Teaching Philosophy

Approach to Teaching

My passion for education stems from my own curiosity into the process of learning and the structure of knowledge. Successful and engaging teaching requires not only passion but using the best science to inform classroom activities, program expectations, assessment design, and everything in-between. I believe that an educator must be flexible and self-aware, and strive to improve their methods rather than settle into a status quo. In this document, I outline three tenets of my approach to teaching: 1) Learning outcomes guiding course design, 2) Teaching informed by the best evidence, 3) Development and collaboration.

1. Learning outcomes guide course design

My teaching is oriented around specific, measureable learning outcomes. My goal as an educator is to create these outcomes at the onset of course design, and use them as a guide for course content and assessments. In this context, learning outcomes for chemistry courses must be 1) S.M.A.R.T. and 2) Three-dimensional according to the Next Generation Science Standards (NGSS).

I see learning outcomes for a course as the outcomes of goals intended for the students, which must be S.M.A.R.T.: Specific, Measureable, Attainable, Relevant, and Timely. This system of creating and working towards goals has proven success in many areas, including education.[1,2] In a third year organic chemistry course where I was the T.A., an example of a S.M.A.R.T. learning outcome was "For a dipolar cycloaddition, draw the HOMO and LUMO of the reaction partners and predict the product regiochemistry".

The NGSS sets a new road map for K-12 science education that can also guide post-secondary science instruction and assessment (Figure 1).[3,4] The standards are centered on three key dimensions of science: 1) Disciplinary Core Ideas, 2) Cross-Cutting Concepts, and 3) Science and Engineering Practices. While there have been several implementations of NGSS-centred approaches in US post-secondary institutions, these standards have yet to be formally applied in Canadian post-secondary education.

The disciplinary core ideas for physical science (Matter, Motion & Stability, Energy, Waves) are typically well covered in traditional post-secondary courses, but the Cross-Cutting Concepts and Science and Engineering Practices tend to be lacking. Incorporating the Cross-Cutting Concepts (*e.g.*, Scale, Systems, Patterns) improves learning outcomes by linking multiple areas of science. Science and Engineering Practices (*e.g.*, "Developing and Using Models") are essential for learners to develop as scientists themselves, and connect the content details with skills and applications. However, while these practices are often implicitly intended in courses, they may be looked over if not explicitly stated in learning outcomes (and included on assessments).

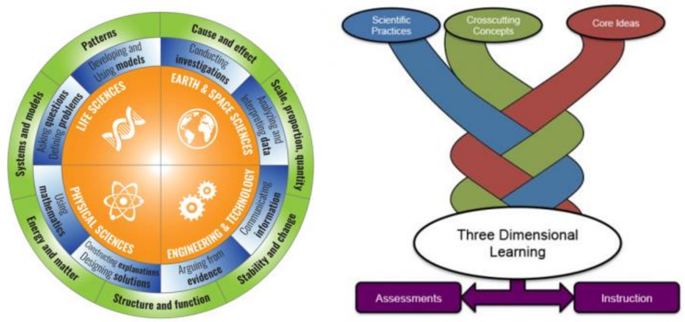

Figure 1. The NGSS have three dimensions: Cross-Cutting Concepts (green), Science and Engineering Practices (blue), and Disciplinary Core Ideas (orange) that come together into a '3-Dimensional' approach to teaching and assessment.

I believe that my intended learning outcomes for a course must be clearly provided to the students, and that classroom activities or exam questions must consistently reflect these desired outcomes. I intend to design a course where learning outcomes are achieved, like skill badges, similar to a gamified curriculum.[5] This design helps students to know exactly what is expected of them, and also allows them to consider their goals and purpose for taking the course.

2. Teaching informed by the best evidence

As a scientist, it is essential for my teaching practices to reflect the scientific literature on teaching and learning. This involves staying informed on learning theories from Science Education and Chemistry Education, and also in more broad areas of the cognitive science, memory research, etc. Three key teaching and learning frameworks influence my current teaching philosophy: Novak's Theory of Education, Modern Information Processing Theory, and the Mental Models Theory.

Novak's Theory of Education, also known as Human Constructivism, is a theory that has had a great impact on science teaching and learning, and has been a key framework for chemistry education in the past decade.[6,7] The theory captures *meaningful learning* as the purposeful connection of new and personally relevant knowledge with one's existing knowledge. Novak's theory thus emphasizes the importance of the student in the learning process: the student must connect new material to their own prior knowledge, and must choose to learn in this way as opposed to rote memorization (memorization without meaning). The research in this area of chemistry education provides growing support for 1) active learning classrooms, 2) the value of a student's attitudes towards chemistry and their ability to learn, and 3) the need to teach chemistry in a locally or globally meaningful context. Following these recommendations and implications from the literature, my courses will be flipped/blended, which creates an active learning environment by moving problem solving and discussion into the classroom. The curriculum will also include local (departmental) examples of the course material. In addition, one can use questionnaires to gauge the students' attitudes towards their chemistry course, and focus on forging a personal link between chemistry and the learner.

