The Canadian Journal for the Scholarship of Teaching and Learning

Volume 14 | Issue 1 Article 3

Spring 05-31-2023

Facilitated Study Groups for Undergraduate Organic Chemistry: Experience from a Large Public Canadian University

Homaira Hamidzada
University of Toronto, homaira.hamidzada@mail.utoronto.ca
Sarthak Sinha
University of Calgary, sarthak.chinoo@gmail.com
Maggie Roberts
University of Toronto, maggie.roberts@utoronto.ca
Shadi Dalili
University of Toronto, sh.dalili@utoronto.ca

https://doi.org/10.5206/cjsotlrcacea.2023.1.13734

Facilitated Study Groups for Undergraduate Organic Chemistry: Experience from a Large Public Canadian University

Abstract

Undergraduate organic chemistry courses have a reputation for being difficult among students in biological and physical sciences programs. Due to the extensive problem-solving, visualization, and depiction of chemical structures/reactions required, students may perceive learning such content as similar to learning a new language. Several interventions such as course-integrated tutorials or discussion sessions have aimed to assist students. Another effective approach that chemistry educators might consider is Supplemental Instruction (SI), a well-established program that emphasizes student-driven learning whereby student SI leaders facilitate discussions to help students arrive at solutions while also developing effective communication and study skills. A type of SI, Facilitated Study Groups (FSG), established by the Centre for Teaching and Learning at the University of Toronto Scarborough (UTSC) in 2009, were introduced regularly into organic chemistry courses in 2012. This program provides semester-long optional small-group peer learning sessions, each of which corresponds to a course lecture. The aim of this paper is to provide comprehensive coverage detailing the structure of the organic chemistry FSG program, peer facilitation strategies employed, quantitative/qualitative synthesis of student outcomes indicating program uptake. We consistently find significantly higher grades and significantly lower attrition rates for students who regularly attend FSG sessions in comparison to those who do not (n=16 semesters). Given the growing diversity of undergraduate classes in terms of approaches to learning, language, and cultural barriers (international students, English second-language learners, learning and psychosocial disabilities), our FSG sessions seek to foster inclusion amongst our heterogeneous pool of attendees. Here, we describe strategies that tailored FSG sessions to a diverse group of undergraduate students as suggested by a sizable percentage of the class availing themselves of this resource and by a narrative synthesis of end-of-term surveys. Together, we demonstrate successful adoption of an SI-based model for organic chemistry and present a practical framework that includes pedagogically informed session strategies and cost estimates to guide design of similar programs for post-secondary students at other institutions.

Les cours de chimie organique au niveau du premier cycle ont la réputation d'être difficiles parmi les étudiants et les étudiantes inscrits dans des programmes de biologie et de sciences physiques. À cause des exigences en matière de résolution approfondie de problèmes, de visualisation et de représentation de structures et de réactions chimiques, les étudiants et les étudiantes peuvent percevoir l'apprentissage d'un tel contenu comme étant semblable à l'apprentissage d'une nouvelle langue. Plusieurs interventions telles que des tutoriels intégrés ou des séances de discussion visent à aider les étudiants. Une autre approche efficace que les enseignants et les enseignantes de chimie peuvent envisager est l'Instruction supplémentaire (IS), un programme bien établi qui souligne l'apprentissage guidé par l'étudiant, où des leaders étudiants en IS facilitent les discussions afin d'aider les étudiants et les étudiantes à en arriver à des solutions tout en développant des compétences efficaces en communication et en apprentissage. Un type de IS, les groupes d'études facilités (Facilitated Study Groups - FSG), ont été établis par le Centre d'enseignement et d'apprentissage à l'Université de Toronto Scarborough (UTSC) en 2009 et introduits régulièrement dans les cours de chimie organique en 2012. Ce programme offre des séances facultatives d'apprentissage par les pairs en petits groupes, d'une durée d'un semestre, dont chaque séance correspond à un cours magistral. L'objectif de cet article est de fournir une explication complète détaillant la structure du programme FSG en chimie organique, des stratégies de facilitation par les pairs employées, des synthèses quantitatives et qualitatives des résultats des étudiants et des étudiantes indiquant l'adhésion au programme. Nous trouvons toujours que les notes obtenues sont considérablement plus élevées et les taux d'attrition considérablement plus bas parmi les étudiants et les étudiantes qui ont participé régulièrement aux séances de FSG, par rapport à ceux et celles qui n'y ont pas participé (n=16 semestres). Étant donné la diversité grandissante dans les cours de premier cycle en termes d'approches à l'apprentissage, de langue et de barrières culturelles (étudiants internationaux et étudiantes internationales, apprenants et apprenantes d'anglais langue seconde, handicaps d'apprentissage et psychologiques), nos séances de FSG visent à favoriser l'inclusion parmi les bassins hétérogènes de participants et de participantes. Ici, nous décrivons les stratégies qui adaptent les séances de FSG à des groupes divers d'étudiants et d'étudiantes de premier cycle, tel que le suggèrent le fort pourcentage d'étudiants et d'étudiantes qui ont choisi de profiter de cette ressource ainsi que la synthèse narrative des questionnaires remplis après le cours. Ensemble, nous démontrons l'adoption réussie d'un modèle de IS pour la chimie organique et présentons un cadre pratique qui comprend des stratégies de séance à caractère pédagogique et des estimations de coût pour guider la conception de programmes similaires à l'intention d'étudiants et d'étudiantes en enseignement supérieur dans d'autres établissements.

Keywords
second-year undergraduate, organic chemistry, collaborative/cooperative learning, student-centered learning, supplemental instruction; étudiants et étudiantes de deuxième année de premier cycle, chimie organique, apprentissage collaboratif/coopératif, apprentissage centré sur l'étudiant, instruction supplémentaire

Cover Page Footnote
We thank the Centre for Teaching and Learning (CTL) at the University of Toronto Scarborough for implementing and maintaining the FSG program, training facilitators and organizing consistent feedback and evaluation measures. In particular, we thank Dr. Allyson Skene, Dr. Clare Hasenkampf, and Janice Paterson who initiated the pilot program and spearheaded the start of the FSG program. We express sincere gratitude to Dr. Cindy Bongard, who recruited, trained, and mentored the primary authors of this manuscript. Finally, we thank faculty who support FSGs in their courses and students who have taken the initiative to attend.

Introductory courses in the physical sciences are a mandatory component of many undergraduate programs in the physical, environmental, and biological sciences. Most courses in the biological science programs teach foundational concepts that can be learned through the mastery of content. For these students, introductory courses such as general chemistry, organic chemistry and physics can prove especially challenging as they place a greater emphasis on the process of problem solving (Wright, 2017). Although both content- and process-based courses necessitate the understanding and application of core concepts and theories, assessments in process-based courses rely on stepwise problem-solving, mathematical manipulations/calculations, as well as the depiction of molecules, chemical structures, and reactions. For many students, grasping this type of material is akin to learning a new “language” (Childs et al., 2015; Galloway et al., 2017), and after learning the content, students must spend a substantial amount of time practicing it regularly and consistently. As a result, various strategies have been implemented to facilitate the learning process for students in these process-based courses. Whereas conventional course tutorials and discussion sessions aim to reinforce content and provide the practice needed, more effective programs make use of collaborative and engaging sessions, while concomitantly developing a stronger knowledge base in the subject area (Arendale, 2004).

