Transforming Chemistry Education: Models for Transitioning to Green Chemistry Education in Higher Education

GREEN CHEMISTRY COMMITMENT
beyondbenign.org

Andrew Dicks
Professor, Teaching Stream
UNIVERSITY OF TORONTO

David Laviska
Assistant Professor
SETON HALL UNIVERSITY 1856

Nick Kingsley
Associate Professor
M FLINT

Welcome to the Green Chemistry Commitment
Green Chemistry Education Webinar Series

Submit questions at any time during the webinar in the **Control/Chat** box on the **Control Panel**

Natalie O'Neil, Ph.D.
Program Manager
Higher Education
Beyond Benign
@natjoneil

Amy S. Cannon, Ph.D.
Executive Director
Beyond Benign
@Amy_Cannon

Recording and supporting documents will be available:
https://www.beyondbenign.org/he-webinars/

Join the conversation online!

@beyondbenign
#GreenChemistry
#GCCwebinars
#GCCommit, #GCCsigners

https://www.facebook.com/beyondbenign/

GREEN CHEMISTRY COMMITMENT
beyondbenign.org

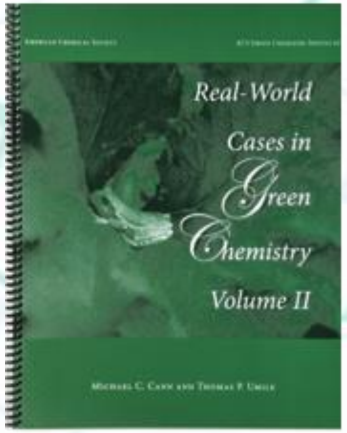
What is the GCC?

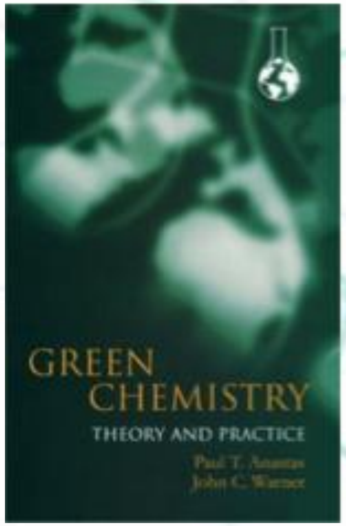
The **Green Chemistry Commitment** (GCC) is a consortium program that unites the green chemistry community around shared goals and a common vision to:

- expand the community of **green chemists**
- **grow** departmental resources
- share **best practices** in green chemistry education
- affect systemic and lasting **change** in chemistry education

https://www.beyondbenign.org/he-green-chemistry-commitment/

Green Chemistry Swag





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A Systems Thinking Department:

Fostering a Culture of Green Chemistry Practice

Jessica C. D'eon, Barbora Morra, Cecilia Kutas Chisu, Kristine B. Quinlan, Amy S. Cannon & Andrew P. Dicks