Modern Information Processing Theory (IPT) is a framework that describes how we intake, process, and store knowledge to memory. While classic information processing theory treats the mind as a computer, modern information processing theory has evolved to include aspects of constructivism and meaningful learning.[8,9] IPT outlines the interaction between sensory input of information into one's working memory, and the interaction of this information with long-term memory (Figure 2).

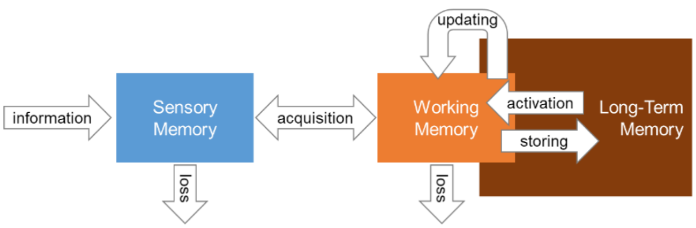

Figure 2. Modern Information Processing Theory, adapted from Stern, *npj Science of Learning* (**2017**). Sensory information is either acquired into working memory of lost. Working memory is fluid and continuously updated based on prior knowledge in long-term memory. Once in working memory, information can activate the long-term memory, and be purposefully stored with prior knowledge in long-term memory.

As an educator, I intend to design course materials that align with aspects of IPT. For example, key information presented in lecture notes or online material must be salient to be transferred into working memory. This can be achieved, for example, by clearly linking new material to the learning outcomes of that lecture of the course. Another takeaway from IPT is that to commit knowledge to memory the learner must make purposeful connections with information in their long-term memory. This means that the necessary components within long-term memory must be elicited into working memory for learning to occur. For example, if my intended learning outcome for a class is to have students "develop a model of water boiling and draw the process on paper", I must elicit from long-term memory their macroscopic and microscopic visualizations of the process as well as prior knowledge of the symbolic systems we use to communicate dynamic processes. This would involve using several representations of the process, and also asking them to describe their model in various ways.

Mental Models Theory (MMT) is a framework from cognitive psychology and science education that has become vital to my teaching philosophy.[10–12] Creating and using models are essential skills in chemistry where educators and researchers rely on a models to predict or explain relationships between reactivity and molecular structure. These models are often abstract, static, and communicated with a complex language of symbolism (*e.g.*, electron-pushing formalism, Lewis structures) (Figure 3).

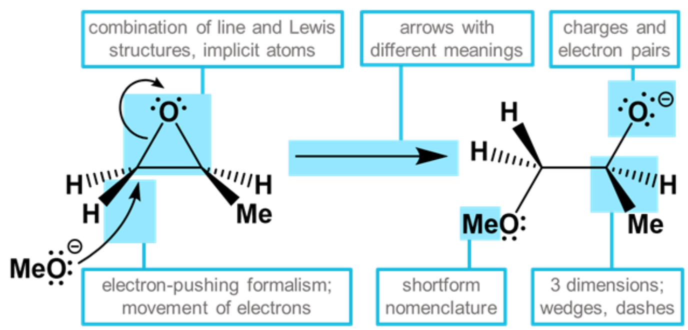

Figure 3. A conceptual model of "organic chemistry's language" is shown here as the symbolism used in a representation of an organic reaction mechanism, including Lewis structures, line structures, the electron-pushing formalism, and other arrows.

In contrast to conceptual models, which represent scientifically accepted knowledge, mental models are personal internalized knowledge structures, which are constantly changing and growing.[13] Research has shown that students own mental models of chemistry's symbolic language are fragmented, as they give little meaning to the symbols on the page.[14–19] This emphasizes the need for discussing the purpose and limitations of our scientific models with students. I intend to build coursework around teaching students to use models as tools to predict and explain phenomena, rather than taking them at face value.

When learning or problem solving, the learner can elect to use multiple models,[13] but errors can arise when necessary models are not activated.[20] Multiple models are necessary to explain phenomena in chemistry,[21–23] for example in chemical kinetics blending models of math and chemistry has been shown to help students develop understanding.[24] The design of course material, animations,[25,26] or learning activities must support learners in the development of their personal mental models, while avoiding the formation of misconceptions.[27]

3. Development and collaboration

One of my goals as an expert and educator is to develop tools to give students opportunities to learn. I believe this educational development not only complements but enhances research in chemistry education.

