Frontiers in Chemical Engineering Education

New Directions and Opportunities – Creating the Future

CCR/NSF Discipline Wide Curriculum Workshops

The Path Forward

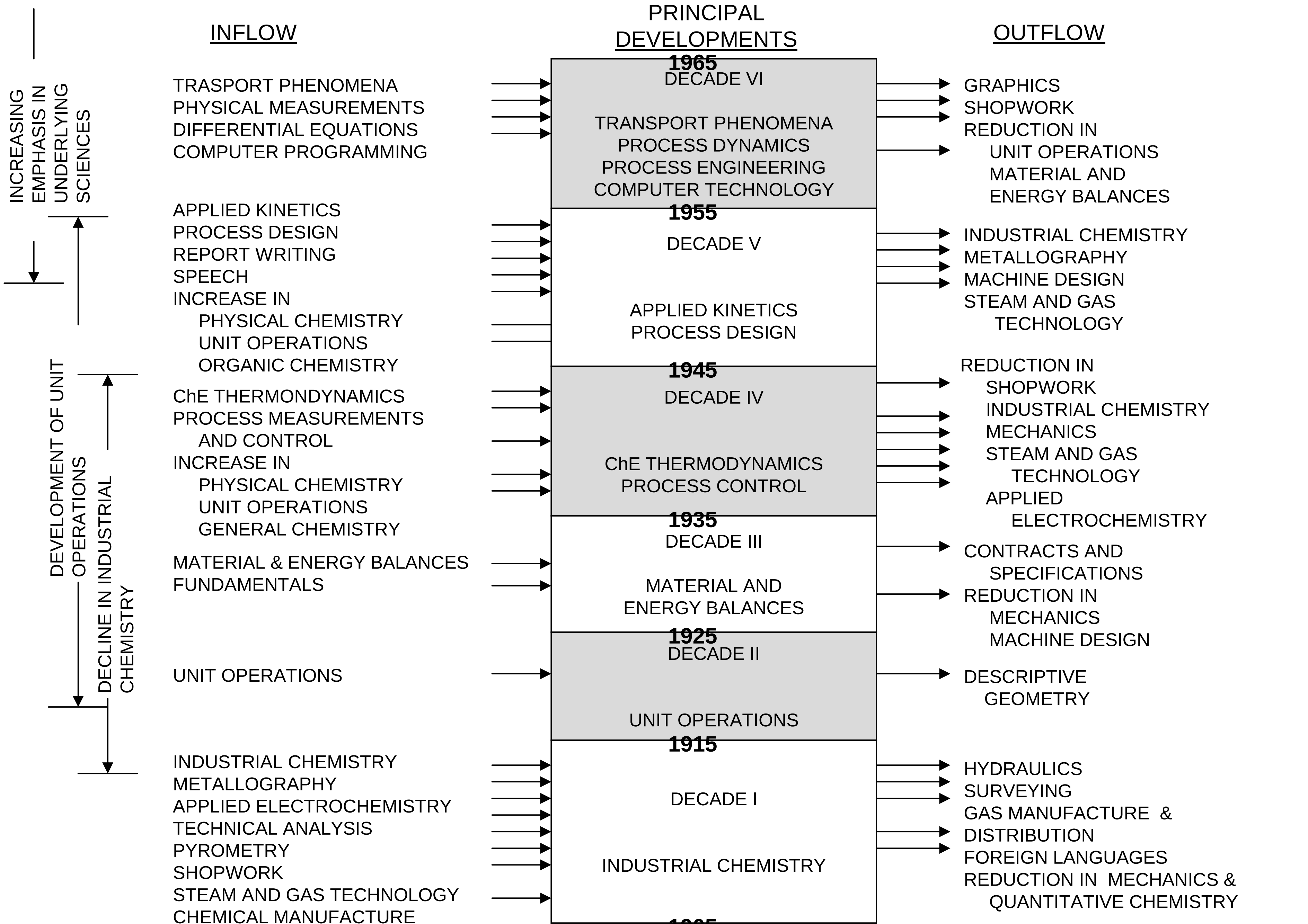
Welcome

- It has been 40+ years since chemical engineering curriculum underwent major change
- During this period the profession has experienced major change
- This change is accelerating
- The intellectual opportunities and career paths for the profession are exciting
- We have the opportunity to create a future chemical engineering curriculum that will produce key graduates for the world ahead

… why is this important?

Drivers for Change

- The integrative and synthesis skills of our students are poorly developed
- Attributes are not well taught
- Our traditional industry has shifted
  - The nature of jobs for US chemical engineers in the future will be different
- Biology represents a new frontier for us as a discipline
  - Not just an application
- Our close connection with basic science makes our graduates very versatile
  - We have failed to articulate this clearly to our stakeholders
  - We have failed to imbed this in our curriculum
- Separation of research and education
- Our student base is at risk
  - Perception of what we do is important to capturing the best and the brightest



Changes in a typical undergraduate chemical engineering curriculum during 60 years. The initial curriculum in 1905 consisted of separate courses in chemistry and conventional engineering.

