Running Head: Flip Chemistry Undergraduate Laboratory

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How Flip Teaching Supports Undergraduate Chemistry Laboratory Learning

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Abstract

In this paper, we define flip teaching as a curricular platform that uses various strategies, tools, and pedagogies to engage learners in self-directed learning outside the classroom before face-to-face meetings with teachers in the classroom. With this understanding, we adopted flip teaching in the design and enactment of one Year 1 and one Year 2 undergraduate chemistry laboratory session at a higher education institution. The undergraduates viewed videos demonstrating the practical procedures and answered pre-laboratory questions posted on the institution's mobile device application before the laboratory lessons. Analyses of the lesson videos, interviews with the undergraduates and instructors, and undergraduate artefacts showed that the undergraduates had developed a better understanding of the theory undergirding the procedures before they performed the practical, and were able to decipher the complex practical procedures. They also experienced less anxiety about the complex practical steps and setup, and subsequently, improved work efficiency. The findings of this study have implications for chemistry educators looking for ways to improve on the design and enactment of the laboratory curriculum to enhance the undergraduates' self-directed learning.

Keywords: flip teaching, chemistry laboratory, undergraduate, video, mobile App, pre-laboratory questions

Introduction

Flip teaching has gained considerable amount of attention in recent years, receiving coverage in the U.S. and U.K. media such as *The Economist*, *Wired*, and *The Daily Telegraph.* This is, in part, because flip teaching challenges the conventional order of teaching and learning where students first undergo instruction in class and then do their homework *outside class*. The main purpose of flip teaching is to ensure that curriculum time can be better used to actively engage students in learning rather than focussing on didactic teaching. A key feature of flip teaching is the use of technology to substitute in-class direct transmission of information. Flip teaching is, however, not simply about the adoption of technology alone. Drawing from our experience researching on flip teaching, we understand it to entail a change in mindset about the curriculum—what constitutes a "lesson", what students and teachers do during out-of-classroom time and in face-to-face meetings, what content is to be taught and learned, what is the sequence of learning activities, what is the scope of a lesson, what are the appropriate pedagogies to deliver the content, and what are some learning strategies students can use. In other words, flip teaching does not refer to a set of teaching strategies but a curricular platform embodying a broader set of curricular considerations aimed at increasing student active participation in the their education.

This paper describes an exploratory research that examines the use of flip teaching as an alternative chemistry laboratory curriculum model at a Singapore tertiary institution focusing on teacher education at both undergraduate and postgraduate levels. The research question that guided our inquiry was: *How does flip teaching support the undergraduates' chemistry laboratory learning?* Two science and two science education faculty members who are authors of this paper collaborated on a larger study to examine strategies that support more active student learning in laboratory lessons. The third and fourth authors were also the instructors of the chemistry laboratory courses being studied. This study focussing on flip teaching was a continuation of an earlier baseline (unpublished) study of the curriculum that identified areas of improvement for facilitating student learning.

The baseline study investigated how the undergraduates prepared for their chemistry laboratory lessons in the traditional setting, which typically involved the instructors giving a pre-laboratory briefing (that lasted 30 minutes on average) on the procedures the undergraduates would undertake for the session, and provided a general overview of the chemical reactions that would take place during the practical. The undergraduates spent the rest of the session completing the practical, aided by a laboratory manual that detailed the broad steps required to complete the practical. A week later, they would submit a laboratory report which would be graded. From the pre- and post-laboratory surveys and interviews with the undergraduates we found that the practicals were often done in a rushed manner as the undergraduates had only three hours to complete their laboratory work. This resulted in them not having enough time to think about what they did in the laboratory and link the practicals to the theories taught in lectures. Despite the pre-laboratory briefings, the undergraduates had minimal understanding of the chemistry concepts undergirding the practical procedures. Further, they did not receive detailed feedback on their performances during the laboratory sessions as there was usually no time for post-lab debriefs. The undergraduates expressed a desire for instructors to provide explicit links between the theory and practice, with suggestions such as having instructors explain why it was necessary for certain steps to be done before others.

Based upon the findings, the research team identified flip teaching as one plausible curriculum model to address the above findings. We, the authors, posited that the flip teaching approach was appropriate in the research context as the undergraduates were expected to be able to learn independently and read up on the practicals to make sense of the practical procedures, reagents, apparatus, setup, and chemical reactions before they carried out the practicals. This paper reports on the flip lesson design and implementation in two chemistry laboratory sessions in the new academic year following the baseline study.

Objectives of the study

While most studies on flip teaching reported on the advantages and disadvantages of flip teaching and learning, we were interested in the *process* of flip teaching and learning. In particular, we wanted to know *how* the undergraduates had harnessed the flip lesson curriculum resource (the detailed video demonstration of the practical procedure) for their own learning. We apply an epistemic lens to examine and understand how teaching and learning had occurred as a result of flipping the laboratory lesson. The flip lesson included: (1) providing the demonstration video to the undergraduates before the laboratory lesson, (2) restructuring the laboratory lesson to include post-laboratory feedback and reduced pre-laboratory briefing, and (3) changing the laboratory lesson discourse to include more in-depth discussion on the theory undergirding the laboratory processes. We aimed to understand how epistemological gains could be made, through flip teaching, at the nexus of *episteme-techne* in the curriculum space of the laboratory. According to Aristotle (cited in Flyvbjerg, 2001), "[E]pisteme concerns theoretical *know why* and *techne* denotes technical *know how*" (p. 56, emphasis in original). In the context of the science laboratory, the theoretical *know why* refers to the scientific theory underpinning the processes and the technical *know how* refers to the practical techniques and skills.

To our knowledge, no previous empirical studies had reported on flip teaching in the context of science laboratory lessons as most studies focused on lectures and classrooms. Chemistry instructors in schools and higher education contexts interested in improving the quality of science laboratory teaching and learning may be interested to learn how flip teaching can be applied in science laboratory context. The findings and discussion in this paper will provide insights into how flip teaching may enhance the quality of science laboratory learning, both in schools and in tertiary institutions.

In the section that follows, we discuss the literature on the limited impact of science laboratory work on student learning. Next, we discuss what has been reported about flip teaching. Due to the lack of prior studies on flip teaching in science laboratory contexts, our review includes empirical studies on flip teaching in classroom and lecture settings, and science and non-science lessons. Finally, we offer our own definition of flip teaching.

Discussion of the Literature

Laboratory work

Laboratory work plays a central role in science education and it generally refers to activities in which students manipulate equipment, handle material, and make observations for the sense-making of phenomena (Hofstein *et al.*, 2013). Laboratory work is considered to be important in students' learning of science because it is able to facilitate the understanding of scientific concepts and the nature of science, provide opportunities to learn inquiry skills and problem solving, cultivate scientific habits of mind, and help students develop positive attitude towards science and the learning of science (Nakhleh *et al.*, 2002; Hodson, 2005; Hofstein *et al.*, 2013).

