

IT 894 – DESIGN AND INVENTIVE ENGINEERING

Fall 2006

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Lectures: Friday, 4:30 p.m. – 7:10 p.m.

Office Hours: Friday, 1:00 p.m. - 4:00 p.m.

Textbook: No single textbook is recommended. The list of readings related to the individual topics is provided in the course outline

Final Exam: Final exam will be comprehensive.

Course Requirements:

1. Active participation in all classes.
2. Three home assignments.
3. Presentation in the class.
4. Comprehensive final exam.

Grading Scheme:

1. Three home assignments - 30 %.
2. Presentation - 40 %.
3. Final exam (take home exam) - 30 %.

MAIN TOPICS

1. **Fundamentals** (4 lectures)

1.0. *Introduction*

1.1. *Transdisciplinarity*

Knowledge evolution, contradictions and solutions, fusion versus transdisciplinarity, transdisciplinarity, transdisciplinary knowledge, Design and Inventive Engineering.

- A.P. Sage, "The Intellectual Basis for and Content of Systems Engineering," INCOSE INSIGHT, Vol. 8, No. 2, 2006.
- Sage, A. P., "Transdisciplinarity Perspectives in Systems Engineering and Management," a Chapter in *Transdisciplinarity: Recreating Integrated Knowledge*, M. A. Somerville and D. Rapport, Eds. EOLSS Publishers Ltd., Oxford UK, 2000, pp. 158-169.
- J. Koza, "Knowledge Soup," lecture notes, Smithsonian Institute, Washington DC, 2003.

1.2. *Transdisciplinary Engineering Creativity: Three Dimensions*

1.2.1. *Creative Class*

Evolution of a society, transformation, creative class descriptors and components, regional growth and driving forces, creative community, Memphis principia, creative class values, social and creative capital.

- R. Florida, *The Rise of the Creative Class*, Basic Books, 2002.
- R. Florida, *The Flight of the Creative Class*, Harper Business, 2004

1.2.2. *The Medici Effect*

The Medicis, the Medici Effect, intersection, intersection of disciplines, creative versus innovative ideas, directional versus intersectional ideas.

- F. Johansson, *The Medici Effect*, Harvard Business School Press, 2004.

1.2.3. *The Renaissance Man*

Renaissance, discoveries, key figures, paradigm change, Renaissance versus Information Technology Revolution, Leonardo da Vinci, his life, art and scientific contributions, da Vincian principia: Curiosita, Dimonstrazione, Sensazione, Sfumato, Arte/Scienza, Corpolita, Connessione, principia and design science, inventions, methodological reflection, vision and impact.

- Bramly, S., *Discovering the Life of Leonardo da Vinci*, Harper Collins, New York, 1991.
- Gelb, M., *How to Think like Leonardo da Vinci*, Random House, New York, 1998.
- Kicinger, R., "Leonardo da Vinci," Research Report, IT&E School, George Mason University, 1999.

1.3. *System Designing (September 14, 2006)*

System; engineering design process; design representation space; symbolic and numerical attributes; design concept and detailed design; conceptual and detailed design process stages, various models; conceptual design paradigms; routine versus inventive design concepts; categorization of designs; generation of design concepts: holistic view, inventive designing and its four generations.

- Dym, C., Little, P., *Engineering Design*, John Wiley and Sons, 1999.
- Pahl, G., Beitz, W., *Engineering Design*, Springer, 1996.
- Antonsson, E.K., Cagan, J. (Editors), *Formal Engineering Design Synthesis*, Cambridge University Press, 2001.

1.4. *System Architecting (Dr. James Martin) (September 14, 2006)*

History; architecting versus engineering; science-based and art-based methods; architecting paradigm; complexity and systems; systems approach; architect; waterfall models.

- Rechtin, E., *Systems Architecting, Creating and Building Complex Systems*, Prentice Hall, 1991.
- Maier, M.W., Rechtin, E., *The Art of Systems Architecting*, CRS Press, 2000.
- Buede, D., *The Engineering Design of Systems*, Wiley Publishing House, 2000.

1.5. *Design and Inventive Engineering*

Science and engineering science; history of engineering; engineering design: science or art; design engineering; inventive engineering; routine versus inventive design; IT and design paradigm change; knowledge and knowledge paradigm in design; general methodology; methodics, design support tool development; why inventive engineering.