Substantial research over the past few decades suggests that small group settings using interactive learning activities may be superior to traditional settings, as they are correlated with improved academic achievements (Ferreri & O’Connor, 2013; Freeman et al., 2014; Gaudet et al., 2010; Hake, 1998; Springer et al., 1999). In further support of the benefits of small group dynamics, a meta-analysis of 225 studies found that although active learning strategies increase performance in STEM courses of all sizes, an even stronger benefit is found in smaller-sized classes (Freeman et al., 2014). More importantly, these small collaborative sessions are also correlated with the development of more positive attitudes towards (a) learning (Springer et al., 1999), (b) teamwork (Ferreri & O’Connor, 2013; Gaudet et al., 2010), (c) leadership (Gosser et al., 1996), (d) enhanced self-esteem (Bertucci et al., 2010), and (e) the understanding and application of theories (McDuff, 2012). Working in collaborative small groups has also been shown to be effective in online courses, where students interacting with peers for various course assessments achieved higher grades and were more satisfied than those who worked in isolation (Murat Kurucay & Fethi, 2017). An examination of test data from 62 introductory physics courses revealed that implementing activities that rely heavily on peer-to-peer engagement in undergraduate physics courses led to improved problem-solving performance, demonstrating the benefits of such strategies in process-based courses (Hake, 1998). Indeed, collaborative group sessions can catalyze the development of skills and learning strategies that will be useful for students beyond their academic performance for many years to come.

There are numerous programs that foster collaborative learning at the post-secondary level (Arendale, 2004). Supplemental instruction (SI) is a key example of a supplementary course component well-documented in the literature to correlate with increased student performance and retention rates (Arendale, 2004). SI was first developed in 1973 by Dr. Deanna Martin at the University of Missouri Kansas City (UMKC) (Arendale, 1994, 2002). The SI program, which is also referred to as Peer Assisted Study Sessions (PASS) at many institutions, targets historically difficult courses with low averages and high attrition rates (Arendale, 1994, 2002). SI sessions are voluntary for students to attend and take place regularly throughout the semester (Arendale, 1994, 2002). Importantly, small-group collaborative SI sessions are led by former successful students of the course and are open for all students to attend, regardless of where they stand academically

(Arendale, 1994, 2002). The peer-led nature of SI programs is an important differentiator from the Process-Oriented Guided Inquiry Learning (POGIL) model which proposes active instructor involvement for facilitating the development of similar process skills (Farrell et al., 1999; Hu & Shepherd, 2013).

Since the inception of the program, much research has been devoted to assessing the effectiveness of SI through the evaluation of students' academic performance. It has been well-established that participation in SI sessions is correlated with improved student grades and lower withdrawal rates (Blanc et al., 1983; Congos & Schoeps, 1998; Dawson et al., 2014; Skoglund et al., 2018). Studies have reported a benefit of SI across diverse disciplines, including calculus (Khan, 2018), engineering (Wilmot et al., 2016), computer science (Schuster, 2018), accounting (Etter et al., 2000), business (Ning & Downing, 2010), biology (Moore & LeDee, 2006; Rath et al., 2007) and chemistry (Congos & Schoeps, 1998; Lundeberg, 1990; Toby et al., 2016; Webster & Hooper, 1998). SI has also been correlated with enhanced learning competence (Ning & Downing, 2010), learning skills, and subsequent knowledge application (Congos & Schoeps, 1998), and leads to study group formation outside of SI sessions (Maxwell, 1998).

Although the positive impact of SI has been well-documented, and the small group sessions are ideal for trying a variety of approaches, little has been reported regarding specific models and activities that may confer benefit for a heterogeneous group of SI attendees. Indeed, there is a growing diversity in undergraduate classes, including international students, English as a second-language learners, and those with disabilities. These language and cultural barriers may be exacerbated in traditionally difficult courses such as organic chemistry. Thus, it is imperative to adapt to these varying needs within SI sessions by implementing strategies that take into consideration the groups' diversity and specific learning requirements. The SI program happened to meet the needs of the students and courses at our institution at the time of implementation, such as high attrition rates and low grades, as well as leveraging former students rather than course instructors to mentor students outside of instruction hours. In this article, we report methods implemented at the University of Toronto Scarborough's (UTSC) SI program, called Facilitated Study Groups (FSG for our high enrollment introductory organic chemistry course (course code: CHMB41). We describe the structure of the FSG program for organic chemistry, discuss specific strategies implemented in FSG sessions, outcomes spanning several years of FSG sessions that

demonstrate successful adoption of an SI-based model for organic chemistry, and provide narrative evidence of improved student confidence through a sense of community at a large public university.

Methodology

Here, we provide a retrospective report of the FSG program for organic chemistry at UTSC. We assess student outcomes both quantitatively, as measured by grades and course attrition for FSG participants and non-participants, and qualitatively through student feedback. In addition, we outline several key strategies employed in FSG sessions, including two session methods encompassing a variety of approaches to engage participants in organic chemistry. Since this report is based on secondary use of existing de-identified records for program evaluation purposes, this study does not fall within the scope of REB review as outlined in the Tri-Council Policy Statement.

Facilitated Study Groups

Various factors have indicated a need for supplemental learning support at UTSC, including tremendous population growth and increasing numbers of online courses reducing teacher-student contact. UTSC also has considerable language and cultural diversity that contribute a dynamic character to the campus, such as an expanding number of international students and students registered in our AccessAbility Services (see Appendix A). The effects of large class sizes and online learning are intensified for students who face language, social, and cultural barriers, but these issues can be mitigated through the introduction of small-group, collaborative learning SI sessions, especially in high-risk courses. The FSG program was implemented at UTSC in 2008 as a pilot project supporting three courses. Over the years, the program has grown substantially and currently supports 18-25 courses each semester in the sciences and social sciences, including biology, chemistry, physics, calculus, statistics, linguistics, and psychology.

Beginning in 2012, FSGs were offered regularly for Organic Chemistry I, a second-year undergraduate course introducing students to the fundamental concepts in chemical bonding, acidity of organic compounds, stereochemistry, and reaction mechanisms (such as additions, substitutions, and eliminations). Each year, the fall semester (September to December) and winter semester (January to April) courses are comprised of 400-450 and 90-110 students, respectively. All students are enrolled in the same lecture for the course, and the teaching team consists of one course instructor and lab coordinator, 10-12 laboratory teaching assistants and 4-5 tutorial teaching assistants. The students are supported by optional small-group collaborative FSG sessions that correspond to each hour of lecture throughout the semester. It should be noted that the teaching teams for the course (lectures, laboratories, and tutorials) are separate from the FSG program and facilitators. FSG session timings were optimized each semester based on results from a class-wide survey where students indicated preferences from a curated list of times when a room and the designated facilitator were both available. Of note, conflicts with concurrent, high-enrollment courses (e.g., second-year biology courses) were purposefully avoided during scheduling. FSG sessions are typically offered three times a week and students can attend as many sessions as they wish. The leaders of these sessions, known as FSG facilitators, are undergraduate students selected based on a similar set of qualifications as those outlined in Supplemental Instruction Supervisor Manual (University of Missouri – Kansas City, 2004). Briefly, the manual specifies the following as minimum qualifications: (a) sophomore (second year) or higher standing, (b) cumulative GPA 3.0 or higher, (c) content-competency (evaluated by the course instructor), and (d) interpersonal skills to effectively lead discussions (evaluated by the SI Program Director). Indeed, selection of new facilitators into our FSG program closely mirrors these recommendations as facilitators are those who previously excelled in the course (completing with letter grade A or higher) and are frequently recommended to the program by course instructors. If no such recommendations are forwarded, facilitators are shortlisted from a pool of interested applicants based on course grade and relevant interpersonal qualities. Facilitators are responsible for (a) attending lectures alongside students to pinpoint the most imperative content to cover; (b) planning FSG sessions and associated materials to engage students, such as worksheets and other educational activities; and (c) leading sessions at scheduled times throughout the week. At the time when the two primary authors worked in the program, facilitators were trained as follows: Prior to the start of each academic semester new and returning facilitators attended two, four-hour training sessions in which they were introduced to SI pedagogy, analyzed worksheets employed by previous facilitators, and engaged in mock sessions in which different scenarios were role-played. Each facilitator was formally evaluated over the semester by the program coordinator, fellow peer facilitators, and end-of-term student surveys made available through online learning portals like Blackboard. Feedback from such evaluations was discussed through intermittent group training sessions and during one-on-one meetings with the program coordinator.