However, laboratory work may have limited impact on students' learning of science if the activities are "prescribed from a given bank of recipes and routines, typically of an undemanding nature, which ultimately trivialized the activity" (McNally, 2006, p. 426). Most students learn that they only need to follow instructions and perform the required analyses in laboratory work to obtain satisfactory results (Montes & Rockley, 2002). They are inclined to focus "on those aspects of the task that they believe will gain them the most credit in terms of course grades" (Tiberghien *et al.*, 2001, p. 487). Students tend not to see the importance of linking what they do during laboratory work with theories that they learn in class, so they have little theory to guide them in the activities that they do (Hart *et al.*, 2000; Sere, 2002; Tiberghien et al., 2001). With little understanding of the purpose of the apparatus and procedures, and what they should observe and measure from the practicals, Sere (2002) argued that students were not able to engage meaningfully in laboratory work. Chittleborough et al. (2007) addressed this problem using online pre-laboratory exercises in an introductory first year university chemistry course. They found that it had allowed greater flexibility in the undergraduates' use of time and the place where they did the exercises, freed up more time for providing feedback on the students' responses, and provided the opportunity for students to learn from their mistakes with no penalty for incorrect answers. As compared to reading the laboratory manual alone, the undergraduates were more well-prepared to do the practicals as they understood the theory behind the procedures, and the type, use, and choice of apparatus before they perform the practicals.

Chittelborough et al.'s (2007) study showed that pre-laboratory exercises could be incorporated in a flip science laboratory lesson. In the flip laboratory lessons we designed, the undergraduates also had to answer pre-laboratory questions. Below, we discuss flip teaching and how it has been used to address some limitations of teaching and learning.

Flip teaching

Even before information and communication technology (ICT) became commonplace in the society, teachers had, at times, required students to complete readings before a lesson so that the curriculum time may be freed for other learning activities (Strayer, 2012). However, the advancement of ICT has allowed content delivery outside class to be more accessible, faster, and engaging than before (Chittleborough *et al.*, 2007). Growing up with digital technology, students of today are often familiar with and constantly engaging with various digital devices. The current generation of Digital Natives (OECD, 2006) are therefore, able to learn effectively through ICT.

The use of technology to replace predominantly didactic in-class lectures first emerged in education literature about a decade ago when terms such as "classroom flip" (Baker, 2000; Forertch *et al.*, 2002) and "inverted classroom" (Lage *et al.*, 2000) were mentioned. Since 2005, when the video-sharing website YouTube was founded, the ability for any individual to create and share video content was made possible (Wesch, 2008), and the immense popularity of Khan Academy's micro-lecture videos exemplified the potential of video lessons (Khan Academy, 2013). Not long after, several U.S. high school teachers such as Karl Fisch, and Aaron Sams and Jonathan Bergmann began practicing flip teaching (Pink, 2010; Bergmann & Sams, 2012), which received attention and was promoted by the media as an active way to engage students.

Flip versus traditional teaching

Flip teaching differs from traditional didactic teaching in that students engage in some form of active, self-directed learning before they enter the classroom. By traditional teaching, we refer to the model of having students come into class to learn—during which teachers may adopt a range of pedagogical strategies such as didactic teaching, inquiry, group work, student presentation, and so on—and then do their homework after school. The time before the lesson is a void as students wait to be taught and apply what they have learned in class only after the lesson. The term "flip classroom" is derived from the "flipping" of instructions; traditional classroom activity (i.e. lecturing) becomes the homework, and traditional homework activities are completed in class. This is illustrated in Table 1, which shows what happens before, during, and after a lesson in a traditional and flip teaching model.

Table 1: Differences between traditional and flip classroom teaching.

Type of lesson	Pre-lesson	During lesson	Post-lesson
Traditional		Teacher-centred lesson i.e. students sit and listen most of the time	Student do homework related to what is taught in class
Flip	Self-directed or peer learning	Teacher-facilitated lesson i.e. students work on practices related to the pre-lesson activity	Students have no homework, work on practices that are more challenging, or prepare for the next lesson.

The flip classroom provides teachers with greater flexibility over the classroom time as students have the time to engage lesson content at a deeper level. This is, at times, achieved by having students use technology to complete rudimentary study of basic concepts (i.e. through online lectures) ahead of time, so that they will be ready for deeper learning during class. In our review of the literature, we found fundamental differences in the traditional and flip teaching models in terms of the epistemological beliefs about students, teachers, and learning. We unpack some of these and present them in Table 2 below.

Table 2: Comparison of the assumptions underlying traditional didactic and flip teaching.

	Traditional didactic teaching	**Flip teaching**
Student motivation	Students are viewed as unable or unmotivated to learn on their own.	The use of IT and student-centred activities will entice students to learn on their own or with their peers.
Student knowledge	Students come to class with a blank slate to consume knowledge from teachers.	Students are social agents and co-constructors of knowledge. Students are equipped with the relevant knowledge to learn when they go into class* and hence, teachers can build on that prior knowledge common among students.
Student work	Students will be able to do their homework after the teacher has taught them the content.	Students need further support from teachers and peers to do their work as they may not have attained complete understanding of the topic.
Teacher role	Teacher has authority and represents expert figure in class.	Teacher plays a facilitator role to support students' learning in and outside the classroom.

* Note that while we are aware that not all students will learn on their own before class, it is not the focus of this paper to discuss this issue. This is because there are just as many reasons why students may not have done their reading before class as not doing their homework. For example, the activity is not interesting to students or that they have personal matters to attend to which distracts them from their work. The responsibility of the teacher is to ensure that curriculum activities are meaningful to students and that there is continuity from the pre-lesson activity to the during class activity so that students will be motivated to complete the assigned tasks before class.

Defining flip teaching

Nonetheless, the definition of flip teaching remains ambiguous. For example, Bergmann and Sams (2012) argued that to flip a lesson is to swap what is traditionally done at home and in class. Strayer (2012) defined flip teaching as a specific type of blended learning design that uses technology to move lectures outside the classroom and uses learning activities to move practice with concepts inside the classroom. More commonly, flip teaching is frequently defined as a strategy with the purpose of reallocating students' learning time.

In our review of empirical (Table 3) and non-empirical literature we found flip teaching to consist of common characteristics in each of the following domains:

- Curriculum structure—The curriculum time is extended to before formal class time to provide extended curricular platforms for non-teacher directed learning to take place outside the classroom (see Table 1).
- Power structure—Students play a key role in making decisions on what, how, and when they learn outside class. In class, they participate in the active co-construction of knowledge with their peers and teachers.
- Mindset—A change in thinking and perception about student and teacher roles, students' ability to learn on their own, places where learning and teaching can take place, and the order of teaching and learning.
- Pedagogical tools—Teachers will direct students to learn using ICT-based resources accessible outside the classroom and then build on what students have learned in class.

Based on our synthesis of the above information and experience doing flip teaching, we define flip teaching as follows:

Flip teaching is a curricular platform that uses various strategies, tools, and pedagogies to engage students in self-directed learning outside the classroom before face-to-face meetings with teachers in the classroom.

Table 3: Summary of 11 empirical studies on flip teaching.