1.6. *Engineering Method*

Engineering optimum; the principal rule of the engineering method; heuristics; engineering state of the art; engineering heuristics: rules of thumb and order of magnitude, factors of safety, attitude-determining heuristics, risk controlling heuristics, resource allocation heuristics; definition of engineering and engineering design; engineering versus applied sciences; engineering method.

- Koen, B.V., *Definition of the Engineering Method*, American Society for Engineering Education, 1985.
- Koen, B.V., *Discussion of THE Method*, Oxford University Press, 2003.

1.7. *Heuristics and Decision Rules: from Praxiology to Computer Science*

Several perspectives: from philosophy to computer science; sources of heuristics; praxiology fundamentals, directives and examples; Koen's heuristics and system architecting; engineer versus architect;

architecting heuristics; psychology, heuristics and design styles; heuristics versus decision rules; instructor's heuristics.

- Koen, B.V., *Definition of the Engineering Method*, American Society for Engineering Education, 1985
- Maier, W.M., Rechtin, E., *The Art of Systems Architecting*, Systems Engineering Series, CRC Press, 1997.
- Strzalecki, A., "Creativity in Design: General Model and its Verification," Arciszewski, T., (Editor), special issue on Innovation: the Key to the Technological and Social Progress, *Journal of Technological Forecasting and Social Change*.

2. Design Engineering (4 lectures)

2.1. Formal Designing (3 lectures)

2.1.1. AI in Design (Professor John Gero) (September 29, 2006)

Designing: a definition, a transformation model; function, design description, behavior, evaluation, synthesis model, design process and its components and stages, design activities, representation subspaces, routine, innovative and creative designing.

- Gero, J., "Computational Models of Innovative and Creative Design Processes, special double issue, "Innovation: the key to Progress in Technology and Society," Arciszewski, T., (Guest Editor), *Journal of Technological Forecasting and Social Change*, North-Holland, Vol. 64, No. 2&3, June/July, 2000.

2.2.6. Evolutionary Designing (Dr. Rafal Kicinger) (October 6)

Fundamentals of evolutionary computation, design representation spaces, conceptual process as an evolutionary process, integrated approach to inventive design, integrated design support tools, lines of evolution and fitness landscapes in inventive design, Inventors 2000 and 2003, morphogenesis, generative design, creative design, generative representations, cellular automata, distributed evolutionary design, island-model evolutionary algorithms, multi-population evolution.

- Arciszewski, T., DeJong K., "Evolutionary Computation in Civil Engineering: Research Frontiers," invited article, Topping, B.H.V., (Editor), *Civil and Structural Engineering Computing* 2001, pp. 161-185.
- Kicinger, R., Arciszewski, T., and De Jong, K. A. (2004). "Evolutionary computation and structural design: a survey of the state of the art." *Computers & Structures*, submitted
- Murawski K, Arciszewski T, and DeJong K: 2001, Evolutionary Computation in structural design, *Journal of Engineering with Computers*, vol. 16, Springer-Verlag, London, pp. 275-286.
- Kicinger, R., Arciszewski, T., and De Jong, K. A. (2004). "Morphogenesis and structural design: cellular automata representations of steel structures in tall buildings." *Proceedings of the Congress on Evolutionary Computation (CEC'2004)*, Portland, Oregon, 411-418.
- Kicinger, R., Arciszewski, T., and De Jong, K. A. (2004). "Distributed evolutionary design: island-model based optimization of steel skeleton structures in tall buildings." *Proceedings of the 10th International Conference on Computing in Civil and Building Engineering (ICCCBE-X)*, K. Beucke, B. Firmenich, D. Donath, R. Fruchter, and K. Roddis, eds., Weimar, Germany, 190.

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2.2.1. *Designing as Search*

History, human and non-human problem solving, similarities and differences, manipulation of knowledge representation, Newell and Simon's outline of problem solving, program, internal representation, problem solving as search, novice versus expert problem solving, graphical models of problem solving, human memory and its limitations, impact on problem solving, memory buffers, backward and forward problem solving, means-end analysis, schema and schemata, actual human problem solving.