All organic chemistry FSG sessions are led by one facilitator within any given semester to maintain consistency in content covered and the session structure. FSG sessions typically cover course content taught in lectures in the previous week. However, participants can also suggest areas of focus as facilitators have the flexibility to adjust content based on students' needs and are not bound by a rigid agenda or list of content to cover. As such, FSG sessions not only engage students in small group collaborative learning, but also provide opportunities for students to direct their own learning.

Over the course of eight years (2012-2019) in our organic chemistry FSG sessions, students attended an average of over seven sessions throughout the semester, representing almost one quarter of the total number of sessions offered, suggesting that those who do attend, do so fairly frequently (Table 1). Remarkably, on average, almost 40 percent of the class attended FSG sessions at least once during the semester, and each session had over 16 students present. Altogether, this data suggests that the group composition is in dynamic flux throughout the semester; thus, utilizing methods that respond to this diversity and support a broad range of learning preferences is crucial.

Table 1

Attendance in Organic Chemistry FSG Sessions

Average # Sessions Students Attend	Average % of Total Sessions Students Attended Throughout Semester	Average Attendance per Session	% of Class Who Attended Sessions
7.47 ± 3.61	23.45 ± 11.88	16.1 ± 7.11	38.37 ± 16.16

Considering these various factors of session size and composition, and miscellany, we designed the organic chemistry FSG sessions in a way that ensures adaptability to each cohort of participants and their learning preferences. In the proceeding sections we discuss different aspects of planning and executing SI sessions for organic chemistry to provide a practical framework that can be repurposed for supporting student success across a diverse range of post-secondary contexts.

Key Strategies for Effective Organic Chemistry Si Sessions

In order to accommodate the varying learning needs of FSG participants, we relied on some general guiding principles. Each of these principles aims to provide a strategy for collaborative discussion and learning in organic chemistry, while concomitantly meeting individual student needs or learning preferences. We argue that these foundational principles contribute to accessible learning and student success in large undergraduate chemistry courses, and by extension all FSGs, SI and classrooms in general. In this section, we outline strategies that were used at the time that the primary authors worked in the program, recognizing that there may be leeway for differences.

Variation

Organic chemistry courses largely emphasize process-based problems, requiring students to solve questions in a stepwise and systematic manner, despite misconceptions that much of the material can be memorized. However, to master these types of questions most effectively, it is necessary to have a strong foundational background in the underlying theory. This renders it necessary to incorporate many different types of questions within SI sessions to first provide students with a deeper understanding of the concepts, followed by the application of these concepts to problems. The variety of types of questions helps students to approach theoretical concepts in a myriad of ways and appeals to diverse learning preferences. Therefore, variation represents a way to *strategically* expose students to conceptual questions that are fundamental to solving problems, which is the major component of organic chemistry. We highlight variation here in three levels, with particular examples that relate to organic chemistry:

Variation in Worksheet Question Types. We implemented the “variation” aspect of our approach within our FSG sessions through the design of structured worksheets that help guide the session discussions. Within the worksheets, the first component emphasized the theory through the form of multiple-choice questions, short recall questions, and fillable summary sheets (see Appendix B). Table 2 depicts several examples of theory-based questions which may be executed in a variety of ways according to student preferences. Summary sheets were beneficial in the context of reaction mechanisms in order to help students organize similar reactions and more clearly distinguish between the products, such as substitution and elimination reactions.

Variation in Executing Discussions. We also implemented the “variation” aspect of our approach for the discussion portion of the FSG sessions by providing students opportunity to brainstorm on chart paper, present to others in the group on a chalkboard, or primarily engage through verbal discussions.

Variation in Question Difficulty. Variation in the difficulty level of questions served to develop a stronger foundation in the content and allow students to gain additional practice before proceeding to more challenging questions. Given that the challenging questions may be intimidating for students, starting with more conceptual, recall, or shorter problem-solving questions that build the foundation for complex questions can motivate students and build confidence during the learning process.

In the next section, we discuss two session strategies that combine these question types and discussion execution methods. With all of these varying factors, facilitators can adapt their sessions to their students, while students have the opportunity to reinforce concepts and practice questions using methods they feel most comfortable with, demonstrating that these principles support a diverse student population.

Pausing

Solving organic chemistry problems not only requires background knowledge in several content areas, such as recognizing reaction types, reagents, substrates, and overall reaction products, but also the ability to apply this knowledge to new examples. Additionally, students must be able to rationalize the stability and progress of reactions, while taking into consideration pertinent rules and exceptions. These complexities may be amplified for students by many factors, including level of comfort within a group setting, the fact that they are learning the content and the required thinking pattern for the first time, as well as language barriers. As such, patience and pausing are crucial to provide students sufficient time to arrive at their own solutions. We implemented this aspect of our approach within our organic chemistry FSG sessions by varying response times, which we define as the time between the facilitator posing a question and a student response, which is highly dependent on the type of question posed. Upon presenting a question to either a smaller group (3-5 students) or the entire FSG session group (20-25 students), it is critical to pause and wait for students to have the opportunity to integrate their course knowledge and devise a solution, either individually or in pairs or small groups. Importantly, this pause provided students a chance to interact and try solutions out on each other. For shorter questions, less time was allocated, such as short statement responses regarding the underlying theory. For longer questions focusing on students' ideas as to how to approach a problem-solving question, more time was warranted (Table 2 and Appendix B). Through this implementation of pauses, our sessions addressed the needs of students at all levels. Indeed, the pause method has been shown to encourage participation across diverse student populations (Braun & Simpson, 2004; Chen et al., 2020). Nonetheless, the time ranges presented herein fluctuate according to the particular group of students, their level of comfort with the content and the session environment. Thus, session timings are highly flexible to suit the cohort of students and facilitators are trained to be flexible and accommodating in this student-centered approach. Facilitators are trained on how timings should be adjusted at the facilitator's discretion to accommodate both student understanding as well as efficient progress, and through consistent feedback obtained from attendees as discussed below.

Motivation and Encouragement

Students benefit most when they actively participate in SI session discussions. However, collaborative learning can be challenging for some students: when practicing unfamiliar content, students may not participate to avoid losing face in front of their peers by offering incorrect answers. In our organic chemistry FSG sessions, we implemented different approaches to motivate and encourage discussion, taking risks, and asking questions, and to promote a sense of community (Table 2).

Facilitators practiced actions that might serve to boost students' self-confidence and encourage them to communicate their thoughts and responses. For example, facilitators aimed to enhance student resourcefulness by means of developing student-student relationships. This involved: (a) having students work together to find appropriate lecture slides necessary to understand a concept or problem, and (b) having students identify collaboratively what they know and the steps towards solving a problem. Facilitators also provided students with a series of short statement response questions (as described in variation above) intended to lead them in the desired direction in a progressive fashion. Importantly, we also recognize the need for developing student-facilitator relationships to foster a supportive classroom setting. We implemented this through discussing the organic chemistry course itself to encourage a positive perspective, as students are often intimidated by the content, and by explicitly thanking students for voluntarily attending the sessions and taking initiative in their own learning. These student-facilitator relationships help to build trust, thus encouraging students to feel comfortable participating in session discussions.

To encourage students to share their methods of approaching problem-solving within a group setting, such as how to draw reaction mechanisms or synthesis questions, students first worked through the questions and shared their responses within a smaller group as a way to encourage them to learn from one another, ask each other questions, and complement each other's strengths and weaknesses. Following these smaller group activities, the discussion was brought back to the entire session where students were encouraged to present their steps either individually or as a smaller group to the full session. Students may feel more confident with their responses after having discussed them within their smaller groups, especially if the facilitator acknowledges their efforts and expresses gratitude that they shared their ideas with their peers. While we did not gauge student confidence in our program, thematic analyses of student feedback have highlighted that enhanced self-esteem and confidence are key reinforcers of student attendance and engagement in SI sessions (Armstrong et al., 2011; Bengesai, 2011; McGuire, 2006). Altogether, these methods provide a positive, supportive learning experience for students by encouraging discussion, participation, and motivating all students to participate again in the future, creating a cyclical pattern of participation and motivation.