Changing Nature of Chemical Engineering

- Our industry
- Career paths
- Research opportunities
- Underlying science

Chemical Industry Observations

- The industry is global
- Mergers of companies and product lines
- Chemical companies are becoming life science companies and spinning off chemical units
- Virtual companies - out-sourcing of services - including research
- The chemical industry is cyclical
- Time to market for new products has dramatically decreased
- Graduates can expect to have multiple professional jobs
- Chemical engineering no longer is dominated by petrochemicals/bulk chemicals

Trends in the Chemical Industry

- Historically, a Larger Contributor to the GDP than any other Manufacturing Industry (OECD)
- Chemical Sciences and Engineering are the Largest Contributors to Technology
  - All industries create chemical technology
  - The underpinning of all industries' technology relies on chemical technology
  - The cross industry technology spillovers are highest from the electrical and chemical industries
  - Chemistry is an important part of the science base of all industries
- Growth Rates in of the Chemical Industry
  - 1993-2003: 3.9% per year
  - 2004-2014: 2.5 to 2.7 %. Below the GDP growth rate (3.0 to 3.3%)
- Geographic Allocation of Growth (2002-2014)
  - US and EU, ~ 2% per year; Japan, <1% per year…Below GDP Growth
  - Asia, 10% per year

Where Do Companies See Future Growth? (2004-2015)

- Commodities:
  - Primarily in Asia………... 9-10 % per yr
- Product-Oriented Chemicals and Materials:
  - "Solutions-to-the-Customer" ……………………........ 10-15% per yr
    - Integration of technological services, chemicals, materials
  - Information/Electronics/Telecommunications............10-15%
    - Semiconductors; Displays; Inks; Specialty polymers; Energy devices
  - Medical ……………………………………………......... 6-10 %
    - Diagnostic, Packaging, Fabrics, Surgical supplies
  - Safety, Security, Protection ……………………..…… 6-10%
    - Diagnostic, Protective Materials
  - Life Amenities (Home, Office) ……………………..….. 5-8 %
    - Materials/Components for cleaner, healthier environment; Personal care
  - Transportation………………………………………..…… 5-6 %
    - Material components and energy devices for automobiles & airplanes

An Industrial View

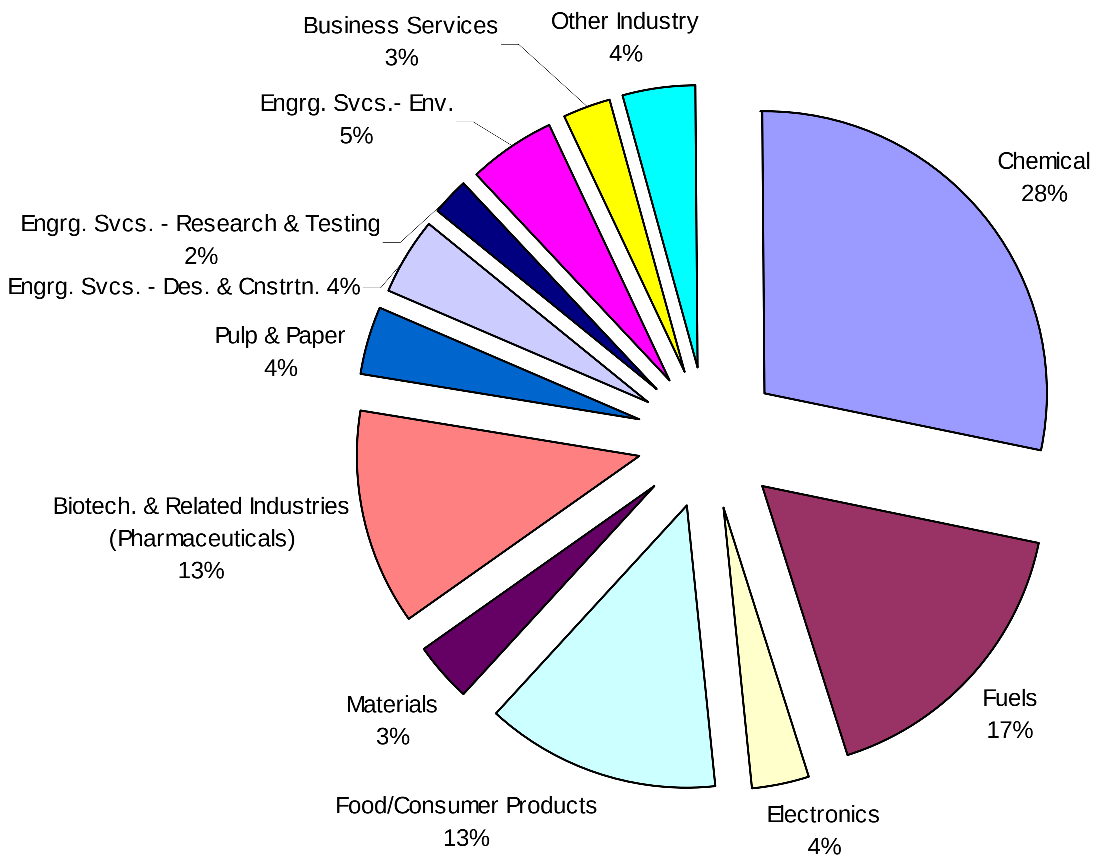
- The ability of U.S. chemical engineers to innovate and think creatively will have a key role in national competitiveness. China is training many more chemical engineers than the U.S., and these engineers will do “rote-learning” calculations as well as U.S. engineers. U.S. engineers will have value by knowing “how to invent, how to design, how to make things happen.”
- Innovation and creative thinking likely will remain out of the realm of computers, while “rote-learning” calculations no longer are. U.S. engineers will have value by doing things that computers cannot.