Source	Research context	Home activities	Class activities	Selected outcomes of flipping	
				Positive	Negative
Davies, Dean, & Ball (2013)	Undergraduate course in introductory spreadsheet course	Textbook reading, videos supported by thought-provoking problems, complete homework and exams in MS Excel.	Class attendance optional.	Optional attendance allowed students better use of their time. Flipped classes can easily accommodate large classes. Students are able to pace themselves based on own level of understanding.	Requires greater upfront investment for development of video resources.
Forertch, Moses, Strikwerda, & Litzkow (2002)	Undergraduate course in Computer Science	Video streaming software, eTEACH® and quizzes.	Individual computer tutorial, and three-person computer problem solving.	More convenient and conducive to learn from video. Improved conceptual understanding through collaboration.	Require more self-discipline.
Gannod, Burge, & Helmick (2007)	Undergraduate course in Service oriented architecture and web services	Video blogs, PowerPoint with voiceovers, screencast.	Variety of class activities, primarily application development assignments.	Positive reception to inverted classroom model. Appropriate in-class activities. Podcast was an effective learning tool.	Not all students were engaged during in-class activity.

Johnson & Renner (2012)	Two high school courses in Computer Application	Completing textbook tutorial, supported by Adobe Flash screencast video.	Completing computer project in pairs without teacher support.	Increased on-task discussions. Evidence of higher level thinking.	Students not motivated. Students do not automatically prefer cooperative group work.
Lage, Platt, & Treglia (2000)	Undergraduate course in Economics	Videotaped lectures/ audio-guided PowerPoint, and worksheets.	Experiment/ labs, worksheet discussion, review questions.	Students and instructors favorably impressed. Increased one-on-one interactions.	Higher set-up cost.
McGivney-Burelle & Xue (2013)	Undergraduate course in Calculus	Two to three short online video, complete sample problems.	Entrance quiz at start of every lesson to assess pre-class preparation, small group problem solving.	Improved exam performance over control group. Students liked videos. Preference for working on challenging problems than listening to lecture in class. working at own pace in class, having instructor help when working on problems.	Some did not like not able to ask questions when watching videos. Video creation was time consuming.
Pierce & Fox (2012)	University course in Pharmacy	Video streaming through iTunes U.	Process-oriented guided inquiry learning (POGIL) activity: Stimulated patient care, calculations, student-centred discussions.	Increased opportunities for knowledge application through in-class activity. Significant exam performance improvement. Students' preference for flipped classroom.	
Smith (2013)	Undergraduate course in	Narrated PowerPoint	Graded follow-up	Videos perceived as	Students found homework

	general chemistry	presentation streamed through "Mediasite" software, online homework.	quiz questions, non-graded questions that allows for group discussions sometimes.	useful and easy to use. 5-7 minute videos found to be appropriate in length, flipped classroom perceived to be effective. Quiz questions useful for reinforcement. In-class problem solving made class more engaging and enlightening.	videos burdensome in terms of time.
Strayer (2012)	Undergraduate course in Statistics	Intelligent tutoring system, ALEKS.	Varied activities. To engage content in different context from ALEKS.	More cooperation than traditional classroom.	Lower task orientation. More likely to plug numbers into formulas and disengage when activities got boring
Wilson (2013)	Undergraduate course in statistics	Textbook reading quiz, encouraged to access "Khan Academy" website for statistics videos, homework assignment.	Varied activities, course content reflection, group homework assignment discussion.	Students found class activities beneficial. course grade improvement.	Some perceived increased outside-class responsibilities as unfair or unreasonable.
Zappe, Leicht, Messner, Litzinger, & Lee (2009)	Undergraduate course in architectural engineering	Online videos on iTunes U, online quizzes.	Group projects	Flipped classes, increased time spent on problem-solving. Having instructors during in-class activities were helpful for content understanding. Group projects	Fifty-minute, and subsequently reduced to 30-minute videos were perceived as too long, half of students found it easy to be distracted watching the videos.

				in class was perceived as a good use of time.	

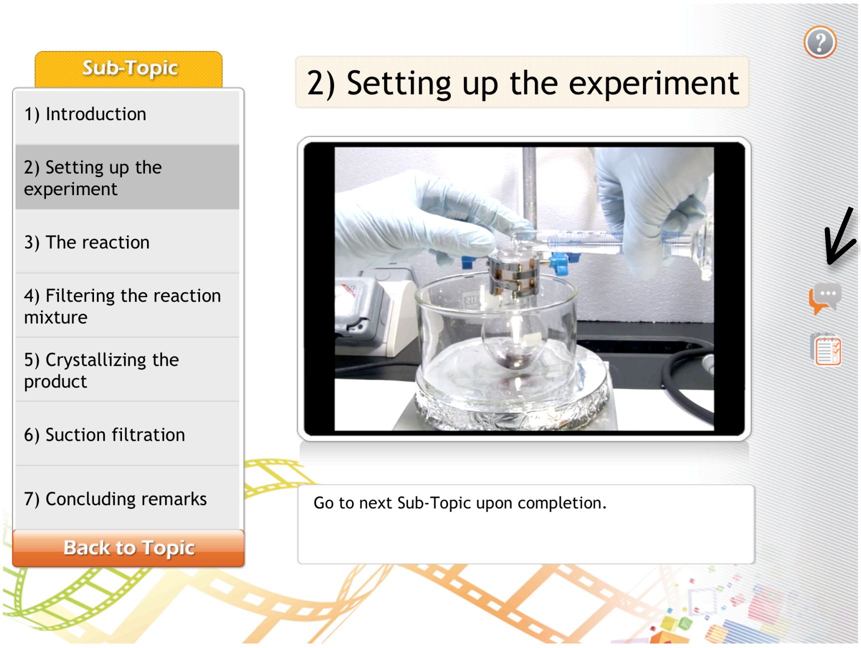
Methods

In this section, we describe the methods of the study including the design of the flip chemistry laboratory curriculum being studied, the research participants, and the research methods in data collection and analysis.

Flip chemistry lesson

The instructors required the undergraduates to view the video on a web browser or smartphone application (App) designed and produced by the institution at which this study was carried out. The two instructors teaching a Year 1 Inorganic Chemistry and a Year 2 Organic Chemistry course, respectively, each selected one out of three or four laboratory sessions in the course to be a flip lesson. The instructors prepared a script and narrated it as they conducted the practical. The entire practical process was video-recorded and edited by media engineers. The video editing included segmenting the video into shorter clips named according to the practical procedures carried out. A week prior to the laboratory lesson, the undergraduates were informed of the App which they could download at no cost on Android or iOS supported mobile devices (e.g., cellphones, mobile pads, tablets) and given the password to access the video clips posted in the channel created for each course. Alternatively, if the undergraduates did not own a smartphone, they could view the video on the institution's online learning and resource platform. The undergraduates could view the video clips any time and anywhere with Internet access, rewind, forward, pause, and skip the video recordings according to their pace of learning. Figure 1 below shows two screen shots of the videos viewed on a mobile device.

