniques employed by students in their group work and well as in problem-solving by students on a board
Organized knowledge of the major branches of physics	*Initial opportunities:* Phys 251, Phys 252	All courses	Assessment of the quality of capstone projects and research presentations
Computational and Laboratory Techniques	Phys 251L, Phys 252L	Phys 360, Phys 370, Phys 411L, experimental research	Assessment of the quality of lab reports

Desired learning outcomes	Opportunities to achieve		Assessment strategies
	Introductory courses	Upper division courses and other opportunities	
Communication skills			
• give formal and informal scientific presentations to various audiences, including peers		All courses, presentations reporting on capstone project and undergraduate research	Assessment of the quality of classroom presentation, capstone presentations, *Undergraduate Research Day* presentations (both oral and poster), presentations at national and local research conferences
• communicate clearly and concisely in writing	Phys 251L, Phys 252L *Limited opportunities:* Phys 251, Phys 252, Phys 251R, Phys 252R,	All courses, capstone project	Assessment of the quality of written HW solutions, lab reports, capstone reports, research publications, outcomes of applications for summer REU programs
• participate effectively and productively in class discussions.	Phys 251L, Phys 252L *Limited opportunities:* Phys 251, Phys 252, Phys 251R, Phys 252R,	All courses	Assessment of the quality of class discussions
Ability to Complete a Guided Research Project		Phys 215: Research for undergraduates, capstone project, independent research projects	Assessment of the quality of capstone reports, capstone oral presentations, *Undergraduate Research Day* presentations (both oral and poster), presentations at national and local research conferences, outcomes of applications for summer REU programs and success rate of summer research both at NDSU and at external REU cites
Intellectual Maturity	All courses	All courses, capstone project, independent research projects, serving as undergraduate learning assistants (LAs) and teaching assistants (TAs) in lab courses, participation in outreach activities	Assessment of the quality of d projects and undergraduate research presentations. Feedback from faculty and students on the quality of teaching by undergraduate LAs and TAs as well as interactions during outreach activities. Outcomes of applications for summer REU programs and success rate of summer research both at NDSU and at external REU cites.