… Douglas Cameron, Director of Biotechnology, Cargill

Manpower Issues

- Public perception of “chemical” is negative
  - $Essential_2$ will help (www.americanchemistry.com)
- Consumers (potential students) do not know what we do in emerging technologies such as biotechnology and nanotechnology
  - Does the way we describe ourselves today clarify this?
- Enrollments are small relative to other engineering disciplines
  - Not necessarily bad, but we want the best
- Employment opportunities are diverse
  - Reflects research opportunities in our departments
- Enrollments appear to be cyclic
  - Are they really?
  - Do they need to be?

Industrial Employment for BS



AIChE Department of Career Services
December 2003

BS Starting Salaries*

Chemical engineering leads all fields

Field	Starting salary	Pct change from 2003
Business administration	$38,258	6.2
General accounting	$41,058	1
Marketing	$34,712	2
Computer science	$49,036	4.1
Information science and systems	$42,375	10.7
Civil engineering	$42,056	0.9
Electrical engineering	$51,124	2.7
Chemical engineering	$52,539	0.3
Chemistry	$37,618	- 0.3
Mechanical engineering	$48,578	0
Biology and life science	$29,629	0.6
Math and statistics	$43,567	7.5

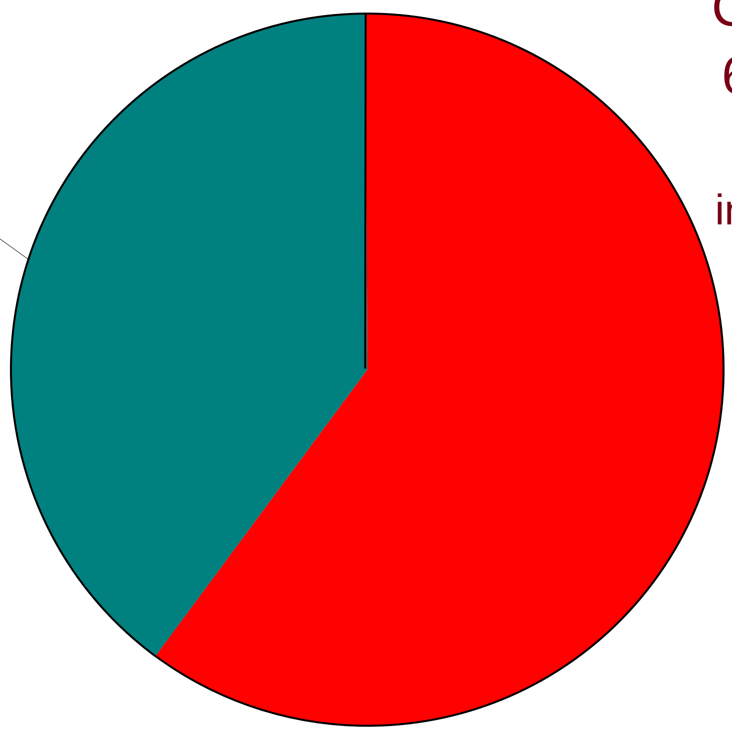
*Salary Survey, National Association of Colleges and Employers, Fall 2004, Volume 43, Issue 4

Opportunities

- Chemical engineering is a uniquely positioned at the interface between molecular sciences and engineering with many exciting opportunities, including:
  - Life sciences (genetics, pharmaceuticals ….)
  - Energy - fuel cells, catalysis,
  - Sustainable systems
  - Molecular control of processes and devices
  - …
- Other disciplines have opportunities in these areas as well and are beginning to have interest in process, synthesis, analysis issues traditionally addressed within chemical engineering
- We need to have a clear vision of chemical engineering in order to function effectively in multidisciplinary research

