Secondary School Chemistry

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Clock Reaction: Outreach Attraction

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Support for science outreach has been emphasized in recent literature *(1−3)*. Community science initiatives are being encouraged and undertaken by institutions *(4−7)*, researchers *(8)*, educators *(9)*, and students *(10, 11)* alike. One way to offer school-age students a stimulating chemistry experience is to host an event on campus and involve the students in laboratory experiments. The university environment is ideal for this type of outreach because materials, instrumentation, and expert volunteers are readily available. Students can be exposed to more advanced activities than would be possible in a classroom, and a greater hands-on component is afforded compared to traveling demonstration shows.

Clock reaction experiments provide a dramatic visual means by which to showcase chemical reactions and the concept of reaction rate, as well as investigate important variables affecting reaction rates. The iodine (Landolt) clock reaction *(12)* and variants thereof *(13−22)* are commonly employed as quantitative undergraduate experiments or qualitative grade school demonstrations. Therefore, it was natural to revise an available undergraduate procedure to make it accessible to a younger audience; in this case, students at the grade 9 level.

The first-year chemistry curriculum at Dalhousie University includes the study of a peroxydisulfate−iodide clock reaction *(23, 24)*, the chemistry of which is outlined in eqs 1−3. As triiodide is formed via eq 1, it reacts with thiosulfate as shown in eq 2. Any remaining triiodide from eq 1 reacts with starch, leading to the production of the anticipated dark blue amylose−pentaiodide complex, denoted as starch−I_5^-, via eq 3 *(21)*. If more of the iodine scavenger, thiosulfate, is added to the reaction solution, the dark blue amylose−pentaiodide complex is disassembled, the solution becomes colorless, and the process repeats until the dark blue color appears once again.

$$S_2O_8^{2-}{}_{(aq)} + 3I^-{}_{(aq)} \rightarrow I_3^-{}_{(aq)} + 2SO_4^{2-}{}_{(aq)} \qquad (1)$$

$$2S_2O_3^{2-}{}_{(aq)} + I_3^-{}_{(aq)} \rightarrow 3I^-{}_{(aq)} + S_4O_6^{2-}{}_{(aq)} \qquad (2)$$

$$2I_3^-{}_{(aq)} + \text{starch}_{(aq)} \rightarrow \text{starch}-I_5^-{}_{(aq)} + I^-{}_{(aq)} \qquad (3)$$

Herein we describe a chemistry outreach activity based on modifications to this undergraduate clock reaction experiment *(23)*. Graduate student volunteers assisted several classes of local grade 9 students, who visited the Dalhousie University Department of Chemistry, to perform the revised laboratory experiment. In contrast to the undergraduate experiment, the visiting students were not asked to quantitatively determine reaction rate information or delve into the detailed chemistry addressed above. Instead, the students were presented with simplified reaction eqs 4 and 5, and worked in pairs to qualitatively assess how changes in reactant concentration, catalysis, and temperature influenced the time required for the characteristic dark blue color to be observed. The students recorded their observations in experiment booklets (see the supporting information), considered practical questions, and drew conclusions.

$$(NH_4)_2S_2O_8 + 2KI \rightarrow I_2 + K_2SO_4 + (NH_4)_2SO_4 \qquad (4)$$

$$\text{Iodine } (I_2) + \text{starch} \rightarrow \text{blue-black color} \qquad (5)$$

Hazards

During the outreach activity, students used relatively small amounts of moderately concentrated aqueous solutions of potassium iodide, potassium nitrate, ammonium peroxydisulfate, starch, sodium thiosulfate, and copper(II) sulfate. There is always a potential for harm to human health when working with chemicals; hence, safety is of primary importance. All of the compounds involved in the experiment have an up to moderate (≤ 2) National Fire Protection Association (NFPA) health rating and could be harmful if exposed to skin, inhaled, or ingested. However, if the solutions are used under supervision and as directed in the student experiment booklet, no significant hazards are posed by any of the chemicals involved. Note that lab safety rules should be discussed prior to the experiment. The Lab Documentation (see the online supporting information) includes previsit safety information for teachers.

Experiment Synopsis

In pairs, the students completed and compared four experiment trials (Table 1), demonstrating the effects of doubling the potassium iodide concentration, adding copper(II) sulfate solution as a catalyst, and increasing the reaction temperature, all relative to the control experiment. To begin each trial, one partner added an aliquot (test tube) of sodium thiosulfate solution and Solution B to the beaker containing Solution A with stirring, while the other partner timed the reaction. They recorded the time at which the dark blue color of the starch−iodine complex appeared. Another test tube of sodium thiosulfate solution was added immediately, and again the time it took for the dark blue color to appear was recorded. This sequence of events was repeated until all four test tubes of

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Table 1. Contents of Reaction Mixtures Examined by Grade 9 Students