Figure 1: A screenshot of the video taken from a mobile device. Titles of the video segments, sequenced as in the practical procedure, are shown on the left side of the screen. The right side of the screen is where the video may be viewed. The video frame may be expanded into a full screen mode. Instructions on what to do after viewing the video are given below the video frame.



Access pre-laboratory questions by tapping on this icon (arrow out of alignment)

Tables 4a and 4b show the curriculum structures of the two flip laboratory lessons and those of the same practicals conducted in the traditional way the year before. In order to actively engage the undergraduates to think about the chemistry underlying each step in the laboratory procedure before carrying out the practicals, pre-laboratory questions were posted online (see Figure 1 icon on the right). The undergraduates were required to submit the answers at the beginning of the lesson. The instructors would engage them in a whole class discussion about the questions to ensure that all students had the correct understanding. During the laboratory work, the undergraduates were allowed to refer to the videos on their mobile devices when they needed to troubleshoot. In one flip lesson, time was set aside at the end of the lesson to conduct a whole class debrief about their laboratory performance. Note that the undergraduates still had to do their laboratory report as homework as it was a graded assignment and there was not enough time in class to complete the detailed laboratory report.

Table 4a: Curriculum design of the Year 1 Tin (IV) iodide practical.

Type of lesson	Pre-lesson	During Lesson	Post-Lesson
Traditional (Baseline study)	Undergraduates read laboratory manual without guidance	Pre-laboratory briefing (23 min) Labwork (158 min)	Homework: Laboratory report
Flip laboratory lesson	Undergraduates read laboratory manual complemented with demonstration videos (13 min long), and answer pre-laboratory questions	Pre-laboratory discussion (14 min) Labwork (113 min) Post-laboratory debrief (17 min)	Homework: Laboratory report

Table 4b: Curriculum design of the Year 2 Wittig practical.

Type of lesson	Pre-lesson	During Lesson	Post-Lesson
Traditional (Baseline study)	Undergraduates read laboratory manual without guidance	Pre-laboratory briefing (23 min) Labwork (158 min)	Homework: Laboratory report
Flip laboratory lesson	Undergraduates read laboratory manual complemented with demonstration videos (13 min long), and answer pre-laboratory questions	Pre-laboratory discussion (9 min) Labwork (142 min)	Homework: Laboratory report

Research participants

The research participants of the study included 11 Year 1 (four males and seven females) and 21 Year 2 (10 males and 11 females) undergraduates who had given informed consent to participate in the study. Those who were below the age of 21 provided both informed assent and parents' consent. About 30% of the Year 2 undergraduates were chemistry majors. Year 1 undergraduates choose their majors at the end of the first semester in their first year of study but are allowed to make changes until the end of their second year. More than 95% of them owned a smartphone and all of them owned a personal laptop. The undergraduates were also pre-service teachers, and would take courses in pedagogy in their third and fourth years and do their teaching practice in their second, third and fourth years.

Data collection

The data collected include student interviews, lesson videos, and student artefacts. We summarised the data collected in Table 5. All interviews and videos were transcribed.

Table 5: Data collected and analyses conducted.

Data collected	Quantity of data	Remarks or comments
Instructor interviews	• Total of 2 interviews (one each with one Year 1 & one Year 2 undergraduate) • Total duration: 36 min	Sample question asked: • Why did you choose to flip this practical? • How did you flip your lesson?
Student semi-structured interviews (end of course)	• Total of 6 interviews (one each with three Year 1 & three Year 2 undergraduates) • Total duration: 3h 30 min	Sample questions asked: • How was the lesson different from a standard lesson? • Did you find yourself working differently in this flip practical lesson?

Student informal interviews (during flip lesson)	• Total of 12 interviews (one each with six Year 1 & six Year 2 undergraduates) • Total duration: 54 min	Sample questions asked: • How did you use the video to prepare for the lesson? • How long did you take to watch the videos? • How did it affect you learning?
Student stimulated recall interview	• 1 interview with one Year 1 student • Total duration: 11 min	We showed one Year 1 undergraduate a video clip of herself referring to the demonstration video recording as she was doing the practical. We asked what she was doing and why she referred to the video. The purpose is to gain insights into how students use the videos in class.
Lesson observations	• 2 laboratory lesson videos (one Year 1 & one Year 2 laboratory) • Duration: 3h per lesson	We video-recorded how undergraduates carried out the practical.
Student artefact	• 1 photograph taken from a Year 1 undergraduate laboratory manual	The annotated laboratory instruction sheet showed how the undergraduate used the video to make sense of the procedures.

Data analysis

The lesson video transcriptions, interview transcriptions, and artefacts were independently coded using qualitative methods by two of the researchers. We used the constant comparative approach (Glaser, 1965) in coding the transcriptions. First, we examined the photograph of the student's annotated laboratory handout and interview transcripts to code for how the undergraduates used the demonstration videos when they were preparing for the laboratory lessons. Some emergent codes include *unpacking steps*, *making notes*, and *answering pre-laboratory questions*. During the coding process, when new codes were identified from reading the transcriptions we looked back at the previous coded transcriptions and re-coded them again. The process was iterative. Then we coded the lesson video transcription, in particular, the pre- and/or post-laboratory briefings during which questions posted on the App were discussed. Only one laboratory lesson had a post-laboratory briefing. We coded the transcriptions for examples on the discussion of theories and concepts and how these deepen the undergraduates' theoretical understanding of the laboratory processes. Any differences in the coding (e.g., codes used and excerpts coded) were negotiated until a common agreement was reached.

Findings and Discussion

In this section, we describe the two flip laboratory lessons and present the undergraduates' perspectives of their learning experience in these lessons. How the flip curriculum supported the undergraduates' learning in laboratory classes will be the focus of our discussion.

Year 1 practical on synthesis of tin(IV) iodide

In this practical, the undergraduates were tasked to synthesise tin(IV) iodide by refluxing the starting reagents followed by filtration and recrystallisation to obtain the pure product (refer to Appendix A for the complete practical procedure).

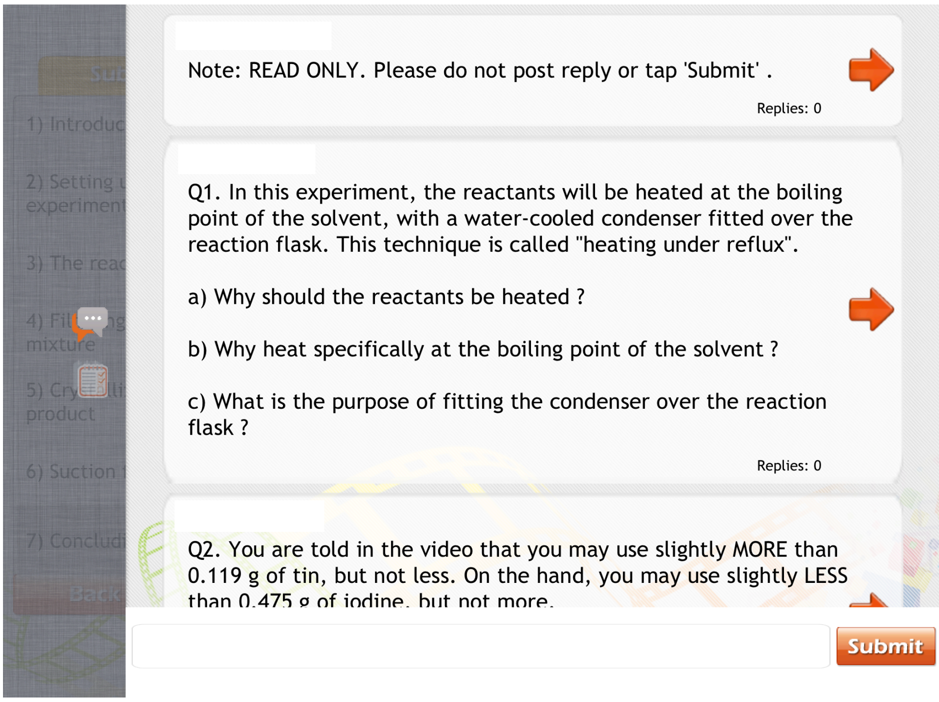
Pre-laboratory demonstration video of the practical