Chemical technology creation is core or important in all 15 of the industries

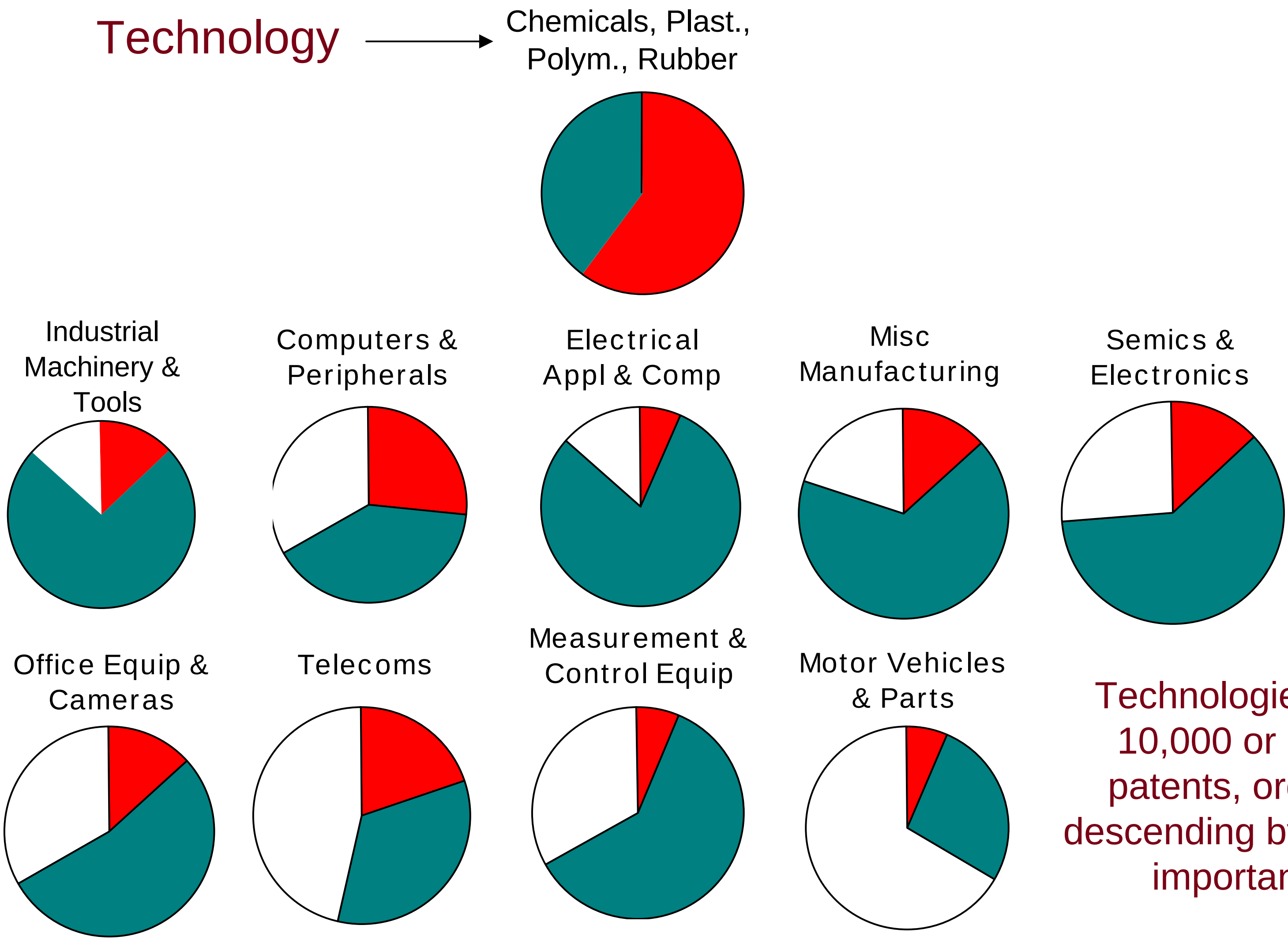
Chemicals, Plast., Polym., Rubber



Industry
Engrng., Oil Field Svcs.
Metals & Mechan.
Electrical & Electron.
Automotive
Computers & Semicond.
Telecommunications

Industry
Chemicals
Energy
Pharmaceuticals
Biotechnology
Food, Bev. & Tobacco
Health Care
Materials
Forest, Paper, Textiles
Instrument. & Optical