Department of Chemistry, University of Toronto
& Beyond Benign,Wilmington, MA

beyondbenign
green chemistry education

www.un.org/sustainabledevelopment

Of educational importance…

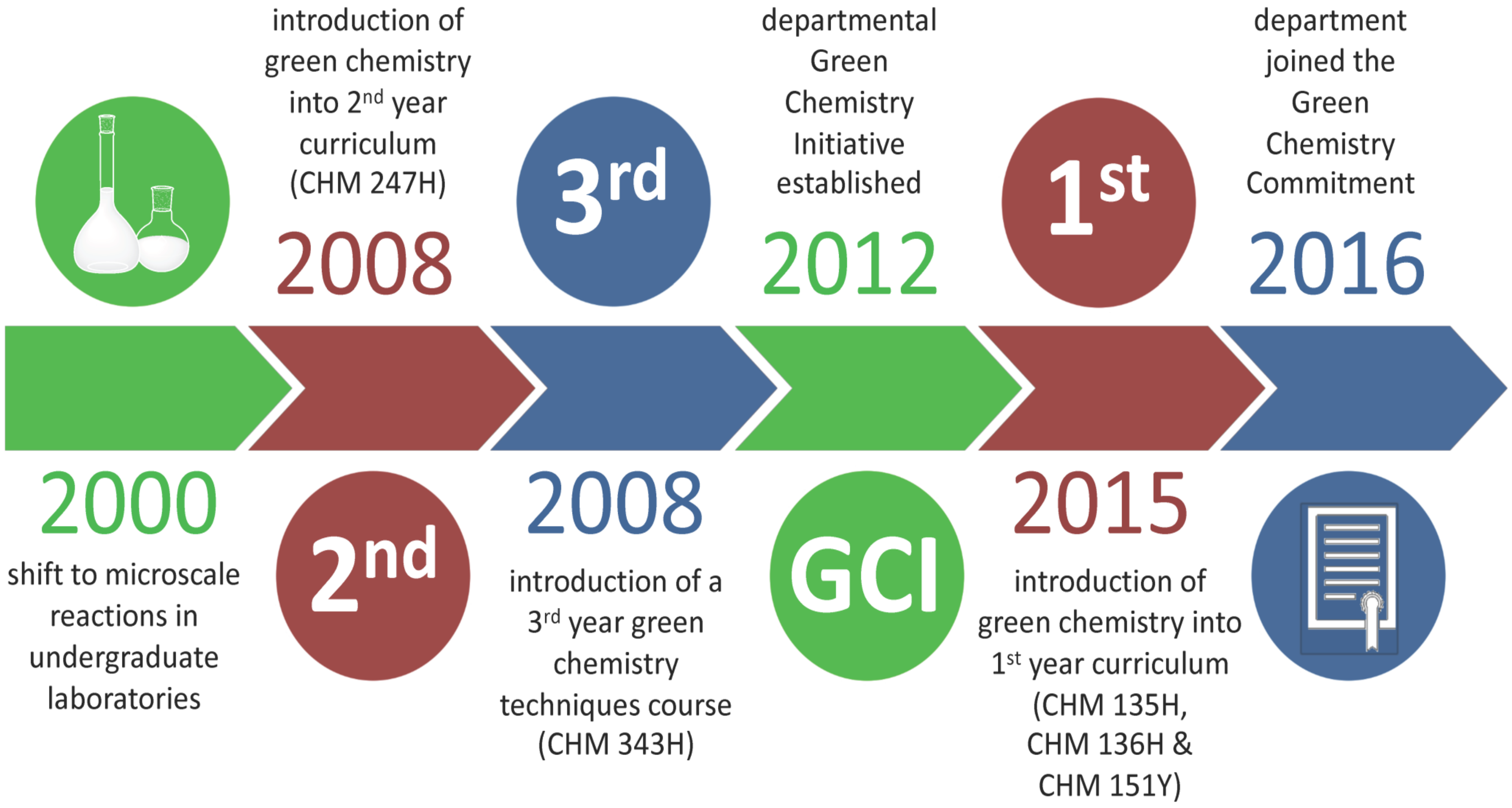
* modern university chemistry education requires curricula that specifically address societal/environmental challenges that students will face

* to my mind, this requires the following:

- *integration of sustainability principles into course**s**, program**s**, research practice**s**, and **other activities***
- *an early introduction of these principles to **scientists***
- *a further emphasis on problem-solving/decision-making*

J. Chem. Educ. **2019**, *96*, 2836

Departmental timeline



The 12 Principles: Systems thinking

Green Chemistry

Everyone's Doing It!

The 12 Principles of Green Chemistry

A framework for designing or improving materials, products, processes and systems.

1. Prevent Waste
2. Atom Economy
3. Less Hazardous Synthesis
4. Design Benign Chemicals
5. Benign Solvents & Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis (vs. Stoichiometric)
10. Design for Degradation
11. Real-Time Analysis for Pollution Prevention
12. Inherently Benign Chemistry for Accident Prevention

*Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice, Oxford University Press: New York, 1998, p.30. By permission of Oxford University Press.

www.acs.org/greenchemistry

* "reductionist" vs. "holistic" approach to teaching…

* big picture:

elimination of hazards

elimination of waste

2008 onwards: Organic I & II

* CHM 136H: Introductory Organic I enrollment: ~1800 life science students per academic year

* five experiments: no specific “greening” done

* however… analysis of experiments in terms of:

what was green?
what was not green?
what could be made greener?

J. Chem. Educ. **2004**, *81*, 1187

Current Organic I wet experiments

Experiment Title	Details	Green Principles Considered
Solubility Behavior as Clues to Structure	• testing five known solutes in various solvents/aq. solutions to relate structure to solubility behavior • testing solubility of an unknown to elucidate structural components	• P5 (safer solvents and auxiliaries) • use GSK solvent guide, consider solvent attributes • use MSDS/hazard symbols for solids
Recrystallization of an Unknown Solid	• purification by recrystallization • characterization by melting point determination	• P6 (design for energy efficiency) and P5
Separation of a Solid Mixture by Extraction	• separation of an unknown solid mixture by liquid-liquid extraction • characterization of products by reactivity with aq. $FeCl_3$ and melting point determination	• P7 (use of renewable feedstocks) • identify possible mixture components derived from renewable feedstocks • P5 and P6 also applied
Formation of a Tertiary Alkyl Halide	• conversion of *t*-butanol to *t*-butyl chloride with concentrated HCl • washing and isolation by extraction • determination of boiling point by simple distillation	• P2 (atom economy) • P3 (less hazardous synthesis) • P5, P6 and P7 also applied