- Hunt, E., "Problem Solving," Chapter 7, *Thinking and Problem Solving*, Sternberg, R.J. (Editor), Academic Press, 1994.

2.2.5. *Constraint Search*

Constraints and their classification, constraint search and its basic types, acquisition of constraints, constraint search-based system for conceptual design, examples of constraints, computer concept generation and structural examples.

- Hajdo, P., (1991). *Methodology of Integrated Design of Partially Restrained Joints in Steel Frames*, Ph.D. Dissertation, Wayne State University.
- Hajdo, P., Arciszewski, T., (1991). "Computer Generation of Structural Concepts: A Knowledge-Based Approach," *Proceedings of the ASCE Seventh Conference on Computing in Civil Engineering*, pp. 278-287.

2.3. Design Evaluation

Evaluation in engineering design, various definitions, classical multicriteria evaluation (Churchman and Ackoff): assumptions, procedure, examples, engineering multicriteria evaluation: assumptions, procedure, industrial examples, multicriteria utility-based evaluation, evaluation knowledge and its acquisition, knowledge-based evaluation approach, evaluation criteria and their identification, evaluation criteria and evaluation attributes hierarchies, evaluation knowledge-based system: basic assumptions, architecture, operations, example of actual implementation, research directions.

- Arafat, G., (1991). *Concept Evaluation in Engineering Design: A Knowledge-Based Approach*, Ph.D. Dissertation, Wayne State University.
- Arafat, G., Goodman, B., Arciszewski, T., (1993). "Ramzes: A Knowledge-Based System for Structural Concept Evaluation," *Computing Systems in Engineering*, Vol. 4, No. 2-3, pp. 211-221.

2.1. Design Theories (1 lecture)

2.1.2. Axiomatic Design Theory

Design process, design parameters, functional requirements, decision making in design, design axioms, the independence axiom, the information axiom, history of axioms in science and engineering,

problem definition, functional requirements in the context of innovation, house of quality in manufacturing, hierarchies of functional requirements and attributes, constraints and their categorization, axiomatic design theory: two axioms, theorems and corollaries, uncoupled, coupled and decoupled designs.

- Suh, N.P., *The Principles of Design*, Oxford University Press, 1990.
- Suh NP: 2001, *Axiomatic Design, Advances and Applications*, Oxford University Press, New York, Oxford.

2.1.2. *Inferential Design Theory*

Inferential learning theory, design process, conceptual design process, conceptual design paradigm, applicability of the IDT, basic methodological assumptions, design knowledge transmutations, transmutations as inference, individual transmutations and their engineering interpretation, examples of transmutations, research directions and building design support tools, CREDO - a computer tool for conceptual design and its practical use.

- Arciszewski, T., Michalski, R.S., "Inferential Design Theory," *Proceedings of the 3rd International Conference AI in Design*, Lausanne, 1994.
- Karni, R., Arciszewski, T., "A Tool for Conceptual Design of Production and Operation Systems," *Journal of Design Research*, No. 9, pp. 146-167, 1997.
- Arciszewski, T., Karni, R., "Ideation-Based Conceptual Design of a Materials Handling and Transfer System,' *Proceedings of the 32nd International Matador Conference*, Manchester, England, 1997.

3. Inventive Engineering (2.5 lectures)

3.1. *Brainstorming*

Group problem solving, psychology of problem solving, associations, procedure, group organization and optimal design, IdeaFisher - a tool for brainstorming and its use in the class.

- *IdeaFisherPRO*, User's Guide for Macintosh, IdeaFisher Systems, Inc., 1995.
- Fisher, M., (1996). *The Idea Fisher*, Pacesetter Books.
- Lumsdaine, E., Lumsdaine, M., (1995). *Creative Problem Solving: Thinking Skills for a Changing World*, McGraw-Hill.

3.3. Synectics

History, definition of synectics, invention design group, creative problem solving, psychological aspects of ideation, synector and synectics group, creative mechanisms: making the strange familiar and making the familiar strange, analogies: personal, direct, symbolic, fantasy, procedure, industrial examples, use of MindLink software.

- Gordon, W.J.J. *Synectics, The Development of Creative Capacity*, 1961.
- *The MindLink Handbook for Creative Problem Solving: Mindlink Problem Solver*, MindLink, 1992.