No other technology comes close

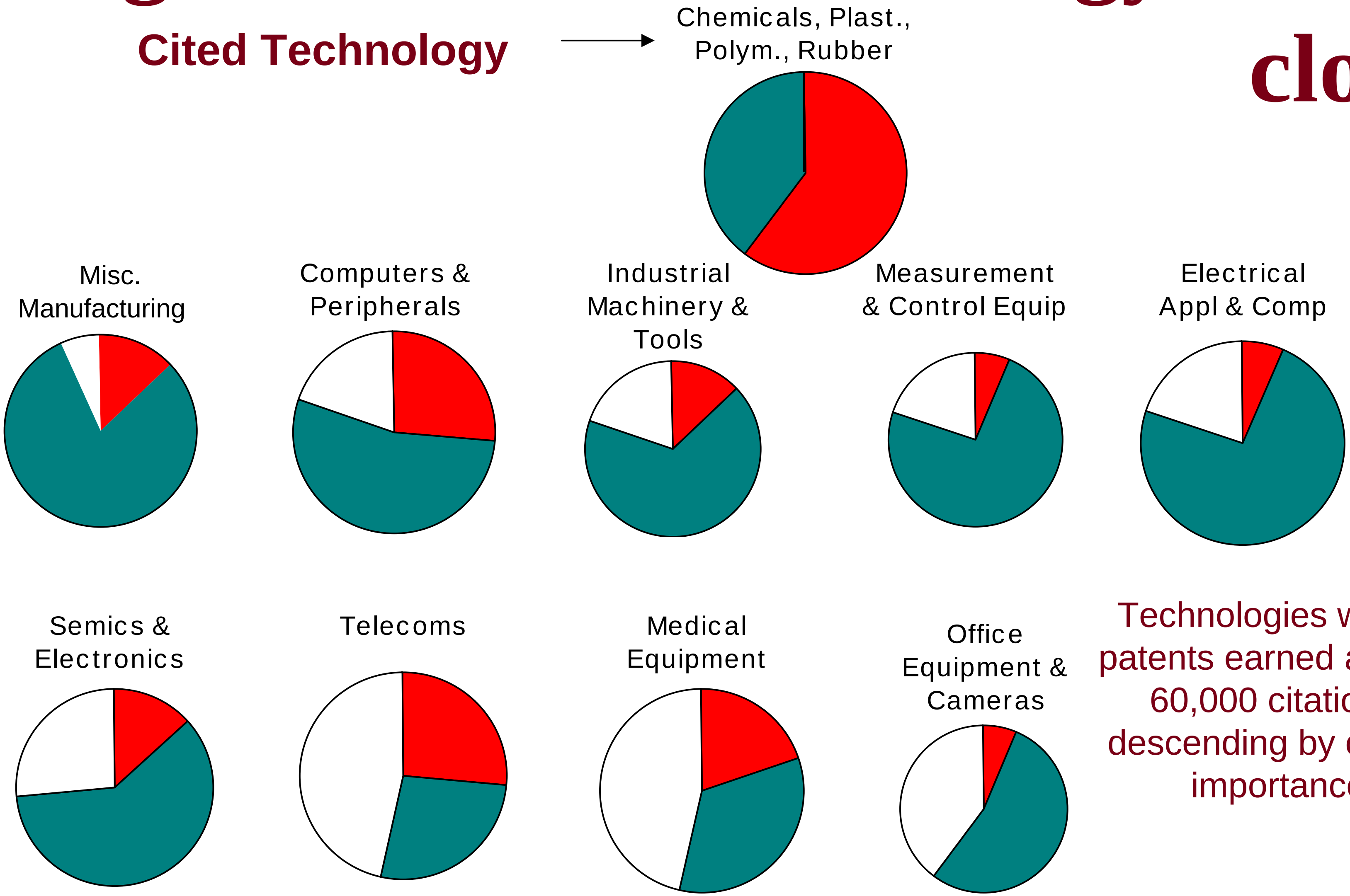


Technologies with 10,000 or more patents, ordered descending by overall importance

How many industries build upon chemical technology?

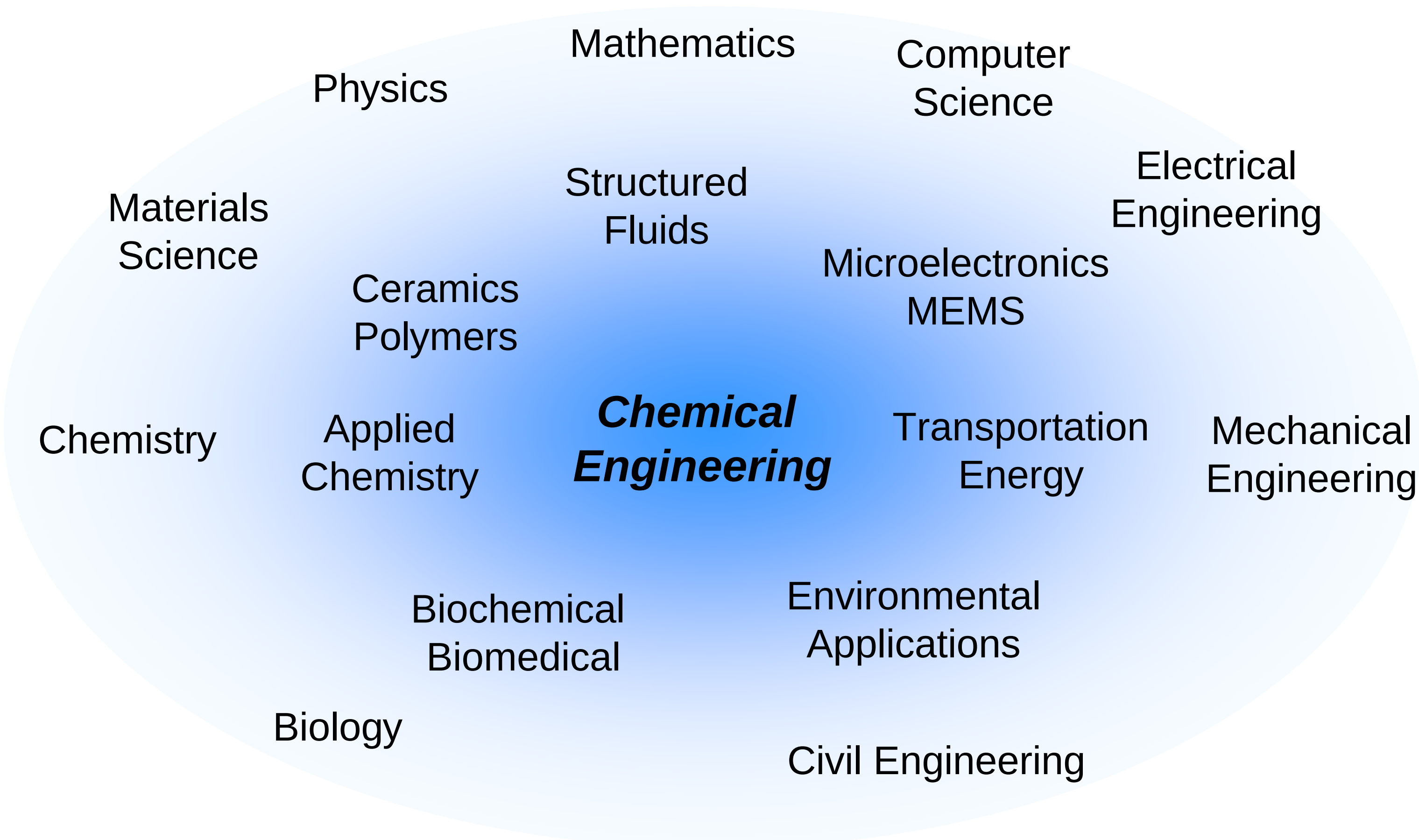
- Definitions:
  - ■ Core technology: Technology accounts for at least 10% of citations from industry patents.
  - ■ Important technology:Technology accounts for between 1% and 10% of citations from industry patents.
  - □ Irrelevant technology: Technology accounts for less than 1% of citations from industry patents.