J. Chem. Educ. **2019**, *96*, 2836

2016 onwards: General Chemistry

* CHM 135H: Physical Principles enrollment: ~1800 students per academic year

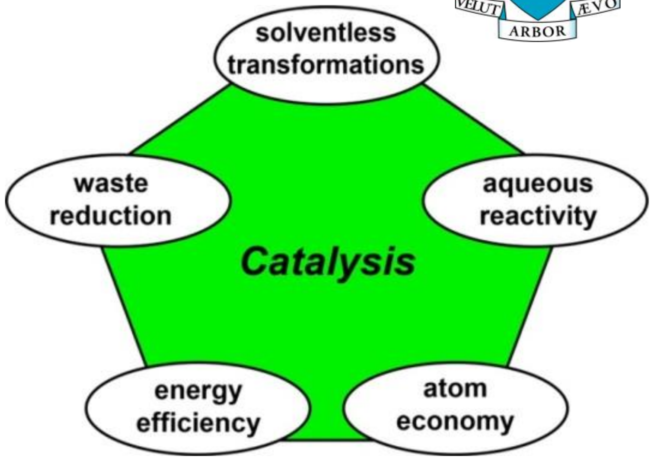
* first experiment:

- quantification of H_2 gas formed on reacting Mg with HCl
- introduction of green chemistry metrics (AE, RME) and a reaction as a "system"

J. Chem. Educ. **2019**, *96*, 2836

CHM 343H: Organic Synthesis Techniques

* enrollment ~ 30 - 40,
  first taught in Spring 2008



* mix of chemistry program students

* design new, GREENER experiments (total 50 hours):

(a) CATALYTIC reactivity (b) "solvent-free" reactions
(c) replacing organic solvents with water
(d) student-driven (e) class reinforcement

J. Chem. Educ. **2013**, *90*, 519

2019: Developing "laboratory autonomy"

Experiment 1: Synthesis of an Antidepressant (Moclobemide)

Experiment 2: Three-Step Sunscreen Analog Synthesis

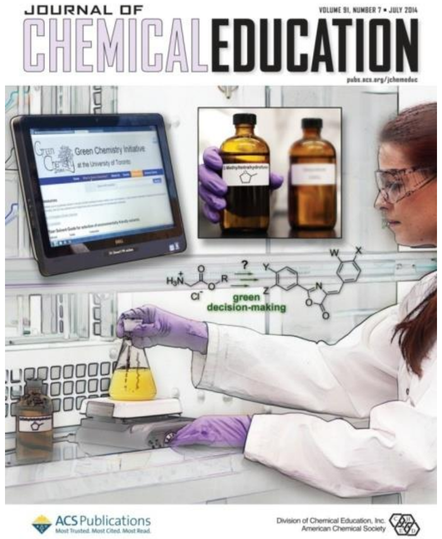
Experiment 3: The Reduction of 4-t-Butylcyclohexanone