These developments, at any scale, require strong collaborations with fellow professors, educators, pedagogical support services, and the students themselves. I strive in my current position to build connections with the Faculty of Education, the Chemistry Department, and actively participate in workshops from pedagogical support services.

Teaching Contributions

1. Teaching responsibilities

I have been a teaching assistant in several courses and in various capacities as listed in the table below.

Course	Responsibilities
First Year Organic Chemistry Laboratory	• Leading a small group of students through weekly experiments • Providing and discussing feedback on written reports
Second Year Organic Chemistry	• Leading weekly tutorial sessions (~ 30 students) using self-made teaching materials
Medicinal Chemistry (4th year)	• Working with the professor to design assessment items for problem sets and summative exams • Grading all assessments
Third Year Organic Chemistry	• Leading weekly tutorial sessions, guiding ~100 students through problem sets in an active-learning format • Grading assessments
Advanced Analytical Laboratory (4th year)	• Creating and conveying specific learning outcomes for each experiment • Demonstrating analytical methods and guiding students through advanced protocols • Creating a rubric for future teaching assistants

2. Advisory responsibilities

I have supervised several students in synthetic chemistry or educational projects, including 3 honours project students and 3 research assistant undergraduates. In these projects, the students lead and set goals, while I offer support and regular feedback. In my experience, students are most successful and creative when given the time to explore their own curiosities, and given the opportunity to make mistakes. I always aim to create a dynamic partnership with the student, where we are both helping each other achieve our goals. For example, a recent summer student had to learn a new statistical method for her research project, which she then taught to me and other members of the research group. I encourage my students to present their goals to the research group early in the project, and collaborate to build a road map for the project. As the project progresses, I have the student create written or PowerPoint summaries of their findings, and present again in research group meetings.

3. Science Communication

Chemistry is an exciting science that influences every aspect of life, a science that will play a key role in solving global challenges as outlined by the UN sustainability goals.[28,29] However, this identity for chemistry in our future can be lost on non-experts and students, partly because chemists have failed to communicate their work effectively. I believe that communication to non-experts is an essential practice in science -- "Science isn't finished until it's communicated" (Sir M. Walport, UK Chief Scientific Adviser). For this reason, I believe it is important to teach these skills to undergraduate and graduate students within their chemistry courses. This is especially true for undergraduates, for whom "first year" chemistry may actually be their last formal chemistry training before they follow other career paths.

I have made it a priority in my career to communicate my on-going research. This began during my PhD, where I developed a new research page for the research group. Since then, I have created and contributed to open-access educational resources such as infographics, and informational videos. I also have an active presence online to discuss my career and promote science advocacy. These practices expanded the reach of my research while allowing me to develop valuable communication skills that I intend to teach to my students.

References

(1) Brown, G.; Leonard, C.; Arthur-Kelly, M. Writing SMARTER Goals for Professional Learning and Improving Classroom Practices. *Reflective Pract.* **2016**, *17* (5), 621–635.

(2) Towns, M. H. Developing Learning Objectives and Assessment Plans at a Variety of Institutions: Examples and Case Studies. **2018**, *20*, 51.

(3) Underwood, S. M.; Posey, L. A.; Herrington, D. G.; Carmel, J. H.; Cooper, M. M. Adapting Assessment Tasks To Support Three-Dimensional Learning. *J. Chem. Educ* **2018**, *95*, 51.

(4) Laverty, J. T.; Underwood, S. M.; Matz, R. L.; Posey, L. A.; Carmel, J. H.; Caballero, M. D.; Fata-Hartley, C. L.; Ebert-May, D.; Jardeleza, S. E.; Cooper, M. M. Characterizing College Science Assessments: The Three-Dimensional Learning Assessment Protocol. *PLoS One* **2016**, *11* (9), e0162333.

(5) Subhash, S.; Cudney, E. A. Gamified Learning in Higher Education: A Systematic Review of the Literature. *Comput. Human Behav.* **2018**, *87*, 192–206.

(6) Novak, J. D. Human Constructivism: A Unification of Psychological and Epistemological Phenomena in Meaning Making. *Int. J. Pers. Constr. Psychol.* **1993**, *6* (2), 167–193.

(7) Bretz, S. L. Novak's Theory of Education: Human Constructivism and Meaningful Learning. *J. Chem. Educ.* **2001**, *78* (8), 1107.

(8) Mayer, R. E. Information Processing. In *APA educational psychology handbook, Vol 1: Theories, constructs, and critical issues.*; K. R. Harris, Graham, S., Urdan, T., McCormick, C. B., Sinatra, G. M., Sweller, J., Eds.; American Psychological Association: Washington, 2012; pp 85–99.