Collaboration and Open Discussion

In an attempt to engage all SI session attendees and to foster inclusion, it remains critical to facilitate open group discussion and to refrain from sustained one-on-one, facilitator-student conversations. In our FSG sessions, we applied this notion of openness through re-directing individual discussions and questions to the entire group. In the context of organic chemistry, worksheet questions were broken down into a series of parts to allow several students to contribute to the development of the solution. In a reaction mechanism or synthesis question, students were first asked to predict the type of reaction based on the substrates and reagents involved. Then, we proceeded with the question stepwise allowing a different student to attempt answering at each stage. Finally, upon arriving at the final solution, students were asked to reflect on the approach taken, recognizing the pertinent components of the reaction, as well as any associated rules and exceptions. Several forms of organic chemistry questions can utilize such approaches, such as drawing cyclohexane chair conformations (Table 2).

Importantly, between each step of this approach, as students contributed their thoughts, the facilitator re-directed the discussion to the entire group by asking several guiding questions to seek consensus or different approaches. For instance, students may have distinct methods for visualizing molecules and assigning R and S configurations or converting skeletal structures to Newman projections. SI sessions are an ideal platform to share these varying perspectives with classmates if the facilitator employs such discussion-building gambits as, “That was a great response; does everyone agree with this?”, or “Thank you for contributing; does anyone have a different way of approaching this question?” Ultimately, this sets the stage for communication between students and fosters a community of active learning.

Feedback

The final component of our SI session approach serves to assess the effectiveness of all preceding components. Aside from verbally seeking feedback within a session by asking students how they feel about the content being covered and modes of delivery in real time, more formalized approaches should be taken as well. Anonymously acquiring feedback consistently throughout the semester is important to ensure the methods implemented suit the preferences of the attendees so that actions can be taken within the term to adjust as needed. Across many semesters, groups of students are quite diverse in their preferences and background, and this variation also exists across a single semester as the particular student composition within sessions changes. As such, attaining feedback at the start of the semester, mid-semester, and at the end of the term is critical to consistently adapting to student needs.

Soliciting feedback on what students find particularly challenging in that week’s lecture from the course instructor and attendees assists the facilitator to tailor content to meet context-specific student needs. This approach is consistent with the broader SI framework described by Hurley et al. (2006). This approach fosters an environment where students can freely articulate which concepts require additional support and how the content can be delivered to maximize knowledge retention. It also allows the facilitator to employ techniques like asking questions of varying conceptual difficulty focused specifically on topics that students deem to be most beneficial to their learning. In our organic chemistry FSG sessions, we administered short, informal surveys very early in the semester (in the first week of FSG sessions). The aim of this feedback was to ensure the approaches taken within the first few sessions helped students learn the content based on the preferences of the current cohort. Firstly, we asked students for their preferred session format, indicating that organic chemistry sessions can be executed as a series of activities (see proceeding section), educational games (e.g., online team-based quizzes to test organic chemistry conceptual knowledge), and small-group learning for problem-solving and reaction mechanism questions. In addition to also asking for the type of questions on worksheets (multiple-choice, conceptual, problem-solving and applications), we asked students to indicate particular topics in organic chemistry they would prefer to review in FSG sessions. It is important to incorporate time within the first few sessions to focus on areas that are foundational to organic chemistry that students have stated they need practice with. For example, although nomenclature and drawing molecular structures may be prerequisite knowledge for an organic chemistry course, it would be helpful to spend a short period of time on questions that require such background knowledge if students have specified that it would indeed be helpful to do so. By mid-semester, we administered a survey similar to the first one, with additional questions asking students for feedback on the methods that worked well within FSGs and how they could be improved.

Furthermore, the mid-semester survey was important for gathering some general thoughts on the organic chemistry course in order to better understand how FSGs can help alleviate any potential challenges by focusing on specific areas or types of questions (e.g., drawing Fischer projections, or distinguishing between a group of reaction mechanisms). Lastly, we administered online end-of-term surveys after the last FSG session (see Appendix D). These end-of-term surveys were consistent across all courses in which FSG sessions were offered. The feedback was important in informing facilitators how FSGs may have benefitted students, what could be done differently to help students succeed in subsequent terms, as well as logistical information such as thoughts on the length and timing of the sessions. A key aspect of attaining feedback is for facilitators to later reflect on what changes they will implement in future terms. In summary, attaining feedback throughout the semester ensures that the methods implemented, and the SI approaches utilized are conducive to the learning of each particular group of organic chemistry students (Table 2).

Table 2

Summary of the Key Considerations for Effective Organic Chemistry SI Sessions

Variation in Conceptual Questions **Question Types**	**Sample Question**
Multiple-choice	Which of the following compounds has a net dipole moment? (a) CBr_4 (b) CH_4 (c) CH_3Br (d) $AlCl_3$
Short answer	Discuss whether it is possible to draw NO_3^- with the central N having a formal charge of 0?
Summary sheets	See Appendix C
Response Times During Session Discussions **Question Posed by Facilitator**	**Response Times**
Short statement responses E.g.,1: Stating what type of reaction will occur with the given substrates and reagents E.g., 2: Classifying Newman projections as either staggered or eclipsed	20-30 seconds. If no response: 1) Direct students to appropriate resources 2) Provide a hint 3) Group students together for discussion 3) Ask a simpler question or breakdown the question previously posed
Problem-solving responses E.g.: How to approach a mechanism or synthesis question	2 minutes for thought & discussion. If no response: 1) Break down the question into several *short statement responses* 2) Provide more time
Promoting Participation in Discussions **Form of Motivation or Encouragement**	**Examples**
Individual basis	1) Variation in level of difficulty of worksheet questions 2) Facilitator-student relationships
Group setting	1) Small-group activities enhancing collaborations and community-building 2) Gratitude and encouragement following discussion of responses

Fostering Open Group Discussions **Example Questions**	**Method of Approach**
Mechanism or synthesis question	1) Recognize substrate, reagents, and type of reaction 2) Predict the type of product to be formed 3) Proceed with question stepwise 4) Reflect on final solution
Drawing cyclohexane chair conformations	1) Determine position and orientation of each substituent 2) Consider strain present in each conformation 3) Assess stability 4) Reflect on final solution
Assessing and Improving Session Effectiveness **Time of Feedback Collection**	**Feedback Question Topics**
Pre-semester	1) Format of sessions (activity-based, educational games, small-group learning) 2) Format of questions (multiple-choice, conceptual, problem-solving, applications) 3) Areas in organic chemistry need most help with (drawing molecular structures, nomenclature, etc.) 4) Other comments and requests
Mid-semester	In addition to the pre-semester questions: 1) Methods used in FSGs that have worked well 2) Suggestions for the remainder of the term 3) Thoughts on the organic chemistry course and how FSGs can help with particular topics
Post-semester	See end-of-term survey in Appendix D

Organic Chemistry Session Activities

Up to this point, we have discussed our SI approaches as they apply to organic chemistry sessions, highlighting the key factors to implement within a session plan. In this section, we briefly summarize two examples of activities that we have executed within organic chemistry FSGs and the execution of the SI session strategies outlined in the previous section.

Double Methods

Within organic chemistry, it is pertinent to consider that there may be several approaches to solve any given problem, and these varying methods may suit different students. The Double Methods strategy can be applied to both conceptual and problem-based questions. Students are divided into smaller groups to brainstorm their approach to the question. The group size varies according to the number of attendees present, although we have found that three to four students per group is the optimal balance of individual engagement and comfort. Double Methods is a strategy that can be used at the start of a session for theory-based questions, followed by the application of that theory to various problems. For example, in the context of reaction mechanisms, it would be essential to begin with multiple-choice or short-statement response questions assessing knowledge of the basic input and output of the reaction, reagents involved, functional groups lost or formed, and associated stability and reactivity. This would then be followed by practice with several reaction mechanisms or synthesis questions. In either case, Double Methods would involve student discussion within their smaller groups, and subsequently each group would separately present their thought process and solution to the larger group (Figure 1). Of note, students are given a range of 5-15 minutes to discuss within the smaller groups depending on the complexity and length of the question. During this time, the facilitator circulates the room to check in and guide students through re-directing questions. Given that any question can be solved using a variety of approaches, there is a high likelihood that different groups will use different methods, hence the term Double Methods. This strategy promotes the opportunity for collaboration in a group by providing students the chance to communicate their ideas and hear differing perspectives. It also increases students' self-confidence as they realize there is not always one right answer and there are a multitude of ways to solve problems. For example, synthesis questions may be solved using different reagents and reactions while arriving at the same product(s), underscoring the importance of open conversations both within the smaller groups and with the larger session. Indeed, Double Methods promotes discussion between the two presenting groups, as well as with all students present, which is more beneficial than small group work alone without the opportunity for several groups to collaboratively present their methodology and solutions.