Experiment 4: A "Plan-Your-Own" Alcohol Oxidation

Experiment 5: A Sonogashira Cross-Coupling Reaction

Future Leaders in Green Chemistry Assignment Practical Work

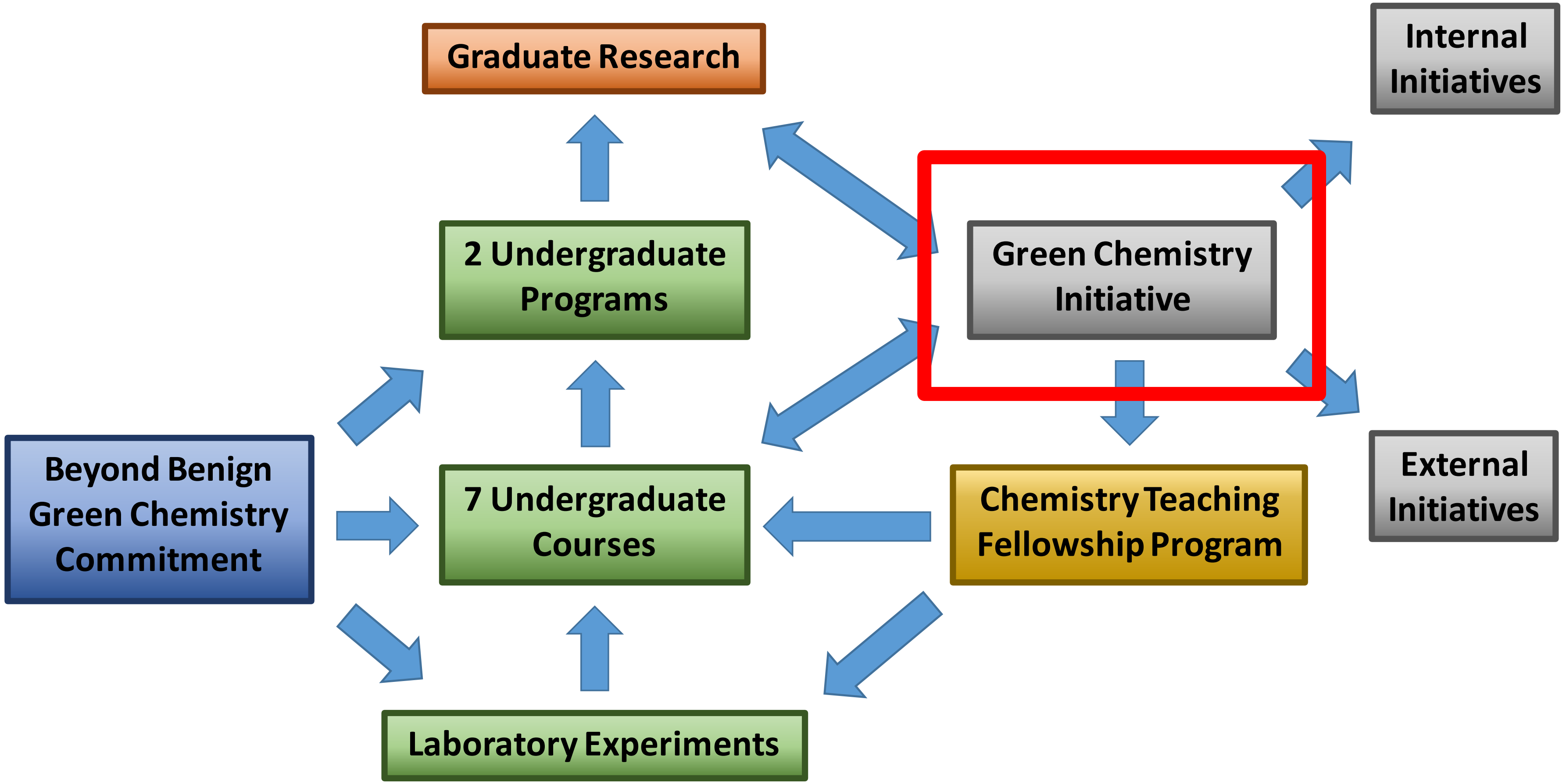
Experiment 6: Suzuki NSAID Analog Synthesis via Microwave Irradiation



Experiment 7: A "Design-Your-Own" Multi-Step Synthesis

J. Chem. Educ. **2014**, *91*, 1040
J. Chem. Educ. **2019**, *96*, 93

Our departmental "system"…



J. Chem. Educ. **2019**, *96*, 2836

The U of T Green Chemistry Initiative (2012)

GOALS:

* to help produce educational materials for students

* to promote sustainable lab. practices

* to raise departmental awareness about green chemistry

www.greenchemuoft.ca

The GCI: Internal & external activities

- spearhead departmental sustainability campaigns (e.g. solvent recycling, “Shut the Sash”)

- annual symposia for U of T & external graduate students

- YouTube video campaign highlights the 12 Principles in an accessible manner (> 55k views)

Green Chem. Lett. Rev. **2019**, *12*, 187: OPEN ACCESS

Final thoughts…

* don’t need to “reinvent the wheel”

* students (ug/graduate) are very interested in this form of curriculum development!

* integration across the curriculum is key: importance of Green Chemistry Commitment

* impact on research activities

Green Chemistry at Seton Hall University

David A. Laviska

Department of Chemistry and Biochemistry; Seton Hall University, South Orange, NJ 07079

Transforming Chemistry Education:
Models for Transitioning to Green Chemistry Education in Higher Education

Hosted by Beyond Benign
April 1, 2020

SETON HALL UNIVERSITY 1856

Green Chemistry Commitment SIGNER

Seton Hall University

Classification
National University (R2 – “High Research Activity”)
Enrollment: 10,200 students (6,200 undergraduate + 4,000 graduate)

Department of Chemistry and Biochemistry
Faculty: 16 full-time (11 tenure/tenure track + 5 non-tenure track)
Research active: 14 faculty
Chemistry majors: ~35 per year (including biochemistry; ACS and non-ACS)