(9) Schunk, D. H. *Learning Theories: An Educational Perspective*, 6th Ed.; Pearson Education Inc.: Boston, MA, 2012.

(10) Johnson-Laird, P. N. Mental Models and Human Reasoning. *Proc. Natl. Acad. Sci.* **2010**, *107* (43), 18243–18250.

(11) Lesh, R.; Hoover, M.; Hole, B.; Kelly, A.; Post, T. R. Principles for Developing Thought-Revealing Activities for Students and Teachers. Lawrence Erlbaum Associates, Inc. 2000, pp 591–646.

(12) Bodner, G. M.; Gardner, D. E.; Briggs, M. W. Models and Modelling. In *Chemists' Guide to Effective Teaching*; Pienta, N., Cooper, M., Greenbowe, T., Eds.; Prentice-Hall: Upper Saddle River, NY, 2005; pp 67–76.

(13) Greca, I. M.; Moreira, M. A. Mental Models, Conceptual Models, and Modelling. *Int. J. Sci. Educ.* **2000**, *22* (1), 1–11.

(14) Bhattacharyya, G. Trials and Tribulations: Student Approaches and Difficulties with Proposing Mechanisms Using the Electron-Pushing Formalism. *Chem. Educ. Res. Pr.* **2014**, *15* (4), 594–609.

(15) Ferguson, R.; Bodner, G. M. Making Sense of the Arrow-Pushing Formalism among Chemistry Majors Enrolled in Organic Chemistry. *Chem. Educ. Res. Pr.* **2008**, *9* (2), 102–113.

(16) Grove, N. P.; Cooper, M. M.; Rush, K. M. Decorating with Arrows: Toward the Development of Representational Competence in Organic Chemistry. *J. Chem. Educ.* **2012**, *89* (7), 844–849.

(17) Bhattacharyya, G.; Bodner, G. M. "It Gets Me to the Product": How Students Propose Organic Mechanisms. *J. Chem. Educ.* **2005**, *82* (9), 1402.

(18) Bhattacharyya, G. From Source to Sink: Mechanistic Reasoning Using the Electron-Pushing Formalism. *J. Chem. Educ.* **2013**, *90* (10), 1282–1289.

(19) Galloway, K. R.; Stoyanovich, C.; Flynn, A. B. Students' Interpretations of Mechanistic Language in Organic Chemistry before Learning Reactions. *Chem. Educ. Res. Pr.* **2017**, *18* (2), 353–374.

(20) Johnson-Laird, P. N. Mental Models and Deduction. *Trends Cogn. Sci.* **2001**, *5* (10), 434–442.

(21) Cheng, M. M. W. Students' Visualisation of Chemical Reactions – Insights into the Particle Model and the Atomic Model. *Chem. Educ. Res. Pract.* **2018**, *19* (1), 227–239.

(22) Cooper, M. M.; Stieff, M.; DeSutter, D. Sketching the Invisible to Predict the Visible: From Drawing to Modeling in Chemistry. *Top. Cogn. Sci.* **2017**, *9* (4), 902–920.

(23) Jones, L. L.; Jordan, K. D.; Stillings, N. A. Molecular Visualization in Chemistry Education: The Role of Multidisciplinary Collaboration. *Chem. Educ. Res. Pr.* **2005**, *6* (3), 136–149.

(24) Bain, K.; Rodriguez, J.-M. G.; Moon, A.; Towns, M. H. The Characterization of Cognitive Processes Involved in Chemical Kinetics Using a Blended Processing Framework. *Chem. Educ. Res. Pr.* **2018**, *19* (2), 617–628.

(25) Akaygun, S. Is the Oxygen Atom Static or Dynamic? The Effect of Generating Animations on Students' Mental Models of Atomic Structure. *Chem. Educ. Res. Pract.* **2016**, *17*, 788–807.

(26) Akaygun, S.; Jones, L. L. Animation or Simulation: Investigating the Importance of Interactivity for Learning Solubility Equilibria. In *ACS Symposium Series*; 2013; Vol. 1142, pp 127–159.

(27) Tasker, R.; Dalton, R. Visualizing the Molecular World - Design, Evaluation, and Use of Animations. In *Visualization Theory and Practice in Science Education*; Gilbert, J. K., Reiner, M., Nakhleh, M., Eds.; Springer: Dordrecht, 2008; pp 103–131.

(28) *Transforming Our World: The 2030 Agenda for Sustainable Development*; 2015. https://sustainabledevelopment.un.org/

(29) Matlin, S. A.; Mehta, G.; Hopf, H.; Krief, A. One-World Chemistry and Systems Thinking. *Nat. Chem.* **2016**, *8* (5), 393-398.