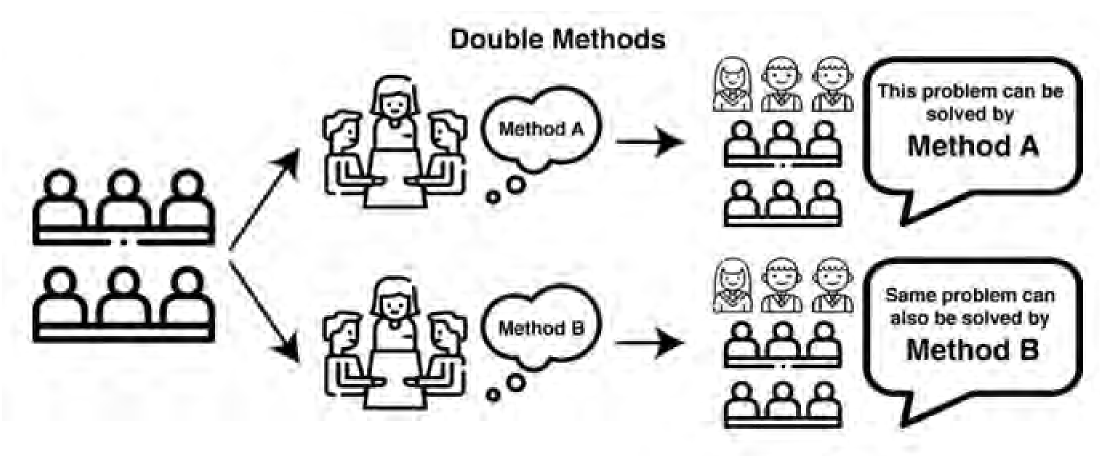
Partner Discussion and Exchange

Whereas Double Methods is most effective for problem-solving and application-based questions, Partner Discussion and Exchange is suitable for conceptual and discussion-heavy content. This strategy comprises three primary stages: students first work through a question individually, then engage in a discussion in pairs, and lastly, exchange partners for the next question (Figure 2). The critical aspect of the second stage is students clearly explaining their solution to their partner. This is important in the learning process as explaining and teaching concepts such as molecular visualizations to a peer help in personal understanding, since individuals are forced to describe concepts in their own words and based on their own perceptions.

Many times, these exchanges lead to clarifying the misconceptions and misunderstandings students may have about certain concepts or processes for example, when drawing Fischer projections, Newman projections, or particular stereoisomers requiring 3D visualization of the molecule. In such questions, students may take incorrect steps that they only recognize when demonstrating them and discussing them with their peers. In addition to the drawing of structures, we have found it helpful for students to engage in a question-answer period with their partners, discussing the associated steps taken to draw the structure, and the stability and reactivity of the different conformations. These follow up discussions many times lead to the "aha!" moments among students learning proper techniques from each other. Moreover, this verbal discussion of the content, whether it is the student's own solution or their partner's, helps to reinforce the material and identify gaps in their knowledge of the underlying theory. In the third stage, students exchange partners, providing the opportunity to further widen their perspectives through discussion with different individuals with their own unique approaches, while concomitantly building smaller communities within a large classroom setting. These 'two-by-two' interactions serve to enhance communication between students with an aim of providing a supportive environment where students feel comfortable sharing their ideas.

Figure 1

Conceptual Summary of Double Methods Session Strategies[1]



[1] Icons used in this figure are from www.flaticon.com and are made by Freepik [https://www.flaticon.com/authors/freepik], srip [https://www.flaticon.com/authors/srip], and itim2101 [https://www.flaticon.com/authors/itim2101].

Figure 2

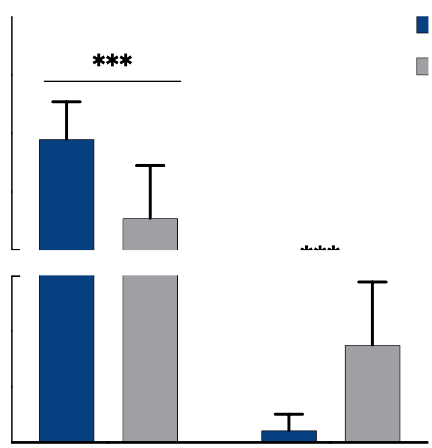
Conceptual Summary of Partner Discussion and Exchange Session Strategies[1]

Student Outcomes: Lessons and Skills Learned

We retrospectively assessed academic performance of FSG attendees over the course of eight years. Our analysis of student grades in Organic Chemistry I between the fall semesters of 2012 through 2019 demonstrates a significantly higher final mean grade (p<0.001) for FSG participants than non-participants (Figure 3). Importantly, the difference in average grade represented two GPA levels at our institution, which follows a 4.0 GPA scale (2.0 GPA versus 2.7 GPA). Across these eight years, we also report significantly lower attrition rates for FSG participants than non-participants (p<0.001).

Figure 3

Average Grades and Attrition Rates for Students who Attended FSG Sessions in Comparison to Those Who Did Not Attend



Note. The average across 8 years (16 semesters) is shown. Error bars: SD. *** P-value < 0.001 unpaired student's t-test.

The FSG session approaches and strategies described here provide a framework for the mastery of organic chemistry material in small group learning settings. Notably, our approach was developed with the goal of cultivating an environment that fosters inclusion, community, and confidence. Both Double Methods and Partner Discussion and Exchange involve small group learning whereby the group composition dynamically changes throughout the session. This ensures that students are not working in isolation and provides the opportunity to build networks with classmates. In our Partner Discussion and Exchange method, students are paired with one other student rather than a group of 3-4 students, which may accommodate group size preferences and levels of comfort with classmates, with an aim to help students gain familiarity with classmates and ultimately feel comfortable seeking help when needed. Importantly, our approach fosters *inclusion* of students at all levels through varying the level of difficulty of practice questions, pausing during discussions to enable sufficient time to process questions, motivating students with encouragement and collecting feedback to ensure the effectiveness of reaching students with diverse learning needs.

Organic chemistry courses may enroll hundreds of students, and necessarily feature lectures as the primary mode of instruction to permit efficiencies of scale. FSG sessions, on the other hand, typically consist of fewer than 20 students, to build a community of active learning in our sessions. Students are able to consistently practice teamwork: whether it is in pairs, small groups, or with the entire group, students work collaboratively to form a solution and then communicate their mutual or conflicting findings to peers. The positive community built encourages students to share opinions that may oppose those of their peers, stimulating more thought-provoking discussions that further deepen the understanding of course content, while also cultivating the idea that communicating knowledge and passing it forward is a key component of the learning process. This dynamic learning environment often leads to students taking initiative in their own learning through many avenues, including the formation of study groups outside of FSGs, building study schedules in parallel with peers, and discussing concepts directly following lectures rather than procrastinating. Thus, our sessions provide an opportunity for students with shared learning goals to connect and build bonds beyond the course and sessions themselves.