In Appendix A, we show selected screenshots of the demonstration video which corresponded to the step, "gravity filter the warm solution rapidly through a loose cotton or glass wool plug using a small glass funnel" in the practical procedure. Although the step was stated succinctly, it consisted of multiple steps including the preparation of the filtration setup, dismantling of the setup, removal of the round bottom flask, and filtering of the mixture.

Pre-laboratory discussion

Prior to the laboratory session, the undergraduates were asked to think about the pre-laboratory questions. Figure 2 below shows a screenshot of the questions posted online.

Figure 2: A screenshot of the pre-laboratory questions page of the demonstration video for the synthesis of tin(IV) iodide. Students read these questions and address them before they go to the laboratory.



When the instructor met the undergraduates in class, he discussed the pre-laboratory questions with them. The pre-laboratory briefing took about 14 minutes and the instructor probed for the undergraduates' understanding on why they should be doing the things stated. The excerpt below provides an idea of the discussion about questions 1(a) and 1(b) in Figure 2.

Excerpt from the pre-laboratory briefing

Instructor: In this experiment, the reactants are heated at the boiling point of the solvent. Okay, so this is how the apparatus looks like right? [pointing to a demonstration set of the apparatus] You heat your reaction mixture here and the condenser that is cooled by water is plugged onto it. So this is called heating under reflux. So why should the reactant be heated? Anyone?

Student A: Increase the rate of reaction.

Instructor: Increase rate of reaction, is that the only reason? Can anybody think of any other reason?

Student B: provide energy.

Instructor: So as to…?

Student B: To form the bond.

Instructor: To form the bond. So you are saying to overcome the activation energy. But it's the same as what he [Student A] is saying right? To increase the rate of reaction. If you provide more energy for it to overcome the activation barrier, you are actually increasing the rate of reaction right? Ok, basically that is the main reason.

(…)

Secondly, why do we heat specifically at the boiling point of the solvent? In principle we can heat it to any temperature we like right? And still the reaction rate will be increased, so why specifically at the boiling point of the solvent?

(…)

The boiling point is the maximum temperature you can achieve for a particular solvent right? So heating at the boiling point means you are maximising the rate for this solvent right? So

> that is the reason why you heat at the boiling point. Because that is the highest temperature you can reach, and that's to maximise the rate of reaction. Another reason is the boiling point is always constant right? So that makes your reaction more easily controlled and reproducible.

In Singapore, the concept that heating increases the rate of reaction is introduced in secondary schools. In the above excerpt the student had applied this prior knowledge to answer the instructor. While the concept was correct, the instructor wanted the undergraduates to elaborate further. One of the undergraduates showed his understanding on why heating would result in faster rate of reaction. The instructor built on his response to explain that it was due to the overcoming of the activation barrier of the reaction.

In the flip laboratory lesson, the undergraduates could view the demonstration video before lesson. They were informed about the steps, ways to setup the apparatus, the observations they could make, and the safety precautions they should take. When they were in doubt while doing the practical, they could refer back to the videos instead of waiting for the instructor to address their query (lesson observation video, March 1, 2013). As such, more time was freed up for the post-laboratory briefing to review the laboratory lesson that was done.

Post-laboratory discussion

In this particular laboratory lesson, the instructor pointed out more than 10 mistakes the undergraduates had made and explained to them why they had done it incorrectly. Additionally, in explaining their mistakes, he also linked it to theory and ethics in practice (e.g., not dumping certain chemicals in the basin). Below is an excerpt from the post-laboratory briefing which shows how he had linked it to theory.

Instructor: The colour changed from violet to yellow very very quickly. And some changed quite slowly. What do you think are the reasons? (…)

Student: The tin is clumped up, so surface area is smaller, so basically slower.

Instructor: Ok, do you all understand? It is a reaction of a solid with a liquid, right?

Student: [inaudible] large pieces of [inaudible]

Instructor: Yes, in such cases, the larger the surface area of the solid, the faster the reaction. The tin is in powder form, so if you don't stir sufficiently well, it will clump together and that will reduce the effective surface area of the tin. So those of you whose reaction went quite fast, generally it was because you stirred vigorously enough, to keep the tin well dispersed.

(…)

Instructor: Okay for the suction. You noticed in the video what I did. After I turned off the suction, before I added the chloroform for washing, I actually pulled out the funnel right? It goes "poof". Because if you don't do that there is still partial vacuum in there. When you add the washing solvent it will go straight through, it wouldn't cover the product. Then the washing would not be even and effective.

Some of the above ideas were again related to the concept of rate of reaction, in particular, the effective surface area of the substance. While it was intuitive to stir a mixture during heating, the undergraduates now learned that vigorous stirring was necessary when the particle sizes were small to prevent them from aggregating together and hence slowing down the reaction.

The instructor also reminded the undergraduates that he had demonstrated in the video to release the vacuum before pouring in the washing solvent. This was a technique not discussed in books but based upon his experience doing suction filtration. The undergraduates' understanding would be reinforced in class if they had viewed the video before the lesson.

Year 2 practical on Wittig synthesis

In this practical, the undergraduates were tasked to carry out Wittig synthesis. The procedure included reaction, extraction, filtration, and recrystallisation to obtain the pure product (refer to Appendix B for the complete practical procedure).