3.4. Morphological Analysis

History, concept of atom, related developments in various countries, systems analysis versus morphological analysis versus stochastic form optimization, methodological assumptions, problem formulation and pegging, morphological field/box/table versus knowledge representation, synthesis, generation of concepts, procedure, stochastic simulation of concept generation process, building morphological table, computer tools, examples of inventing joints in structural engineering.

- Zwicky, F., *Discovery, Invention, Research through the Morphological Analysis*, Macmillan, New York, 1969.
- Ullman, D., G., *The Mechanical Design Process*, McGraw-Hill, 1992.
- Arciszewski, T., "Stochastic Form Optimization," *Journal of Engineering Optimization*, Vol. 13, 1988.

3.5. *TRIZ and Directed Evolution* (Ms. Alla Zusman and Mr. B. Zlotin) (November 10, 2006)

History, concept classification, Altschuller and his thoughts about innovative design, psychological inertia, main assumptions, substance-field engineering system, minimal engineering system, substance-field analysis, contradictions and their classification, identification of contradictions, eight rules of engineering system development, inventive tricks and their collection, design procedure and its stages, ideal solution, elimination of physical contradictions, schools of inventors, computer tools, patented inventions.

- Arciszewski, T., Zlotin, B., "Ideation/Triz: Innovation Key To Competitive Advantage and Growth," Internet, <http://www.ideationtriz.com/report.html>, 1998.
- Anon (1994). *The Innovative WorkBench System User Guide*, Santa Monica, CA, Ideation International.
- Terninko, J., Zusman, A., Zlotin, B., *Systematic Innovation, An Introduction to TRIZ*, St. Lucie Press, 1998.
- *TRIZ in Progress*, Transactions of the Ideation Research Group, Ideation, 1999.
- Clarke, Dana, *TRIZ: Through the Eyes of an American TRIZ Specialist*, Ideation, 1997.
- Clarke, D., "Strategically Evolving the Future: Directed Evolution and Technological Systems Development," special double issue, "Innovation: the key to Progress in Technology and Society," Arciszewski, T., (Guest Editor), *Journal of Technological Forecasting and Social Change*, North-Holland, Vol. 64, No. 2&3, June/July, 2000

3.6. Computational Creativity (Professor John Gero) (November 3, 2006)

4. Design Research Frontiers (4.5 lectures)

4.1. *Inventive Design in Practice* (Drs. Frank Berte and Kalu Uduma) (1 lecture)

Dr. Frank Berte: From MIT-learned analytical skills to creative problem solving, sailing boats and novelty, how new design concepts emerge, are tested and evolved.

Dr. Kalu Uduma: Car safety requirements, crash engineering, crash avoidance design concepts, present design practice, applications of inventive engineering, novel side collision protection devices, future impact protection systems.

- Uduma, K., "Innovation in Auto Safety Design, a Key to Quality Improvement," special double issue, "Innovation: the key to Progress in Technology and Society," Arciszewski, T., (Guest Editor), *Journal of Technological Forecasting and Social Change*, North-Holland, Vol. 64, No. 2&3, June/July, 2000.

4.2. *Constructive Induction*

Selective and constructive induction, primary and constructed attributes, semantic interpretation of constructive attributes, engineering creativity as a constructive induction process, emergent concept and its semantic interpretation, applications of constructive induction in inventive design.

- Arciszewski, T., Michalski, R.S., Wnek, J., "Constructive Induction: the Key to Design Creativity," *Preprints "Computational Models of Creative Design,"* Third International Round-Table Conference, December 1995, pp. 397-426, Heron Island, Australia.

4.3. *Situated Learning and Design* (Professor John Gero) (December 1, 2006)

4.4. *Creative Company* (Dr. Chris Luebke)

4.5. *Bio-inspiration in Design: Conceptual and Computational Inspiration and Generative Representations* (Dr. Rafal Kicing)

4.6. *Collaborative Design and Virtual Studios*, (Dr. Mary Lou Maher)

4.7. *Design for Robustness*, (Kenneth Shelton)

4.8. Ontologies in design

4.9. Design knowledge acquisition

5. Project Presentations (1 lecture)