FSG leaders play an integral role in student outcomes in organic chemistry, a subject that has a reputation as being difficult among undergraduate students. This is done not only through building small group communities that emphasize the inclusion of diverse student groups, but also by boosting students' personal confidence in their abilities and knowledge. Facilitators seamlessly integrate study skills and strategies within discussions and create a positive working environment that offers motivation to attempt questions, encouragement to share responses regardless of level of certainty, and positive feedback following the sharing of solutions. These facilitate the development of a safe and open environment where students feel comfortable engaging in academic discourse. Indeed, our end-of-term survey results across several semesters corroborate that we have met our goal of helping students develop confidence in their organic chemistry knowledge and self-esteem within the course. Students stated the following:

- FSGs are the reason I can happily say that I am surviving the horrors of Organic Chemistry
- Going to FSGs gives me the confidence to perform well on my exams.
- FSGs made the learning experience very fun and unintimidating.
- FSGs helped me to understand the chemistry concepts clearer through discussions with the group and examples/problems discussed was very applicable to test material. Found FSGs very beneficial.
- I find the material challenging but FSGs have helped a great deal in my understanding of the course load.
- […] a super supportive environment without the fear of judgement.

- […] interactive while maintaining a pace in which learning was achievable into the extremes.

Cost Estimate for Implementing Organic Chemistry Sessions

The cost of implementing SI sessions was approximated to be $14 USD per student per semester in 1993 (Shaya et al., 1993). This is approximately $30 CAD per student per semester after adjusting for inflation in 2020. While different renumeration models have arrived at different cost estimates for implementing SI programs, a common theme across each is that the income retained due to the lowered attrition rates far exceeds investment made in such programming (Burmeister, 1996; Congos & Schoeps, 1998). Over the period reported, our FSG facilitators worked part-time and were compensated at a fixed base rate that varied between $14-18 CAD/hour depending on the facilitator's years of experience. For each week of class, the facilitator was paid to attend lectures (3 hours), run sessions (3 hours), and for preparation time (1 hour). In addition to weekly remuneration, the facilitators were also compensated for attending training sessions (8 hours per semester) and for providing peer feedback by attending each other's sessions (1 session/semester) at the same base rate. Given that a semester typically spanned 11 academic weeks, the estimated cost for supporting one semester of organic chemistry ranged between $1,200 CAD to $1,600 CAD. As our average attendance per session was 16.1 ± 7.11, this yielded a cost estimate between $2.20 to $3.00 CAD per student per semester. The cost for supporting FSGs was roughly equal for fall and winter semesters even though there was a dramatic difference in the number of students registered in the course and the number of attendees that availed themselves of sessions. For faculties operating under budgetary constraints (or considering a pilot program to gauge student response), it may be worthwhile to initiate such programming during periods of high student participation to maximize cost-benefit ratios. In our experience, participation peaks during the fall semester (relative to winter and summer semesters) even after adjusting for student enrollment. This time-window may be due to elevated enthusiasm at the beginning of the school year and can therefore be capitalized for piloting such a project. Finally, it is worth noting that facilitator compensation models at different institutes vary widely based on factors such as institutional funding, time commitment required of the facilitators, and the overall structure of the program. For example, while facilitators receive hourly remuneration at UTSC, SI programs also offer other extrinsic and intrinsic forms of compensation, such as professional development opportunities, specialized training, co-curricular record notation, and the intrinsic reward of contributing to the learning community in a deeply satisfying way.

Conclusions

FSG sessions at UTSC support students in a wide range of subjects, offering elective supplemental instruction in challenging courses at the institution. Here, we focus particularly on Organic Chemistry and show that our approach can be used as a framework within sessions to introduce a wide range of concepts and practice problems with varying levels of difficulty, to maintain active discussion, and to encourage participation within more intimate, collaborative groups. It is worth noting that while the primary focus of this paper is organic chemistry FSGs, over the same time span, there were 16 additional courses that were supported by the Centre for Teaching and Learning at UTSC through FSG programs. These included courses in biology, linguistics, mathematics, physics, psychology, business management, and statistics. In our experience, an identical program structure, where each FSG session corresponds to each hour of lecture and facilitators are compensated in an equivalent manner, was successfully generalized to support a diverse range of undergraduate courses. That said, it is important to appreciate that different courses require tailored facilitation techniques to meet student needs (Kenney & Kallison Jr, 1994; Loviscek & Cloutier, 1997; Malm et al., 2012). As such, dissemination of course-specific facilitation strategies and assessment of whether strategies from one domain are effective in another remains a question for future research. Through the use of a wide variation of questions, levels of difficulty, activities, and through consistently seeking student feedback on our methods, we have sought to promote a supportive environment conducive to the learning of a diverse group of students. While we did not assess the impact of FSGs across different demographic groups, previous work has reported that beneficial effects of SI such as the improved likelihood of passing the course are observed in students from different academic and demographic backgrounds (Arendale, 1997; Hillis et al., 2021). In fact, under certain contexts, disadvantaged students such as those from underrepresented minority groups experience preferential benefits from SI relative to their non-disadvantaged counterparts (Yue et al., 2018). This suggests that the FSG strategies described can be assessed further at institutions with a diverse student body. These small group communities within the larger classroom have fostered inclusion, created community, and elevated students' confidence and self-esteem, as corroborated by student feedback reported herein.

References

Arendale, D. (1997). Supplemental instruction (SI): Review of research concerning the effectiveness of SI from the University of Missouri-Kansas City and other institutions from across the United States (pp. 1-25). In Mioduski, Sylvia and Gwyn Enright (Eds.), Proceedings *of the 17th and 18th Annual Institutes for Learning Assistance Professionals: 1996 and 1997*. University Learning Center, University of Arizona.

Arendale, D. R. (1994). Understanding the supplemental instruction model. In D. C. Martin, & D. R. Arendale (Eds.), *Supplemental Instruction: Increasing student achievement and retention.* (New Directions in Teaching and Learning, No. 60, pp. 11-21). San Francisco: Jossey-Bass. https://doi.org/10.1002/tl.37219946004

Arendale, D. R. (2002). History of supplemental instruction (SI): Mainstreaming of developmental education. In D. B. Lundell, & J. L. Higbee (Eds.), *Histories of developmental education* (pp. 15-28). Center for Research on Developmental education and Urban Literacy, General College, University of Minnesota. http://purl.umn.edu/5366

Arendale, D. R. (2004). Pathways of persistence: A review of postsecondary peer cooperative learning programs. In I. Duranczyk, J. L. Higbee, & D. B. Lundell (Eds.), *Best practices for access and retention in higher education* (pp. 27-40). University of Minnesota, General College, Center for Research on Developmental Education and Urban Literacy. http://purl.umn.edu/5363

Armstrong, L., Power, C., Coady, C., & Dormer, L. (2011). Video-based supplemental instruction: Creating opportunities for at-risk students undertaking engineering mathematics. *Journal of Peer Learning*, *4*(1), 3-15.

Bengesai, A. (2011). Engineering students' experiences of supplemental instruction: A case study. *Alternation*, *18*(2), 59-77.

Bertucci, A., Conte, S., Johnson, D. W., & Johnson, R. T. (2010). The impact of size of cooperativegroup on achievement, social support, and self-esteem. *The Journal of General Psychology*, *137*(3), 256-272. https://doi.org/10.1080/00221309.2010.484448

Blanc, R. A., DeBuhr, L. E., & Martin, D. C. (1983). Breaking the attrition cycle: The effects of supplemental instruction on undergraduate performance and attrition. *The Journal of Higher Education*, *54*(1), 80-90. https://doi.org/10.1080/00221546.1983.11778153

Braun, R. L., & Simpson, W. R. (2004). The pause method in undergraduate auditing: An analysis of student assessments and relative effectiveness. *Advances in Accounting Education*, *6*, 69-85. https://doi.org/10.1016/S1085-4622(04)06004-3

Burmeister, S. (1996). Supplemental instruction: an interview with Deanna Martin. *Journal of Developmental Education*, *20*(1), 22.

Chen, T. T., Zhou, Q., Fang, H., & Wang, Y. (2020). Is the pause method in teaching auditing applicable in a different educational environment? A replication. In *Advances in Accounting Education: Teaching and Curriculum Innovations*. Emerald Publishing. https://doi.org/10.1108/S1085-462220200000024017

Childs, P. E., Markic, S., & Ryan, M. C. (2015). The role of language in the teaching and learning of chemistry. In J. Garcia-Martinez & E. Serrano-Torregrosa (Eds), *Chemistry education: Best practices, opportunities and trends* (pp.421-444). Wiley. https://doi.org/10.1002/9783527679300.ch17

Congos, D. H., & Schoeps, N. (1998). Inside supplemental instruction sessions: One model of what happens that improves grades and retention. *Research and Teaching in Developmental Education*, *15*(1), 47-61.