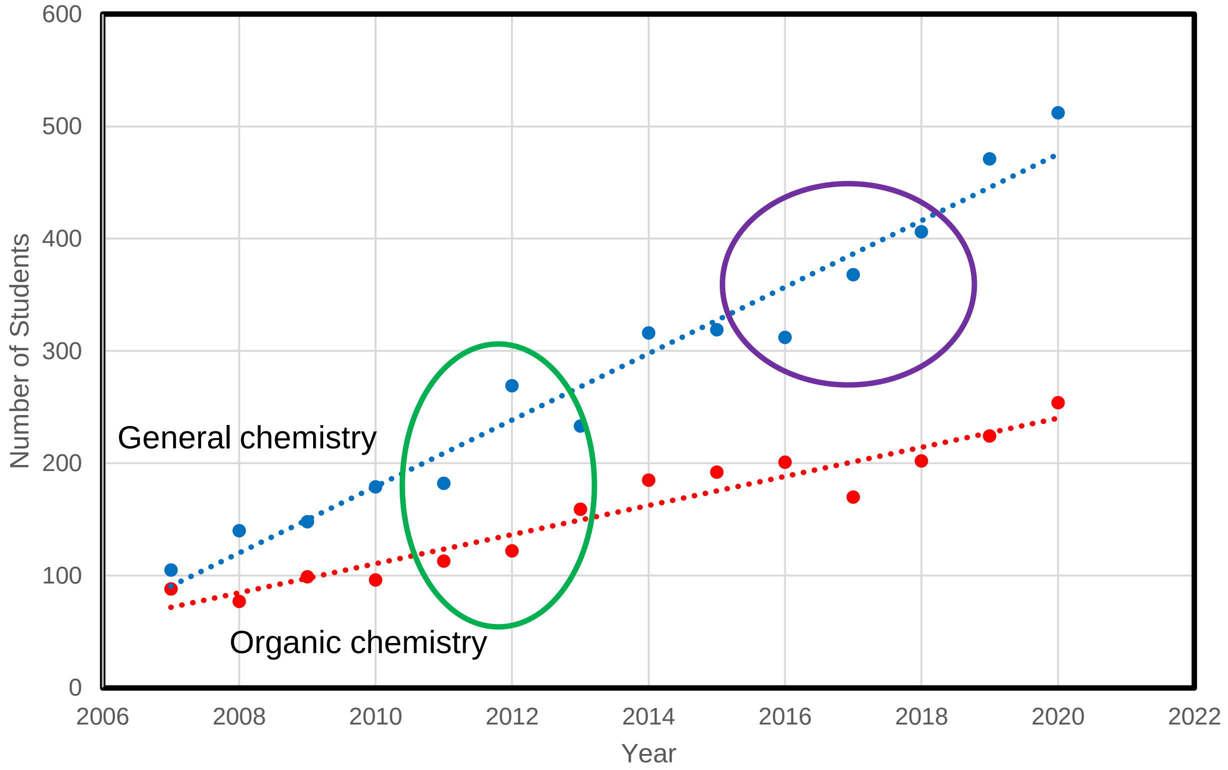
Mission Statement: “Seton Hall University is a major Catholic university. In a diverse and collaborative environment, it focuses on academic and ethical development. Seton Hall students are prepared to be leaders in their professional and community lives in a global society and are challenged by outstanding faculty, an evolving technologically advanced setting, and values-centered curricula.”

Enrollment statistics

Growth in enrollment for students majoring in the sciences (chemistry, biology, physics) was steady from 2000-2010. However, significant jumps were quantified at two key points over the last decade:

2011: SHU started matching the State Tuition Rate (STR) for more students.

2017/18: Hackensack Meridian Medical School at Seton Hall opened for its inaugural class.



*Numbers for 2020 are based on current data from the registrar. Student enrollment in these “gateway” courses are primarily Health Sciences (Biology) majors.

https://www.shu.edu/chemistry/index.cfm

Why Green Chemistry?

This is an important question that every department needs to consider. At Seton Hall:

1. **Mission** – Green Chemistry principles mirror our institutional mission. Specifically, SHU places high value on the broad concepts of sustainability and stewardship.

2. **Local Industry** – Green Chemistry principles are in excellent alignment with best practices for most industries that involve chemical transformations and employees who design and implement them.

3. **Catalysis** – Chemistry at SHU has a long history of focusing on catalysis – a key tenet of Green Chemistry – through the R&D housed within the former Center for Applied Catalysis.

4. **Broadening/Diversifying Curricula** – One of our goals is to enhance the inclusiveness of our courses and make chemistry more appealing to a broader subset of our student population.

5. **Alternative to Health Sciences** – Not all pre-med students flourish; we want them to learn that there are many other highly productive and satisfying career paths.

6. **CONTEXT** – Green Chemistry and related topics like systems thinking, life-cycle analysis, and stewardship of the planet help students take a greater interest in learning fundamental chemistry concepts.

Green Chemistry Initiative

Center for Green Chemistry and Catalysis:

Robert L. Augustine

Setrak K. Tanielyan

Directors of the former Center for Applied Catalysis

SETON HALL GREEN CHEMISTRY INITIATIVE JUNE, 2018

David A. Laviska

Organometallic

Cecilia E. Marzabadi

Organic

Wyatt R. Murphy

Inorganic

(Research areas)

What have we accomplished?