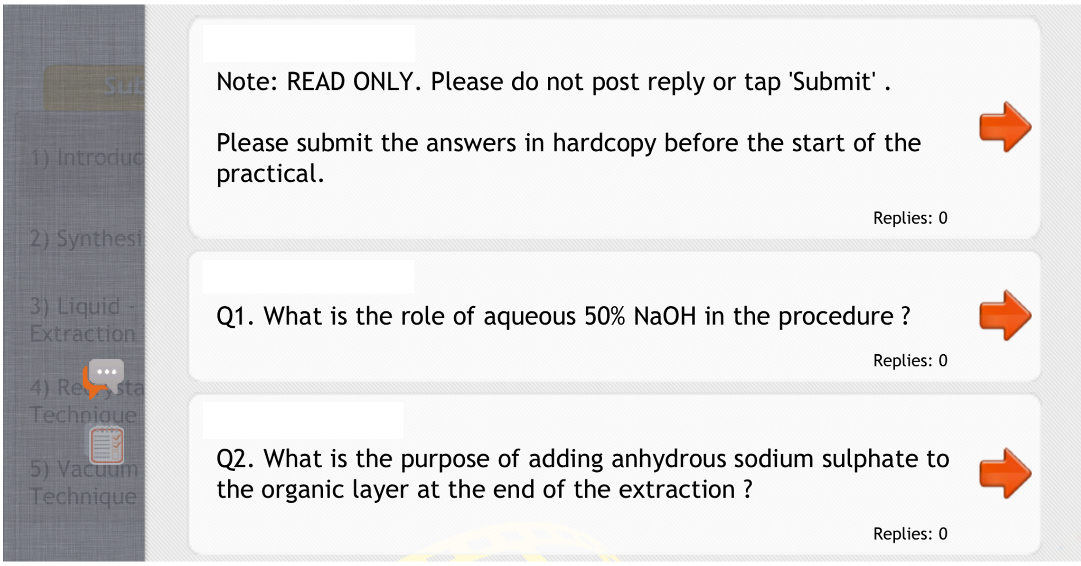
Pre-laboratory demonstration video of the practical

In Appendix B, we show selected screenshots of the flip lesson videos which corresponded to steps 4-8 in the practical procedure. Similar to the previous practical, the video provides detailed breakdown of each step in the procedure. For example, the narrator explained that it was necessary to release the air vent else the pressure would build up in the flask and in the demonstration video, the narrator showed that it was necessary to remove the stopper before the liquid could flow out of the flask.

Pre-laboratory discussion

Figure 3 below shows a screenshot of the questions posted on the mobile App. The undergraduates had to answer these questions and submit them before the instructor discussed their answers. This was to ensure that the undergraduates were adequately prepared and understood the concepts and rationale behind the steps before they embarked on the practicals.

Figure 3: A screenshot of the pre-laboratory question page of the demonstration video for Wittig synthesis.



At the beginning of the lesson, the instructor discussed the pre-laboratory questions with the undergraduates. Below is an example extracted from the pre-laboratory discussion the instructor had with the undergraduates.

Instructor: What is the role of the 50% sodium hydroxide in the procedure? Anyone? [silent]

Student: [inaudible]

Instructor: Form an ylide. Okay, because, remember... [Writes on board] Once you have a [draws on the board] this is the bromide you are using—the triphenylphosphonium bromide. So to form the ylide you need the [draws on board] base to abstract the proton, so that you generate your [writes on board] negatively charged ylide. This ylide can then react with your [draws on board] aldehyde to form the double bond. But! The 50% NaOH serves more than this purpose. [Projector flashes diagram and answer] (…)

Instructor: What is the purpose of adding anhydrous sodium sulphate to the organic layer at the end of the extraction step? Anyone?

Student: Dry the organic layer.

Instructor: Right, because during extraction you might bring over some residual moisture into your organic extracts. So the addition of this anhydrous sodium sulphate is to ensure that your organic extract is free of residual water. [Projector flashes answer] So purpose is to remove the residual water that is still present in the organic extract. So this is the reason why we add anhydrous sodium sulphate. So you must add adequate amount, to ensure that the organic layer is dry.

As opposed to answering the questions in the laboratory report, the instructor had brought forward the questions and undergraduates had to answer the questions for submission beforehand. As such, they had to do some self-reading in order to answer the questions and understand what they were doing before they carry out the practical. They could validate their understanding through the pre-laboratory discussion. For example, in the above excerpt the student would understand the purpose of the anhydrous sodium sulphate rather than just go through the procedure of adding and filtering without knowing its function.

Supporting students' laboratory learning

Unpacking and repacking the complex procedures

The analyses of interviews and artefacts show that some undergraduates had used the demonstration videos to unpack the complex practical procedures prior to the laboratory lesson. Several undergraduates said they had viewed the videos and annotated the laboratory instruction sheet given to them. Figure 4 shows a photograph taken from a Year 1 student's (Y1-2) laboratory manual on which he had made annotations next to each step to remind himself of the multiple smaller steps within each step in the practical procedure.

Figure 4: A photograph of a Year 1 undergraduate's annotations on the tin(IV) iodide practical in his laboratory manual. The annotations consisted of schematic diagrams of the practical setup and additional steps not explicitly stated in the laboratory instruction sheet. For example, it included annotations on what to prepare while waiting for a step to be completed.

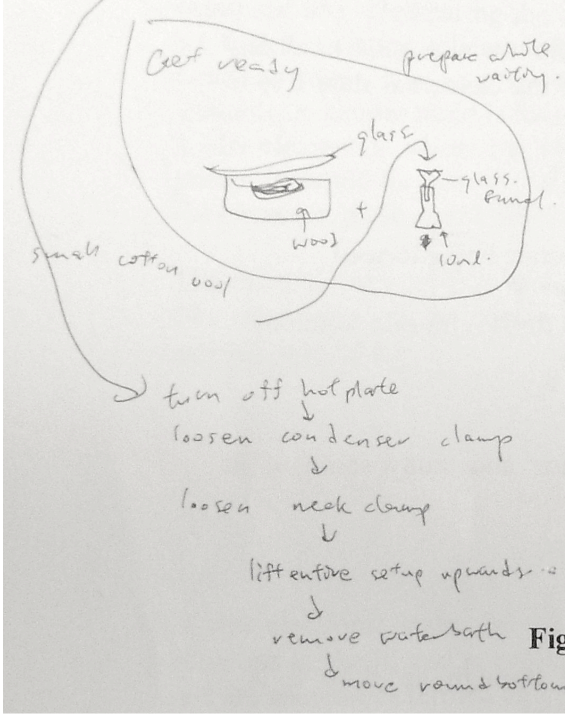
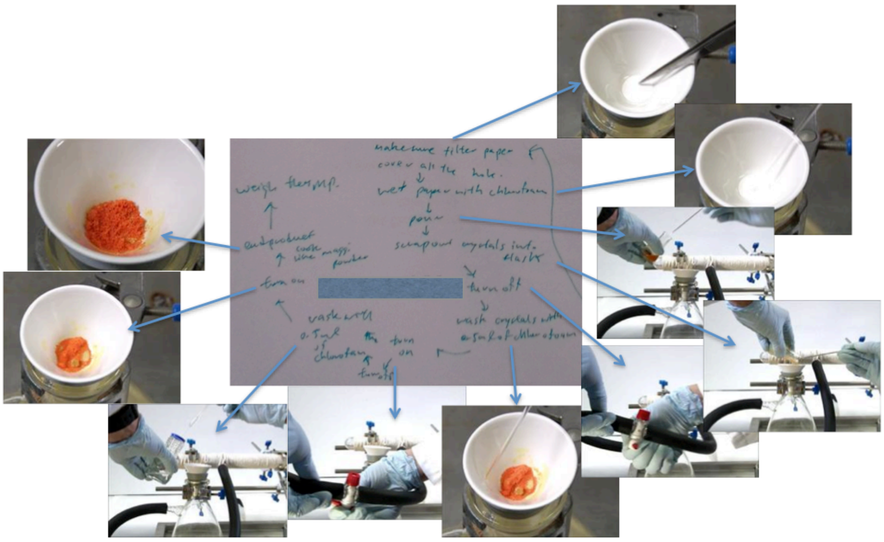


Figure 5 shows how the student's annotations corresponded to the videos.