Again, no other technology comes close



Technologies whose patents earned at least 60,000 citations, descending by overall importance

Chemical Engineering at the Interface



Chemical sciences and engineering are central elements in GDP generation and technology creation

NSF/CCR Curriculum Workshops

- A series of workshops have led to a vision and model for a dramatic change in undergraduate chemical engineering education
- Why discipline wide?
  - This is OUR opportunity.
  - The opportunities/frontiers are too broad for any one or several departments to address effectively
  - The costs – time and money – of developing new educational materials are too high for any of us to absorb alone
  - The coherence resulting for a joint effort will serve the discipline well
    - Maintain clear identify to the world (potential students, industry, government)
    - Ensure good manpower supply to industry and to our graduate programs
    - Ensure that curriculum developments are used

Review of Events to Date

- What's been determined to date:
  - The process
  - The principles
  - The attributes
  - The curriculum
    - Organizing principles
    - Learning strategy
    - Specific content

The Medium for Change: Workshops

- 3 initial workshops held at various locations
- Mostly academic (< 5% industry)
- Work output via:
  - Presentation
  - General large discussion
  - Break out groups with reports back
  - Summary sessions

The Process: Episode 1: A New Hope

- Workshop 1: Orlando, January, 2003
  - "Hey, this curriculum work isn't Mickey Mouse stuff…"
  - Workshop focused on "foundation"
    - Values/Principles
      - What are our values?
    - What is the Case for Change
    - Start of commitment to change
    - What's our vision of this change?

The Process: Episode 2: The Faculty Strike Back

- Workshop 2: Austin, April, 2003
  - “Even the Curriculum looks bigger in Texas…”
  - Workshop focused on:
    - Curriculum strategy: organizing principles for curriculum
    - Deliverable from strategy : students and their attributes
    - Learning strategy: principles for how this curriculum could be taught
    - Confirmation that the change is transformational

The Process: Episode 3: Return of the Educators

- Workshop 3: Cape Cod, June, 2003
  - "Life's a beach when you are doing curriculum work…"
  - Workshop focused on:
    - Learning strategy: More detailed thoughts on how to utilize the organizational principles
    - Curriculum blueprint
    - Outline of mobilization and methodology for change

Principles and Values

- Chemical Engineering is built on certain foundation studies
  - Physics, chemistry, biology and mathematics
- There is a core set of understandings (fundamentals or principles) that form the foundation of chemical engineering work
- Chemical engineering:
  - Is quantitative, involving analysis, design and synthesis
  - Addresses materials and phenomena at all scales from molecular to “super-macro”
  - Solves problems related to both product and process
  - Handles problems across all of its foundation sciences: biology, chemistry and physics

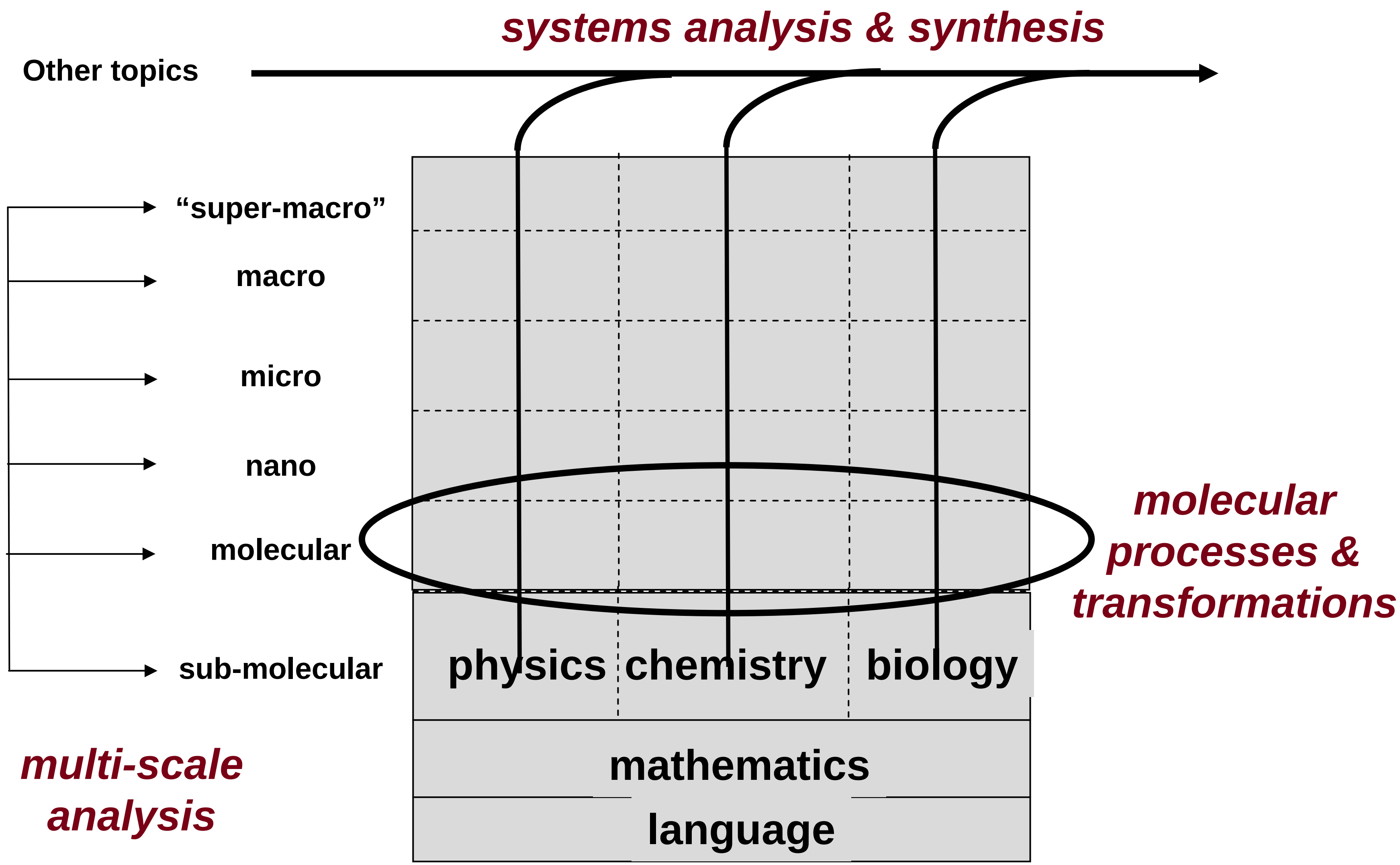
Attributes of the "Product": the BS Chemical Engineer