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➢ Pedagogy

- Entirely new or improved green(er) organic laboratory sequence: 2019-20
- Assessment of student learning regarding green concepts
- Procure equipment for new lab space in support of a green curriculum
- Redesign lab curriculum for general chemistry to align with green chemistry*
- Develop an upper level elective course on green chemistry and catalysis*
- {For the future: Certification in green chemistry}

➢ Center for Green Chemistry and Catalysis

- Student and faculty research
- Formalize the organization within the DC&B at Seton Hall*
- Transforming dedicated lab space for the Green Chemistry Initiative*

➢ Outreach

- Develop a new green-focused curriculum for students studying to become K-12 teachers in coordination with the Dean of Education at Seton Hall*
- Enhanced presence in social media (Facebook, Twitter, Instagram, etc.)*
- Summer internships at Seton Hall and beyond*
- {For the future: Partner with local industry for advising and funding}
- {For the future: Partner with the Liberty Science Center; new Green Chemistry content}

***IN PROGRESS**

Challenges: Curriculum

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“New” sequence of experiments for Organic I and II (non-majors):

Organic 1:

Lab 1: Synthesis of acetaminophen, Decolorizing, Recrystallization
Lab 2: Melting point and Solubility

Lab 3: Solid/Liquid Extraction of Spinach and TLC
Lab 4: Column chromatography and visible spectroscopy

Lab 5: Liquid/liquid extraction: Extraction of Iodine

Lab 6: Simple Distillation (Water/$NaC_2H_3O_2$/Food dye)

Lab 7: Fractional Distillation (Water/EtOH) and Boiling point

Lab 8: IR Identification of polymers

Lab 9: E1 Reaction: Dehydration of 2-methylcyclohexanol and Gas chromatography

Lab 10: NMR

Lab 11: Synthesis of a Fluorescent molecule

Organic 2:

Lab 1: Suzuki-Miyaura Coupling

Lab 2: Preparation of furoin using thiamine catalysis

Lab 3: Oxidation of furoin to furil using copper catalysis

Lab 4: Reaction of 4-methoxyacetophenone with bleach (low pH)

Lab 5: Reaction of 4-methoxyacetophenone with bleach (high pH)

Lab 6: Hydrolysis of PET

Lab 7: Synthesis of Nylon

Lab 8: Diels-Alder reaction

Lab 9: Aldol Condensation

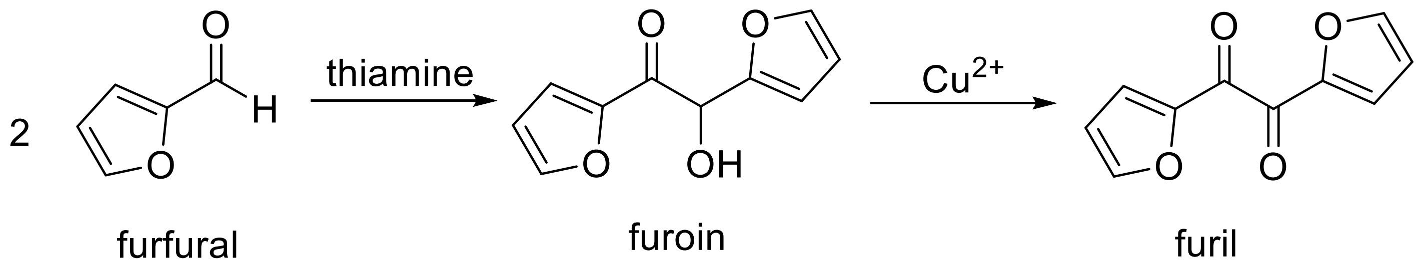
Lab 10: Synthesis of a porphyrin

Experiments: Orange vs. Green

Furfural to furoin to furil

Two consecutive lab sessions:

1. "Benzoin coupling" of two moles of furfural to make furoin
2. Oxidation of the α-hydroxyl ketone furoin to the diketone furil



Orange	Green
Toxic catalyst: CN^-	Benign catalyst: Thiamine
Harsh oxidant: HNO_3	Benign oxidant: Cu^{2+}
1 hr reflux for step 2	Microwave (5 min.)
Recrystallization required	No recrystallization
Renewable reactant	Reactant from biomass

Assessments

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Sample Question: The "green" advantages of five experimental protocols are provided below.

Experiment 1	Experiment 2	Experiment 3
Non-renewable reagents	Two renewable reagents	Non-renewable reagents
Heat to 150 C	No heating (R. T.)	Heat to 75 C
7 hr reaction time	30 min reaction time	1.5 hr reaction time
Includes catalysis	Includes catalysis	Includes catalysis
Aqueous solvent	Aqueous solvent	Benzene solvent
1 by-products	No by-products	2 by-products

A.) Choose the experiment you think is the *most green* and explain your choice.
Answer: Experiment 2
This should be obvious to the students, since all of the factors listed can be considered green and desirable.

B.) Which experiment would be your *second choice*? Explain.
Answer: ?
This probes a higher level of sophistication in student understanding. Since there is no obvious "best answer", the value is in seeing how the students explain/justify their choices.