Figure 5: A photograph of the Year 1 undergraduate's annotations on the tin(IV) iodide practical in his laboratory manual, together with the corresponding screenshots from the video. In order of what was written (clockwise following the pictures): make sure filter paper cover all the hole → wet paper with chloroform → pour → scrape out crystals into flask → turn off → wash crystals with a small amount of chloroform → turn on → wash well with a small amount of chloroform → turn on → end product.



As the student watched the flip video, he unpacked the finer details required in gravity filtration. His annotations were in the form of a flowchart to provide a mental picture on the sequence of steps and apparatus needed. Below is an interview excerpt from another student (Y1-3) who described how the video had helped him:

> [The video contains] a lot of the small details. If you actually watch the video carefully, you will pick up a lot of the small details that he [the instructor] does. Because, I mean, you are actually watching him carrying out the experiment, which I think if we were to do without [the video]; you are just reading it [the instruction], you probably miss out stuff like: When using the vacuum funnel, he switches off the Buchner funnel; he takes it out when he is washing the thing, so that there isn't the partial vacuum there. But I think most

> of us, we just pour in the stuff even though the vacuum is switched off. There is still the partial vacuum, which we will not really care about. Even if you mentioned it, it is something that you might miss. (Student Y1-3, informal class interview, March 1, 2013)

We observed that several undergraduates referred to the videos during the lesson. We conducted a stimulated recall interview with one Year 1 undergraduate (Y1-1) to find out more about why she brought her mobile device into the laboratory. She was shown the video segment (recorded during the laboratory session) in which she was referring to the demonstration video on her mobile device. She said,

> Because I actually watched the video prior to the experiment but there was like a lot of small little few details that he [instructor] included like: For the cork stopper you have to like let it loose for a little, give it some air or something. (…) Then I was just scared that I couldn't remember and that they were crucial to the experiment. (Student Y1-1 undergraduate, interview, 17 May 2013)

She described her laboratory experience as "intimidating". She explained, "Cause you have to like put the water in, then put the water out. I think I was looking for where to clamp? 'Cause it has to be like at a certain height, so that it doesn't get loose or something." There were many details and aspects of a practical setup that needed to be considered and she felt "intimidated" because she had to ensure that she was doing the right thing at every step else she had to repeat the entire practical. She was also looking for the amount of liquid to add into the flask as the information was not specified in the laboratory instruction sheet. Even after looking at her classmate's setup she was not sure that he was doing the right thing. A student (Y1-4) said that after taking notes, she rewrote her own instructions which she found to be clearer than the ones provided for her. Another student (Y1-10) commented that he was able to pick out some details from watching the instructor's actions in the video even though it was not explicated verbally. The student (Y1-10) said,

> Also, one thing he [the instructor] didn't mention, but he did was, when he filter out the... reaction mixture into the small Erlenmeyer flask. There is a tiny bit of cotton wool to filter out the excess tin. And in the video, you see him quite obviously pressing it down with the tweezers, which I think all of us will not even bother to do. And it's not the sort of thing that you would put in the instructions. Because some things you just don't put in instructions, because it seems so logical, but sometimes it just slips your mind.

For other undergraduates, the video served as a visual aid. Below are two excerpts from undergraduates who used the videos as a visual resource:

> I'm more of a visual person, like I'm quite a clumsy person when it comes to manual things. So it's like when I read the lab manual, I may understand but I just don't like... I need to see it for myself, because there are a lot of small details, like I said, like how to clamp this, how to set up the experiment and stuff. So it's not very clear in the lab manual. (Y1-5, informal interview, 17 May 2012)

> [S]ometimes when we just read the manual right, we couldn't understand how does it look like, or what we should be doing. Because it's just words. But when it's visual, we can actually know, exactly, at what stage, what are we supposed to observe. Or at what stage, what are the precautions we are supposed to do. Because we actually see a demonstration on how to use the apparatus and stuff. So it acts like a safety precaution for us also, like we

> know exactly what we need to be careful of, or take note of. (Y2-1, informal interview, 17 May 2012)

As the undergraduates (Y1-5 and Y2-1) had mentioned, there were a lot of details to remember in the practicals. From our baseline study, we observed that since there was only one instructor in the laboratory the undergraduates spent a lot of time waiting for their turn to consult on the expected colour change of the final product to determine the end of reaction, ways to set up the apparatus, and methods to increase the product yield. In the flip laboratory lesson, we observed that a few undergraduates did not wait for their instructors to attend to their queries (lesson observation, May 17, 2013). Rather, they referred to the video or their annotations. As such, all the undergraduates could complete the practical promptly. In the Year 2 the instructor used the remaining time to conduct the post-laboratory debrief on their laboratory performance skills.

In summary, the undergraduates could use the videos to unpack the complex practical procedures by eliciting information that were relevant and useful and reinterpret them to make it understandable in their own terms. This had helped to reduce their anxiety and improve their work efficiency.

Improving understanding of the practicals

The videos did not solely serve as a demonstration tool as the instructors had interjected questions into the videos and these acted as mental triggers to stimulate undergraduates' thinking. As compared to the previous years when the pre-laboratory briefing was mostly about technical and safety issues, more time was spent on understanding the theoretical underpinnings of each step through the discussion of the pre-laboratory questions. According to a few undergraduates, it had provoked them to search for answers and catalyzed their understanding of the theory undergirding the steps. A student (Y2-4) said,

> The pre-lab actually helps us understand the theory behind the whole lab thing. And then also there were a couple of questions on recryst[allisation] which actually help us to—okay, later when we do a recryst[allisation], we need to be careful on how much solvent we add. So in a way, some of the questions were actually related to the video, but the others are actually theory-based, it helps to supplement each other. Like this one [practical] I know what to do when I come to lab, then the questions help me to understand why: "Okay, this is why I'm using this". (Y2-4, informal class interview, March 1, 2013)

The above student commented that pre-laboratory questions were complementary to the videos as it checked on the understanding of theories underpinning the steps. This student, who also participated in the baseline study in her first year, acknowledged that she did not understand the theories related to the practicals until after she had performed the task and answered the post-laboratory questions in the laboratory report. In addressing the pre-laboratory questions in the flip laboratory lesson, she was encouraged to read up and understand the practical before performing the task. This finding is similar to Chittleborough et al.'s (2007) study which found that the pre-laboratory questions had provided learners with an additional opportunity to learn.