- Chemical engineers are adroit problem-solvers
  - They keep it simple, making rational assumptions and estimates
  - They determine which parameters are important
  - Understand and work with uncertainty and sensitivity
- Chemical engineers can apply their skills to open-ended and novel problems, coping with:
  - Incomplete information
  - Multiple (often conflicting) objectives
  - Iterative solution methods
  - Uncertain and "messy" data
  - Complexity
  - Risk and risk-taking
  - Rapid generation and pruning of alternatives
- Chemical Engineers "think like a molecule"
- Chemical engineers seek life-long professional growth by
  - Knowing how to learn
  - Desiring life-long learning
  - Thinking critically
  - Being receptive to new ideas
  - Seeking appropriate connections to other fields
- Chemical engineers understand the broader context
  - They know where chemical engineering fits in
  - They understand and accept the social responsibilities that accompany their discipline
  - They are driven to add value

The new curriculum

- Core set of organizing principles
- Learning strategy
- Time-course for curriculum

Organizing Principles



Are We Educating Optimally?

- Teaching vs. learning
- Less is more
- Competencies vs. content
- Fostering creativity and innovation
- Experiential learning
- Mentoring and other support
- Promoting synthesis – science, engineering, social processes

Learning Strategy

- Curriculum should integrate all organizing principles and basic supportive sciences throughout the educational sequence
- All organizing principles should be operative throughout the sequence and should move from simple to complex ("spiral learning")
- Curriculum should be consistently infused with relevant and demonstrative:
  - Laboratory experiences

Learning Strategy

- Examples
  - Open-ended problems an d case studies
  - Challenges of engineering practice: safety, economics, ethics, regulation, IP, market/social needs
- Curriculum should include a first year chemical engineering experience
- Opportunities for teaming experiences and use of communication skills (oral and written) should be included throughout the curriculum
- Curriculum should address different learning styles

Sample of Integrated Curriculum

Freshman | Sophomore | Junior | Senior

Enabling Courses:
-Physics
-Chemistry
-Biology
-Math
-Mat'ls Sci
-Eng/Comm
-Bus/Mgt

Chem Eng
-The Frosh Experience

Molecular-Scale Transformations

- Molecular Basis of Thermo
- Classification of Molecules
- Molecular Basis of
  - -Reactions
  - -Props & Constitutive Eqns
- Special Topics

Multi-Scale Analysis

- Interfaces & Assemblies
- Homogeneous Reactor Eng
- Multi-scale Descriptions of Reactive Systems
- Beaker to Plant: Principles of Product & Process Design

Systems

- Intro to Systems
- Intro to Molecular Systems
- Systems & the Marketplace

Concerns

- Will student outcomes be demonstrably improved?
- Can we build a consensus in the profession for this large change?
  - “But we already have a great core – thermodynamics, transport, and kinetics – which provide a versatile education for our students.”
- How do we implement this is a timely and uniformly high quality way over a widely disparate distribution of schools and resources and for such a wide and changing distribution of industries?

Industry's thoughts

- From a future US perspective, industry's needs are challenging
  - While smaller than current, there will be still considerable domestic industrial infrastructure and processing that will need to be maintained by engineers
    - No advantage to "outsourcing" this engineering work
  - There will be developing/emerging industries that will need engineers
    - Product development focus in US, manufacturing elsewhere?
    - Given focus, will these be BS degrees or higher?

From Industrial Workshop, Atlanta, June 2005

What about Curriculum

- Curriculum is important
  - Students need to come out with some fundamental knowledge
- But how it's taught, leading to the whole "product," counts equally or more
  - Problem-solving
  - Leadership & teamwork
  - Flexibility/adaptability
  - Innovation
  - Comfort with "hands on" work
  - Knowledge of industrially relevant information

From Industrial Workshop, Atlanta, June 2005

Some Agreement on Curriculum Changes

- Biology as a foundation science
  - Good, if treated proportionally with chemistry and physics
    - Avoid creating chemical engineers that can only do biotechnology
- Remember: we are training B.S. students, not M.S. or Ph.D.s
  - Keep curriculum relevant to the majority of current and future industrial needs
- More and more relevant examples are critical
  - Better awareness of real problems they may face
- A change in curriculum opens an opportunity to change the way in which it is taught
  - Use of an approach to pedagogy that supports the desired final qualities of the student