CONTEXT!

- In-class discussions
- Extra credit assignments
- Exam bonus questions
- End-of-term write-up

Undergraduate research

Lab Development for the Green Chemistry Initiative

Summer 2018	Fall 2018	Spring 2019	Summer 2019	Fall 2019
Dominick	Dominick	----------	Dominick	Dominick
Kyle	Kyle	Kyle	Kyle	
Anthony	Anthony	Anthony		
		Will K.	Will K.	
			Andi-Kaye	
			Will M.	

Laviska Research Group

Individual Research Projects

Summer 2018	Fall 2018	Spring 2019	Summer 2019	Fall 2019
Anthony	Anthony	Anthony	Anthony	Anthony
		Kyle	Kyle	Kyle
			Andi-Kaye	Andi-Kaye
			Will K.	Will K.
			Will M.	Will M.



Summary

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- No single "best" approach
- Flexibility is important
- Collaboration is *extremely* helpful

Get started with an action plan:

1. Think about the question: "Why Green Chemistry"?

2. Write down your answers as GOALS.

3. Seek out others in your department who value similar goals and/or can add to the conversation. (Be bold! Collaborators are helpful.)

4. Pick a starting point. (Make it straightforward!)

5. Read. (There are plenty of resources available through Beyond Benign, the ACSGCI, and elsewhere.)

6. Look for external cheerleaders/mentors/guides. (Don't be shy!)

7. Set a realistic timeline and GO!

Green Chemistry Commitment SIGNER

Who are we?

Campus

- 6,400 Undergraduates and 1,400 Graduate students (F'17)
- >100 Undergraduate programs, 18 Masters, 3 Doctorates
- Many Early College and DEEP (HS duel enroll) Programs

Students

- 92% are Michigan residents, 80% Alumni stay in MI after graduation
- 62% of all students are women
- 16% of all UG degrees issued are STEM programs
- 8% of all UG majors are in Biology or Biochemistry

Department

- 80-100 majors
- 7-15 graduates per year
- 2/3 of majors are Biochemistry

GREEN CHEMISTRY

Green Chemistry Program 2018

BS: Green Chemistry

- 2 Semester of Lecture and Laboratory
  - General Chemistry
  - Organic Chemistry
  - Physical Chemistry
  - Analytical Chemistry
- 1 Semester Lecture and Laboratory
  - Inorganic Chemistry
- 2 Semesters of Seminar
- 2 Semester of Research

2 Semester of Biochemistry Lecture

1 Chemistry Electives

Spectroscopy, Advanced Organic, Polymers, Enzymology, Proteomics

1 Semester of Lecture

- Green Chemistry
- Environmental Toxicology
- Life Cycle Assessment and Industrial Ecology
- Sustainable Design of Products and Systems
- Environmental Law and Public Policy
- Microeconomics

GREEN CHEMISTRY

Green Chemistry Mission

The mission of the Green Chemistry Program is to educate chemists to be ambassadors for the safer and sustainable design of chemicals and processes. Graduates will use interdisciplinary skills to responsibly shape the environmental, social, and economical impacts of chemistry.

GREEN CHEMISTRY

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Programmatic Issues

Course Scheduling

- Course time slots
- Course offerings
- Pre-requisites
- Limited course flexibility
- Substitutions for degree

Program Narrative

- Green Chemistry understanding
- Expertise expectations
- Enrollment expectations

GREEN CHEMISTRY
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How to Gather Support

- Awareness from Green Chemistry Commitment
- Social and Environmental Justice
  - Finding a home for ideas
  - Social Science, Arts and Humanities having shared interest with chemists
- Civic Engagement
- Community Outreach

Across All Curriculum

- Green Chemistry Principles Incorporated Topically
  - Systems Thinking approach
  - United Nation Sustainable Development Goals
  - Environmental Justice and Social Inequality

General Chemistry

Flint Water Crisis

- Ksp and Molar Solubility
  - Lead (II) phosphate vs. lead (II) chloride
  - pH of drinking water
- Water Purification
  - Disinfectant treatment
  - Oxidation of organics
- Plastics
  - Pollution Control

Energy

- Looking for energy and CO_2 emission solutions
- Solar Panels
    - Materials used
    - Life span of panel
    - Disposal of panel
- Wind Turbines
    - 800 pounds of Neodymium, 130 pounds dysprosium
    - China controls majority
    - Bird deaths

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Lab Curriculum

General Chemistry

- Sustainable Polymer incorporation in both semesters
  - ***PUI Sustainable Polymer Education & Research Consortium Workshop***
  - ***Augsburg University and University of Minnesota***
- Iron Determination with Black Tea
  - *J. Chem. Educ.* 2020, 97, 1, 207-214

Organic Chemistry

- Suzuki–Miyaura cross-coupling in green solvent
- Solvent-free Diels–Alder reaction