Dawson, P., van der Meer, J., Skalicky, J., & Cowley, K. (2014). On the effectiveness of supplemental instruction: A systematic review of supplemental instruction and peer-assisted study sessions literature between 2001 and 2010. *Review of Educational Research*, *84*(4), 609-639. https://doi.org/10.3102/0034654314540007

Etter, E. R., Burmeister, S. L., & Elder, R. J. (2000). Improving student performance and retention via supplemental instruction. *Journal of Accounting Education*, *18*(4), 355-368. https://doi.org/10.1016/S0748-5751(01)00006-9

Farrell, J. J., Moog, R. S., & Spencer, J. N. (1999). A guided-inquiry general chemistry course. *Journal of Chemical Education*, *76*(4), 570. https://doi.org/10.1021/ed076p570

Ferreri, S. P., & O'Connor, S. K. (2013). Redesign of a large lecture course into a small-group learning course. *American Journal of Pharmaceutical Education*, *77*(1), 13. https://doi.org/10.5688/ajpe77113

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410-8415. https://doi.org/10.1073/pnas.1319030111

Galloway, K. R., Stoyanovich, C., & Flynn, A. B. (2017). Students' interpretations of mechanistic language in organic chemistry before learning reactions. *Chemistry Education Research and Practice*, *18*(2), 353-374. https://doi.org/10.1039/C6RP00231E

Gaudet, A. D., Ramer, L. M., Nakonechny, J., Cragg, J. J., & Ramer, M. S. (2010). Small-group learning in an upper-level university biology class enhances academic performance and student attitudes toward group work. *PloS one*, *5*(12), e15821. https://doi.org/10.1371/journal.pone.0015821

Gosser, D., Roth, V., Gafney, L., Kampmeier, J., Strozak, V., Varma-Nelson, P., Radel, S., & Weiner, M. (1996). Workshop chemistry: Overcoming the barriers to student success. *The Chemical Educator*, *1*(1), 1-17. https://doi.org/10.1007/s00897960002a

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64-74. https://doi.org/10.1119/1.18809

Hillis, T., Guarcello, M. A., Levine, R. A., & Fan, J. (2021). Causal inference in the presence of missing data using a random forest-based matching algorithm. *Stat*, *10*(1), e326. https://doi.org/10.1002/sta4.326

Hu, H. H., & Shepherd, T. D. (2013). Using POGIL to help students learn to program. *ACM Transactions on Computing Education (TOCE)*, *13*(3), 1-23. https://doi.org/10.1145/2499947.2499950

Hurley, M., Jacobs, G., & Gilbert, M. (2006). The basic SI model. *New Directions for Teaching and Learning*, *2006*(106), 11-22. https://doi.org/10.1002/tl.229

Kenney, P. A., & Kallison Jr, J. M. (1994). Research studies on the effectiveness of Supplemental Instruction in mathematics. *New Directions for Teaching and Learning*, *1994*(60), 75-82. https://doi.org/10.1002/tl.37219946010

Khan, B. R. (2018). *The effectiveness of Supplemental Instruction and online homework in first-semester calculus*. Teachers College, Columbia University.

Kurucay, M., & Inan, F. A. (2017). Examining the effects of learner-learner interactions on satisfaction and learning in an online undergraduate course. *Computers & Education*, *115*, 20-37. https://doi.org/10.1016/j.compedu.2017.06.010

Loviscek, A. L., & Cloutier, N. R. (1997). Supplemental instruction and the enhancement of student performance in economics principles. *The American Economist*, *41*(2), 70-76. https://doi.org/10.1177/056943459704100209

Lundeberg, M. A. (1990). Supplemental instruction in chemistry. *Journal of Research in Science Teaching*, *27*(2), 145-155. https://doi.org/10.1002/tea.3660270206

Malm, J., Bryngfors, L., & Mörner, L.-L. (2012). Supplemental instruction for improving first year results in engineering studies. *Studies in Higher education*, *37*(6), 655-666. https://doi.org/10.1080/03075079.2010.535610

Maxwell, W. E. (1998). Supplemental instruction, learning communities, and students studying together. *Community College Review*, *26*(2), 1-18. https://doi.org/10.1177/009155219802600201

McDuff, E. (2012). Collaborative learning in an undergraduate theory course. *Teaching Sociology*, *40*(2), 166-176. https://doi.org/10.1177/0092055X12437968

McGuire, S. Y. (2006). The impact of supplemental instruction on teaching students how to learn. *New Directions for Teaching and Learning*, *2006*(106), 3-10. https://doi.org/10.1002/tl.228

Moore, R., & LeDee, O. (2006). Supplemental instruction and the performance of developmental education students in an introductory biology course. *Journal of College Reading and Learning*, *36*(2), 9-20. https://doi.org/10.1080/10790195.2006.10850184

Ning, H. K., & Downing, K. (2010). The impact of supplemental instruction on learning competence and academic performance. *Studies in higher education*, *35*(8), 921-939. https://doi.org/10.1080/03075070903390786

Rath, K. A., Peterfreund, A. R., Xenos, S. P., Bayliss, F., & Carnal, N. (2007). Supplemental instruction in introductory biology I: Enhancing the performance and retention of underrepresented minority students. *CBE—Life Sciences Education*, *6*(3), 203-216. https://doi.org/10.1187/cbe.06-10-0198

Schuster, E. (2018). Supplemental instruction: leading to success. *Journal of Computing Sciences in Colleges*, *33*(6), 143-147.

Shaya, S. B., Petty, H. R., & Petty, L. I. (1993). A case study of supplemental instruction in biology focused on at-risk students. *BioScience*, *43*(10), 709-711. https://doi.org/10.2307/1312343

Skoglund, K., Wall, T. J., & Kiene, D. (2018). Impact of supplemental instruction participation on college freshman retention. *Learning Assistance Review*, *23*(1), 115-135.

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research*, *69*(1), 21-51. https://doi.org/10.3102/00346543069001021

Toby, E., Scott, T. P., Migl, D., & Kolodzeji, E. (2016). Supplemental instruction in physical chemistry I. *Learning Assistance Review*, *21*(1), 71-79.

University of Missouri – Kansas City. (2004). Supplemental Instruction leader resource manual. Kansas City, MO: The Curators of the University of Missouri.

Webster, T. J., & Hooper, L. (1998). Supplemental instruction for introductory chemistry courses: A preliminary investigation. *Journal of Chemical Education, 75*(3), 328. https://doi.org/10.1021/ed075p328

Wilmot, J., Peralez, K., & Telang, N. (2016). Supplemental instruction pilot program for an introductory electrical engineering course. Conference proceedings of the First Year Engineering Education Annual Conference, Columbus, Ohio,

Wright, R. L. (2005). Points of view: Content versus process: Is this a fair choice? *Cell Biology Education*, *4*(3), 189-196. https://doi.org/10.1187/cbe.05-04-0075

Yue, H., Rico, R. S., Vang, M. K., & Giuffrida, T. A. (2018). Supplemental instruction: Helping disadvantaged students reduce performance gap. *Journal of Developmental Education*, *41*(2), 18-25.

