School of Systems Engineering
Program of Study: Autonomous Metastructural Engineering

AME 101: Introduction to Programmable Matter

Course Information

Semester:	I (Year One, Fall)
Credits:	3
Prerequisites:	None
Instructor:	CHINMAY THAKUR
Format:	Lecture, Discussion, and Lab/Workshop

Course Description

AME 101 is the foundational course for the Bachelor of Science in Autonomous Metastructural Engineering. It introduces the pioneering paradigm shift at the heart of the AME discipline: treating the physical world not as a collection of static objects, but as a programmable substrate. The course provides a rigorous, first-principles exploration of the theories, materials, and systems that allow matter to be imbued with computation and autonomous function. Students will journey from the nano-scale of engineered living materials to the macro-scale of self-assembling robotic swarms, grounding their understanding in seminal research and the latest scientific breakthroughs.

Rationale and Role in Curriculum

This course serves as the intellectual "genesis" for the AME student. Its primary role is to establish the **common language, core concepts, and philosophical mindset** that unify the entire AME curriculum. Before students can design, simulate, or build complex systems, they must first learn to see the world through the AME lens. AME 101 provides this lens by deconstructing the fundamental challenges of energy, information, actuation, ethics, and scale. It lays the critical groundwork for the core AME workflow—**Conception, Simulation, and Manifestation**—which students will apply with increasing sophistication throughout their four years of study.

Core Learning Objectives

Upon successful completion of this course, students will be able to:

- **Articulate** the foundational principles of programmable matter, metastructures, and engineered living materials.
- **Analyze** historical and contemporary case studies in the field, comparing the trade-offs of different approaches to material design and robotic control.
- **Explain** the fundamental physical and information-theoretic scaling laws that govern the design of autonomous systems at the micro- and macro-scale.
- **Formulate** solutions to complex, large-scale problems by applying the AME paradigm.

- **Situate** the course content within the broader AME curriculum, understanding its relationship to future coursework in simulation, AI, ethics, and specialization tracks.

Topical Flow

The course follows a carefully structured narrative arc designed to build understanding from first principles to complex applications.

Unit I: Foundational Principles (Weeks 1-4)

The course begins by establishing the core AME philosophy, exploring the crucial distinction between analog and digital materials. This unit grounds students in the principles of how information is embodied in matter and how complex, autonomous behavior emerges from simple, local rules, using natural systems like flocking and crystallization as models. This unit culminates in a detailed overview of the AME workflow, mapping the path for the entire degree program.

Unit II: Technical Implementation and Case Studies (Weeks 5-11)

This unit bridges theory and practice by investigating how programmable matter is realized. The analysis is two-pronged:

- **Programmable Substrates:** A deep dive into Engineered Living Materials (ELMs), using primary research to analyze the properties and applications of mycelium networks and bacterial cellulose.
- **Autonomous Systems:** A systematic review of self-assembling robotics, covering both the hardware of connection (e.g., magnetic vs. electrostatic forces) and the algorithms of assembly (e.g., shape-driven vs. task-driven control).

This technical survey is grounded by an analysis of the first-principles physics and scaling laws that govern micro-scale machines, culminating in a midterm examination.

Unit III: Synthesis, Ethics, and Application (Weeks 12-14)

The final unit connects the technical ”how” with the ”why it matters.” It synthesizes the course content by explicitly linking it to the AME specialization tracks. A critical discussion on the ethical, safety, and societal implications of these powerful technologies prepares students for their responsibilities as engineers. The course culminates with the ”Mini-Genesis Project,” where student teams synthesize their knowledge to propose and present a novel AME system to solve a grand challenge.

Assessment Methods

Student learning will be assessed through a combination of analytical writing, examinations, and project-based work:

- **Case Study Analysis:** A research paper analyzing a specific programmable matter technology.
- **Midterm Examination:** Covers foundational concepts and case studies.
- **”Mini-Genesis” Project Proposal:** A team-based final project where students design a conceptual AME system to solve a grand challenge, culminating in a formal proposal and presentation.

Required Texts & Materials

This course is based on a curated selection of primary and secondary source literature that defines the field. There is no single textbook. All readings will be provided to students as PDFs. The core materials include:

- Knaian, A. N. (2008). *Design of Programmable Matter* (M.S. Thesis). MIT.
- Bray, E., & Groß, R. (2023). Recent Developments in Self-Assembling Multi-Robot Systems. *Current Robotics Reports*.
- Gisinger, F., et al. (2025). Engineered Living Materials I (NanoTrust-Dossier No 064en). *Institute of Technology Assessment, Austrian Academy of Sciences*.
- Additional academic papers, technical reports, and AME program documents provided by the instructor.