Inorganic Chemistry Lab

Capstone Presentation

- Pick an experiment they performed while at UM-Flint
  - Source the production of chemicals used
  - Give 8 minute presentation
    - Summary of boundaries
    - Impacts of experiment
    - Synthesis trees
- Biggest impact is always far removed from the system they are directly experiencing

Sustainable Development Goals Projects

Three week project

- 6 page “research” paper
- Infographic summary
- Pick United Nations Sustainable Development Goal
  - Discuss what the Goal is
  - How can Green Chemistry help achieve this goal

Rubric development

Audience, Visual Appeal, Understanding, Clarity/Organization and Fluidity

Green Chemistry Lecture

UN Sustainable Development Goal 15: Life on Land

Preventing Land Degradation

What is Land Degradation?
Any unwanted human disturbance to an environment

Solutions From Green Chemistry

Principle 1	• Prevent Pollution
Principle 4	• Design Safer Chemicals
Principle 10	• Design for Decomposition

Applying Principles:

The Agricultural industry can:

- Reduce excess pesticide use
- Produce pesticides that target a specific pest
- Produce effective pesticides that degrade easily

Agricultural Problems:

Land Degradation
- Pesticide use
- Soil Contamination
- Making/Plowing Fields

Loss of Biodiversity
- Pesticide toxicity
- Decline in insect population
- Decrease in small animals from food source depletion

What is Biodiversity?
The variety of life in an ecosystem

Preserving Biodiversity

1. United Nations Development Programme. *Goal 15: Life on land.* Retrieved from http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-15-life-on-land.html Accessed on 10 Dec. 2018.
2. Noonan-Mooney, Kieran; Gibb, Christine. *The Youth Guide to Biodiversity: How are people affecting biodiversity?* Youth and United Nations Global Alliance. Rome, 2013.
3. Tilman, David; Fargione, Joseph; Wolff, Brian; D'Antonio, Carla; Dobson, Andrew; Howarth, Robert; Schindler, David; Schlesinger William H.; Simberloff, Daniel; Swackhamer, Deborah. Forecasting agriculturally driven global environmental change *Science,* **2001,** *292,* 281-284
4. Anastas, Paul T.; Warner, John C. *Green Chemistry: Theory and Practice.* Oxford University Press: New York, 1998.

Questions?

Submit questions in the **Control/Chat** box on the **Control Panel** for our

Natalie O'Neil, Ph.D.
Program Manager
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Beyond Benign
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@Amy_Cannon

Recording and supporting documents will be available:
https://www.beyondbenign.org/he-webinars/

COVID-19 UPDATES AND VIRTUAL RESOURCES

http://bit.ly/GC_Virtual_Resources

Updated: March 30, 2020

As the novel coronavirus outbreak continues to spread globally, our thoughts turn to our community of educators during this time. On top of the many health and anxiety concerns, faculty and teachers are being asked to shift to on-line teaching, which is no easy task. We remain committed to bringing exemplary Green Chemistry training and resources to educators around the world. We are working to provide alternative programming and reschedule cancelled workshops where possible to support our community. We will share these opportunities through Twitter, Facebook, and on our website. For more information, see our Events page.

To help teachers who are shifting towards virtual learning, below is a list of Green Chemistry virtual resources from us and our partners.

We wish you good health in this crisis and we look forward to staying connected with you all virtually over the next few months.

K-12 virtual resources

Beyond Benign Student Demo of Equilibrium Lab
~3 min video of a equilibrium reaction explained by students.

Beyond Benign Student Demo of Reaction Lab
~3 min video of the HS reaction lab explained by students.

Beyond Benign Student Demo of Sublimation
~3 min video of a sublimation reaction explained by students.

CPALMS Chemistry with a Conscience
Interactive tutorial for HS students

Eric Nash Chemistry Tutorials
Created by lead teacher, Eric Nash
A database of explanation videos of concepts in the typical

Higher Ed virtual resources

American Chemical Society Green Chemistry Institute
Online education resources for Green Chemistry & Engineering

Yale-UNIDO University Curriculum
27 lecture PowerPoints presentations
Supplementary reading and video recommendations
Curriculum Overview Webinar

Beyond Benign Green Chemistry Webinar Archive
31 webinars covering Analytical, Organic, General and Green Chemistry along with Toxicology and Green Chemistry metrics

Carnegie Mellon University Institute for Green Science
Green Chemistry modules available for download
Powerpoint presentations, hand-outs available

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green chemistry education

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Thank you for joining us!

Recordings, supporting documents and upcoming webinars (with registration links):
http://www.beyondbenign.org/he-webinars/

Sign-up for Beyond Benign's quarterly newsletter and webinar announcements on our homepage:
www.beyondbenign.org

Connect with Beyond Benign online with the community!

Stay tuned for the next webinar!