Research Methodology Topics

Module 1: Research Foundations

Research: Systematic inquiry to create verifiable knowledge. Types: Basic/applied; qualitative/quantitative; descriptive/correlational/experimental.

Good Research: VALID (valid, accurate, logical, important, transparent). Process: Problem → Lit Review → Hypothesis → Design → Data → Analysis → Interpret → Report.

Hamming's Core: Work on important problems; have courage; sell ideas; open-door policy; know when to quit.

Thinking Skills: Levels: concrete ↔ abstract. Styles: convergent (one answer) vs divergent (many solutions). Scientific thinking = evidence + falsifiability + system. Divide problems: break into sub-problems with clear interfaces. Verbalization forces clarity. Scale awareness prevents order-of-magnitude errors.

Creativity: Novel + useful. IQ ≥120 predicts little; beyond that, motivation and environment dominate. Process: Prepare → Incubate → Illuminate → Verify. Requirements: Expertise + Creative thinking + Intrinsic motivation + Supportive climate.

Module 2: Problem & Information

Info Gathering: Read: skim → scan → deep read. Search: keyword chaining, citation snowballing, database alerts (Google Scholar, Web of Science). Document with Zotero/Mendeley.

Literature Integration: Map existing work → Identify gaps: contradictions, unreplicated studies, unexplored populations, methodological flaws.

Problem Formulation: Sources: literature gaps, practical needs, theory extension. Attributes: CLEAR (concise, literature-based, ethical, achievable, relevant). Formulate as specific question/hypothesis; allow multiple attack vectors (theory, experiment, simulation).

Problem Solving: Reformulate to expose structure. Represent with diagrams (causal loops, flowcharts, equations). Graphs reveal patterns tables hide. TRIZ: map contradictions → 40 inventive principles. Analogy: transfer solutions across domains. Prescriptions: maintain curiosity log, embrace constructive failure, forced perspective shifts (e.g., reverse the problem).

Module 3: Experiment & Model

Scientific Method: Observe → Hypothesize (testable, falsifiable) → Experiment → Analyze → Conclude.

Variables: Independent (manipulated), Dependent (measured), Controlled (fixed). Always include control group for baseline.

Precision vs Accuracy: Precision = low scatter (reproducible). Accuracy = near truth (low bias). Need both; precision without accuracy = systematic error; accuracy without precision = unreliable.

Error Handling: Random errors: reduce by repetition (n≥3), averaging, improved technique. Detect via statistical tests (t-test, ANOVA). Systematic errors: constant bias. Detect via calibration, alternative methods, blanks. Eliminate by instrument correction, protocol standardization.

Experiment Design: Randomize to avoid bias. Block to control nuisance variables. Factorial design tests multiple factors efficiently. Document everything: dated, signed lab notebook with protocols.

Modelling: Types: physical, conceptual, mathematical. Stages: Define → Construct (equations/abstractions) → Validate (against data) → Analyze → Interpret. Approximations: sacrifice detail for tractability; check sensitivity.

Curve Fitting: Match function to data; assess R^2 and residual patterns. Overfitting = too many parameters.

Scales: Continuum (macro PDEs), Meso (lattice Boltzmann), Micro (molecular dynamics). Case studies typically: fluid dynamics (CFD) + materials (FEM).

Feature	Continuum Scale	Meso-scale	Micro-scale
Assumption	Material is continuous	Material has internal structure	Atoms/molecules govern behavior
Resolution	Macroscopic	Intermediate	Atomic
Methods	FEM, FVM, CFD	Phase-field, DEM, Crystal plasticity	MD, DFT
Captures	Macroscopic behavior	Grain effects, defects, microstructure	Atomic interactions, dislocations
Cost	Low	Medium	Very high
Best for	Engineering design	Microstructure-sensitive behavior	Fundamental physics

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Module 4: Communication

Communication = Impact: Stages: Encode → Transmit → Decode → Feedback. Dimensions: verbal/non-verbal; formal/informal.

Oral: Content > Delivery > Form. Rule of 3: tell them what you'll say → say it → tell them what you said. Non-verbal: eye contact, gestures, vocal variety. Listen actively: paraphrase, question. Contexts: Conference (15min, 1 slide/min), Seminar (45min, deeper), Poster (2min pitch + dialogue).

Slides: 6×6 rule: ≤6 bullets, ≤6 words/bullet. Font ≥24pt. Figures > text. One message per slide. Dark background/light text for projection. Cite in corner. Practice timing: 1 slide ≈ 1-2 minutes.

Writing: IMRaD structure. Rules: ACTIVE voice, precise verbs, short sentences (≤20 words). Layout: white space, consistent headings. Equations: numbered, defined. References: manager (Zotero), journal style (APA/IEEE). Tools: LaTeX for equations/citations; Overleaf

for collaboration.

Common Errors: Inconsistent notation, missing units, poor figure resolution (<300 DPI), plagiarism (self/others), uncited claims, typos in equations, inconsistent tense (past for methods, present for results).