Appendix A

Campus statistics

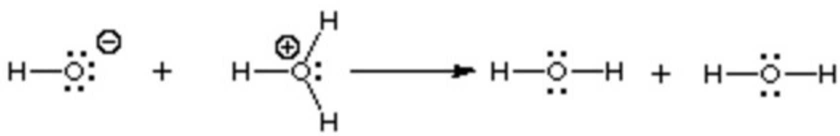
Factor	Description
Campus student population	10,426 students in 2010 13,694 students in 2019 **31% increase**
Courses offering "WebOption" – online learning	201 courses in 2019
International students	1,161 students in 2010 3,163 students from 86 countries in 2019 **172% increase**
AccessAbility Services enrolment	517 students in 2013 1200 students in 2019 **232% increase**

Appendix B
Worksheet

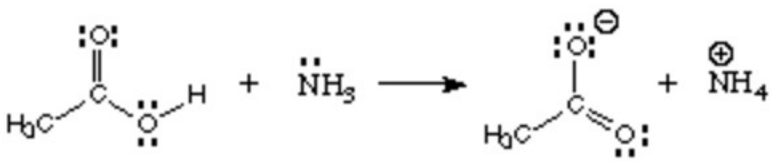
CHMB41 FSG Session 13

1) Heterolytic cleavage forms________________
2) Curved arrows always start from______________ and end on ________________.
3) Draw curved arrows for the following reactions:

(a)

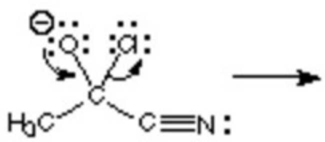


(b)

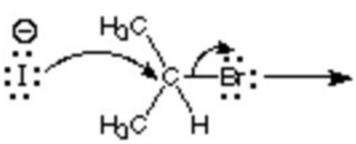


4) Draw the products for the following reactions:

(a)



(b)



5) Indicate whether the following are most likely to be nucleophiles or electrophiles.

(a) NH_3

(b) BH_3

(c) $CH_3CH_2O^-$

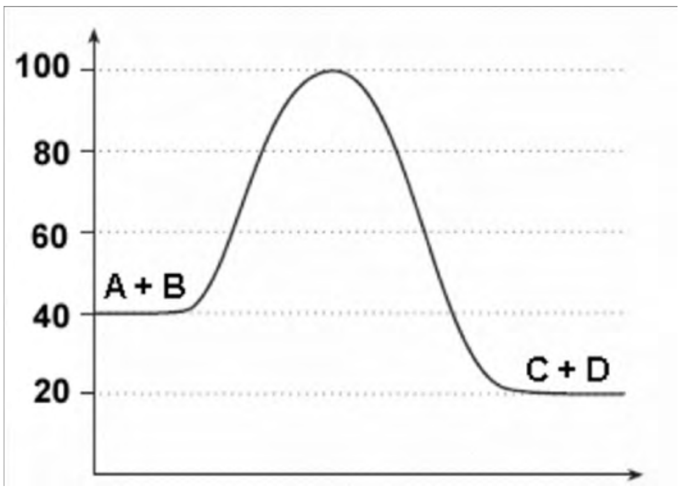
(d) H_3O^+

(e) $^+C(CH_3)$

(f) R_3N

(g) CH_3SH

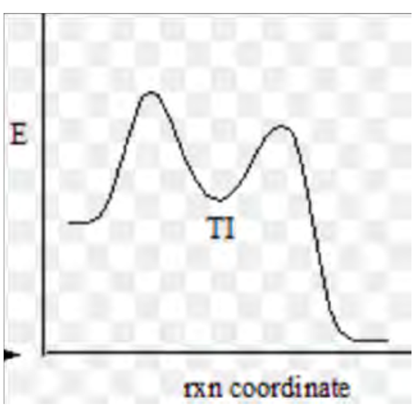
6) Label the x-axis, y-axis, reactants, products, transition state, ΔG°, ΔG‡ of the following reaction energy diagram.



7) (a) How many transition states does the following reaction have?

(b) From the intermediate, which product is formed **faster**, A or B?

(c) Which product is more **stable**, A or B?



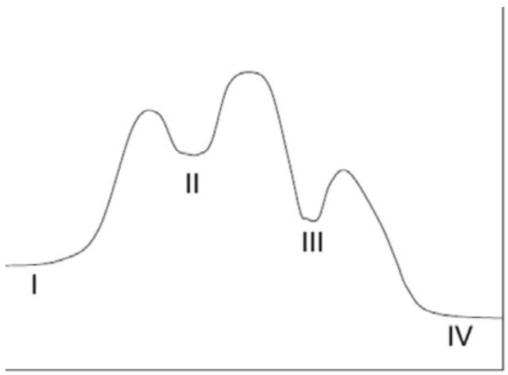
8) In the following energy diagram:

(a) How many transitions states are there?

(b) How many intermediates are formed?

(c) Which step has the greatest activation energy?

(d) What is the rate-determining step?



Appendix C

CHMB41 FSG – Chapter 9 & 10 Summary Sheet

Substitution and Elimination Reactions

1) S_N2 –Substitution Nucleophilic Bimolecular Alkyl Halide + Nucleophile = Factors: Substrate Structure: Methyl, primary, secondary, or tertiary alkyl halide favored? Nucleophile: Strong base or weak? What is the trend of nucleophilicitydown a column in a polar protic solvent? Solvent: Polar protic or aprotic? Do aprotic solvents solvate the negatively charged nucleophile? Leaving Group: strong base or weak base? Rate equation: Rate= Inversion of configuration: R to S, S to R	Mechanism:

2) S_N1 – Substitution Nucleophilic Unimolecular Alkyl Halide + Nucleophile = Factors: Substrate Structure: Methyl, primary, secondary, or tertiary alkyl halide favored? Nucleophile: Does the reaction **r**ate depend on the nucleophile? Why? Solvent: Why are polar protic solvents favored? Leaving Group: strong base or weak base? Rate equation: Rate= *Carbocation rearrangements are possible!* Stereochemistry? If you start off with R, is the product more R, S, or equal R/S?	Mechanism:

3) E2 Alkyl Halide + Base = Alkene Anti-periplanar geometry required! Zaitsev's Rule: Exceptions to Zatisev's Rule: 1) 2) 3) Regioselective and Stereospecific 2 Beta-H's = Cis+ trans formed 1 Beta-H= Either cis OR trans (stereospecific) What conditions favor E2? Can E2 occur for a methylhalide? Is E2 favored in primary, secondary, or tertiary? Does E2 require a strong base? Does E2 require good leaving group? Rate equation: Rate=	Mechanism:

https://doi.org/10.5206/cjsotlrcacea.2023.1.13734

4) E1 Alkyl Halide + Base = Alkene Is anti-periplanar geometry required in E1? Regioselective, but not stereoselective. Why? 2 Beta-H's = Cis + trans formed 1 Beta-H = Cis + trans formed What conditions favor E1? Can E1occur for a methyl halide? Is E1 favored in primary, secondary, or tertiary? Does E1 require a strong base? Does E1 require good leaving group? *Carbocation rearrangements are possible!* Rate equation: Rate =	Mechanism:

Appendix D

End-of-term survey

Instructions Your opinions and comments are very important to the success of the Facilitated Study Group (FSG) program. Please take a few minutes to fill out this survey -- even if you did not attend any FSG sessions.

Thank you!

- **Question 1: Multiple Answer**

How many study groups for this course did you attend?

1-2
3-5
6-10
more than 10
I did not attend any study groups for this course.

- **Question 2: Opinion Scale/Likert**

I found the FSGs helpful.

Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
I did not attend any FSGs for this course.

-

- **Question 3: Opinion Scale/Likert**

  The facilitator actively engaged me with the course material.

Strongly Agree
Agree
Neither Agree nor Disagree
Disagree
Strongly Disagree
I did not attend FSGs for this course.

- **Question 4: Multiple Choice**

  If you didn't attend any FSGs, what was the reason for this? (Please choose the last option if you did attend FSGs.)

I wanted to but couldn’t. The session schedule conflicted with work or other classes.
I didn’t feel it was necessary.
I have been to similar kinds of study sessions for other courses and did not find them helpful.
I intended to, but couldn’t find the time.
Other. Please explain in the comments section.
I did attend FSGs

- **Question 5: Multiple Choice**

  If FSGs are offered in your other courses, how likely is it that you will attend?

Very likely
Somewhat likely
Neither likely nor unlikely
Unlikely
Very unlikely

- **Question 6: Short Answer**
  Additional comments? Please share your thoughts about the FSG program here.