From Industrial Workshop, Atlanta, June 2005

The Case for Cases*

- A transition path would be helpful
  - Series of steps that can be evaluated sequentially
  - Case studies / module units are good
  - Need template for final plan so that these fit together
- Work with industry to choose cases that will reflect problems that students will work on in 2015 and beyond
- Choose cases that reflect the principles developed to date
  - Molecular transformations, multiscale, systems
  - Integration and transparency of curriculum
  - Development of skills and attributes as well as knowledge

*Chicago Workshop, October 2005

Case Studies and Examples

- Diverse
- Relevant and topical
- Integrated into curriculum
  - horizontal integration (over time)
  - vertical integration (between classes at same time)
- Provide real world context
  - safety, economics, ethics, regulation, IP, market/social needs
- Provide real world challenge
  - open-ended, complex, incomplete data, rapid generation, and pruning alternatives
- Reopen the flow of ideas from graduate research to the undergraduate curriculum

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*Chicago Workshop, October 2005

Module Characteristics

- Excitement
- Clearly stated educational goals
  - Intellectual content
  - Skill/attributes
  - Link to molecular transformations, multiscale, systems
- Prerequisites

*Chicago Workshop, October 2005

Module Characteristics (cont'd)

- Instructor materials – as appropriate
  - Background material
  - Presentation strategy
  - Supplemental materials
    - Homework problems
    - Background reading
    - References
  - Support
    - Simulation software
    - Web-based demos or labs
    - Protocols for demonstrations
    - Data sets for analysis
    - Background date behind models

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*Chicago Workshop, October 2005

Module Characteristics (cont'd)

- Content
  - Background, context
  - Formal presentation of intellectual content
  - Bibliography
- Student Activities
  - Project descriptions – individual and team
  - Assignments
    - Individual homework
    - Group projects
    - Simulations
    - Library and web research
  - Brainstorming
  - Presentations
  - Written reports

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*Chicago Workshop, October 2005

Module Characteristics (cont'd)

- Flexibility
  - Adaptable to many modes of use, e.g., homework problems only, small activities, large modules,
  - Scalable
- Evaluation plan/tools
- Adhere to standards
  - QC
  - Consistent notation
  - Platform, portability

*Chicago Workshop, October 2005

Frontiers Prototype Case Study

"How does one stop the next flu pandemic?"

Introduction

What happened in 1918?
(Give Spanish flu statistics – a brief ~5 min. *motivation*)

Why is an avian flu virus of great concern?
(Solicit ideas from class – a brief ~15 min. *thinking* exercise for students.)

Answers: The virus is…
- Is endemic in bird populations.
- Has been observed to move between animal species.
- Has high mutation rates.
- Has high mortality rates.

What can we do? (Move into modules.)

How to…

Monitor the virus? **Prevent infections?** **Control an outbreak?**

MOLECULAR TRANSFORMATIONS ⟺ **MULTI-SCALE ANALYSIS** ⟺ **SYSTEMS DESIGN** ⟺ **SKILLS & ATTRIBUTES**

⇩

How to monitor the virus?

Technology:

DIAGNOSTICS

MOLECULAR TRANSFORMATIONS →

MULTI-SCALE ANALYSIS →

SYSTEMS DESIGN →

How to detect viral species?
An opportunity to discuss the molecular basis of *specificity* and *sensitivity*.

How to develop more powerful diagnostics?
Students could *compare* emerging technologies, *identify* limiting properties and *propose* targeted research, e.g., to improve speed, versatility, ease of use, cost, device lifetime, etc.

Society:

IMAGINE THAT YOU WORK FOR…

How to implement diagnostic systems?
Students could consider how to put a technology *into practice*, e.g., financing, sample acquisition strategies, technical support, social infrastructure, etc.

How to coordinate multiple detection strategies?
Students could assume *different roles* (CDC employees, technical consultants, local officials, etc.) in teams charged with the task of monitoring the virus globally.

← SKILLS & ATTRIBUTES

⇩

How to prevent infections?

Of an individual:

VACCINES

How to design?

An opportunity to design a *molecule*.

MOLECULAR TRANSFORMATIONS →

How to quickly mass produce?

Students could consider how to *mass produce* a vaccine during a national emergency, e.g., could one harness the fermentation capabilities of commodity protein companies (e.g., Genencor) or not? What are the issues?

SYSTEMS DESIGN →

Of a population:

POPULATION MODELS

For a limited supply of vaccines…

Who should receive vaccinations?

An opportunity to discuss *ethics*.

← SKILLS & ATTRIBUTES

What distribution would best prevent an epidemic?

Students could create *models* similar to those of William Fagey in the 1970s, which helped Fagey to decide how to distribute a limited vaccine supply in Africa to eradicate smallpox.

← MULTI-SCALE ANALYSIS

How to control an outbreak?

Antidotes:

DRUG MOLECULES

How to discover?

An opportunity to classify *molecules* and *molecular reactions*.

MOLECULAR TRANSFORMATIONS →

How to quickly mass produce?

An opportunity to discuss *patents* and *generic drugs*.

SKILLS & ATTRIBUTES →

Quarantines:

POPULATION MODELS

How will an epidemic spread?

An opportunity to consider *transport* from molecular → global scales.

Will quarantines stop a pandemic?

Students could *model* a pandemic in the world human population and predict the efficacy of quarantines.

← MULTI-SCALE ANALYSIS

This Workshop

- Provide you with an update (introduction) to this curriculum initiative
  - Partly done
  - Will continue through the workshop
- Invite your participation
- Broaden input from all stakeholders on implementation strategies