		Solution A			Solution B	Four Test Tubes
Trial	Description	0.20 M $KI_{(aq)}$/mL	0.20 M $KNO_{3(aq)}$/mL	1% $Starch_{(aq)}$/mL	0.10 M $(NH_4)_2S_2O_{8(aq)}$/mL	0.02 M $Na_2S_2O_{3(aq)}$/mL
1	Control	20	30	1	10	1 (in each)
2	Increased amount of reactant (KI)	40	10	1	10	1 (in each)
3	Addition of $CuSO_4$ catalyst (1−2 drops)	20	30	1	10	1 (in each)
4	Increased temperature (+10−15 °C)	20	30	1	10	1 (in each)

sodium thiosulfate solution had been added to the reaction mixture. This repeating series of steps not only helped the students become more comfortable with the procedure, but also demonstrated the idea of statistical rigor as part of the scientific method.

In our experience, most pairs finished the full activity within a 90-min time frame, which included our introduction and concluding remarks. Often the students that finished quickly were keen and were easily encouraged by volunteers to investigate an extra set of conditions. In several cases, the extra experiment was even motivated by the student's own questions, such as, "What if I added more catalyst?" and "What if I used high temperature and the catalyst?". For more experimental details see the online supporting information.

Summary Questions

Following completion of the hands-on portion of the outreach activity, the students were presented with a series of summary questions in their experiment booklets. The questions were designed to reinforce some of the main chemistry concepts encountered during the activity, to help the students make connections between chemical reactions and their daily lives, and to provide further structured learning for those who finished early. Not all students completed the questions during their time on campus, but we found that this did not prevent us from meeting our primary goals of creating an enjoyable lab experience, fostering interest in chemistry, and teaching a short lesson about rates of chemical reactions.

The student experiment booklets were not explicitly intended for evaluation; however, we did provide teachers with a separate package that included sample answers to the summary questions (see the supporting information). All teachers decided independently to collect the completed experiment booklets from their students. We now recommend this strategy for future participants, as it provides extra motivation for the students to round out their laboratory experience and reflect on what they have learned.

Consolidating Knowledge

To complete the students' visit to the lab, volunteers polled the student participants (by a show of hands) about the effects of additional reactant, a catalyst, and increased temperature on reaction rate. The design of the experiment lends itself to qualitatively correct answers, and most students did reach the expected conclusions. In instances where a student pair obtained unexpected results, surveying all pairs (equivalent to repeating the experiment many times) ensured that there was overwhelming evidence for the correct outcomes. It also was interesting to ask the outreach participants, again by a show of hands, to determine which of the four trials was fastest. A range of responses was obtained. This is to be expected as neither the amount of catalyst nor temperature was precisely controlled. If time allows, this is an opportunity to discuss possible reasons for different outcomes and to take other questions.

Conclusion

We have modified a common first-year chemistry experiment for use as an outreach attraction. The experiment introduced grade 9 students to a university laboratory and provided for hands-on use of some of the tools of chemistry, including equipment not commonly encountered prior to advanced chemistry courses. Many graduate students accustomed to such equipment were caught off guard by the grade 9 students' particularly impressed reaction to magnetic stir plates. Simply being in a lab environment is a new experience for most grade-school students, thus, increasing the potential "wow-factor" of the activity compared to a classroom experiment. A visiting teacher commented, "The experience of working in an actual laboratory was wonderful. [My students] enjoyed working like scientists...it made what they have been doing in school more real to them."

We have now used the experiment with eight grade 9 classes, including 250 students, teachers, parents, and aides. This age group is of interest, as the students will soon decide whether or not to study chemistry in high school. From this perspective, the experiment is likely to be of interest for grade 10 groups and we believe it could be done with grade 8 students as well. While prior introductions to chemical equations are useful, not all visiting groups had this background. In our opinion, prior introductions to chemical changes (addressed in several younger grades) and the particle theory of matter (introduced in Nova Scotia's grade 7 curriculum; see ref *25*) are sufficient for understanding the chemistry outreach activity as presented here.

Judging by the responses we received from students and teachers and the overall energy level in the lab, we conclude that our modified clock reaction experiment reproducibly yields a positive outreach experience. Furthermore, we suggest that similar outreach activities could be easily implemented at universities that already support a clock reaction experiment within the undergraduate curriculum. There are two main advantages of adapting a laboratory procedure performed regularly by large groups of undergraduate students. First, it is straightforward to access the necessary space, chemicals, literature, and human resources to involve numerous youth participants. Second, offering young people a chance to experiment in a university environment is a unique opportunity. From positive feedback that we received from participants, we noted that such an experience can create exactly the sense of enthusiasm about science that we and other outreach contributors aspire to achieve.

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Supporting Information Available

Student experiment booklet and summary questions; expected conclusions and sample answers to summary questions; instructor notes. This material is available via the Internet at http://pubs.acs.org.