Conclusion and Implications

The focus of this paper was to show how the undergraduates used different aspects of a flip lesson model to support their learning and work in the chemistry laboratory. The undergraduates were provided with demonstration videos of the chemistry practicals and answered pre-laboratory questions related to the theories underpinning the practical procedures before the laboratory lesson. The curriculum time originally spent on lengthier pre-laboratory briefing of the procedures was spent on class discussions related to the procedures and theories before and after the laboratory work. The findings of this study had two implications for chemistry educators—school teachers, university professors, and lecturers.

First, we found that by using instructor-narrated demonstration videos of the practicals accompanied by the pre-laboratory questions for discussion, the undergraduates were more encouraged to learn independently and maintain an active cognitive engagement throughout the Chemistry laboratory lessons. Analyses of the lesson videos, interviews, and student artefacts collected in this study showed that these undergraduates had used the demonstration videos to unpack the complex practical procedures—often written in a parsimonious manner similar to the written format in scientific publications. While the format was consistent with the expectations of scientific journals, and these undergraduates are learning to write like scientists, they may not have the prior knowledge and experience that scientists have to figure out the ways to set up the apparatus and detailed steps to execute . In our study, we saw that these undergraduates engaged with the demonstration videos as a resource to unpack and reorganise the information (e.g., using flow charts, diagrams, and annotations) so that the practical procedures became clearer and more understandable to them. Further, the undergraduates developed a better understanding of the theoretical underpinnings of each step when they viewed the videos and answered the pre-laboratory questions. Formerly, the undergraduates answered the questions in their laboratory reports and since they were only assessed based on their written laboratory reports, many of them whom we interviewed acknowledged that they did not think about why they had to perform certain steps during the laboratory work.

Second, this research has shown that flip teaching is suitable for science laboratory learning and is not limited to lecture or classroom contexts. Besides the difference in content, the main difference of a flip lesson demonstration video designed for lecture and laboratory lies in the technicalities (e.g., knowledge of the technical skills, instruments, apparatus, chemicals, and safety issues) and cognitive reasoning on the practical procedures required in the latter. In a laboratory lesson there are a lot more fine-grained details that an instructor has to remind the undergraduates about and one-to-one facilitation is not always easy. Hence, if the undergraduates already know most of the details before they go to the laboratory, it could possibly reduce the undergraduates' cognitive overloading during laboratory work and instructors' rushing about the laboratory to answer undergraduates' questions. Based on our observations of the undergraduates in the laboratory lessons, we saw that they were more confident and would refer to the video when the instructor was busy attending to other undergraduates. This had reduced their wait time and allowed them to progress faster.

As a final note, we want to underscore the point that the effectiveness of a flip lesson is premised on having thoughtfully designed and well-planned pre-lesson tasks that will extend into the face-to-face lesson. We encourage chemistry instructors to rethink ways of implementing their chemistry laboratory lessons and trial one or a few laboratory lessons like what we had done. The findings of this study are encouraging and we have since been teaching preservice teachers about flip teaching and ways to design a flip lesson so that they could use it in their classrooms in future. Nonetheless, we acknowledge that we are unable to generalise the findings of this study to all educational levels and settings as our study was done in a higher education institute where the undergraduates were more mature, independent, and had more practical and theoretical chemistry knowledge. Further, we have only enacted and studied two flip laboratory lessons. We have planned to expand this study to use flip teaching on all the science laboratory lessons in one course and study how the undergraduates respond to it in comparison to other traditional laboratory courses. We hope that more studies could be done to examine the effectiveness of flip laboratory teaching in higher education and school contexts so that there will be breakthroughs in the undergraduates' laboratory learning.

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Appendix A: Year 1 synthesis of tin(IV) iodide

Practical procedure extracted from the laboratory manual:

> Place 0.119 g (1.00 mmol) of tin, 0.475 g (1.87 mmol) of iodine and 6 mL of chloroform (solvent) into a 50 mL round bottom flask containing a stirrer bar and equipped with a reflux condenser (see Figure A).
>
> Gently, with stirring, heat the flask and contents using a hot water bath until a mild reflux is maintained. This can be detected through a moderate dripping rate from the bottom of the condenser joint. Maintain the system at the reflux temperature until the reaction mixture turns brownish-orange (~ 30 min).
>
> (practical procedure was adapted from Szafran, *et al.*, 1991)

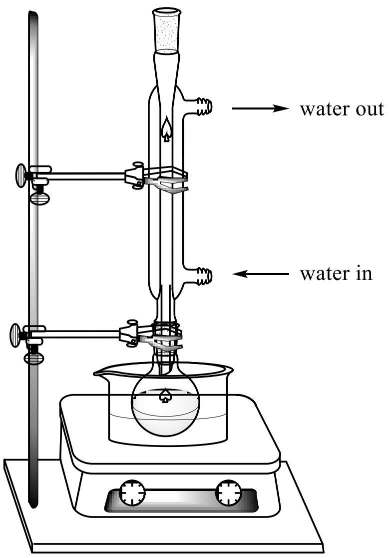


Figure A: The apparatus for the synthesis of tin (IV) iodide.

Isolation of Product:

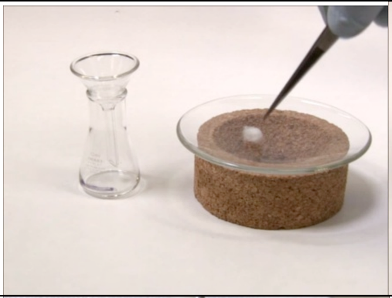
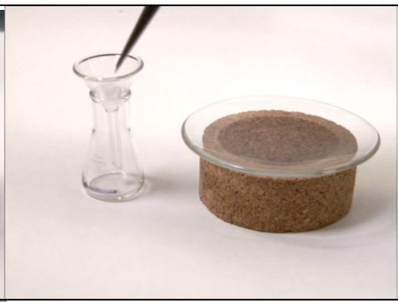
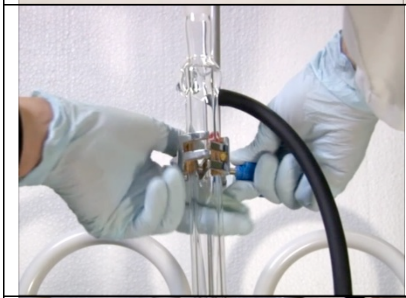
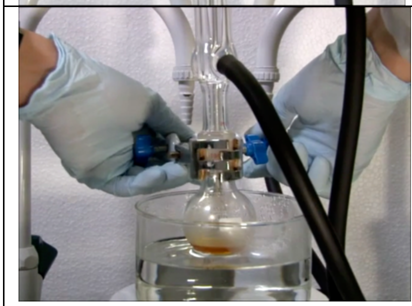
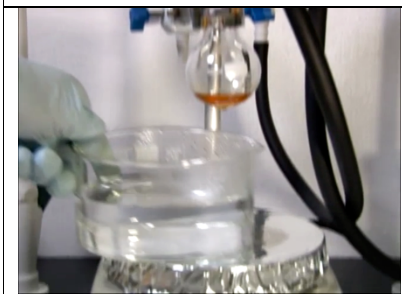
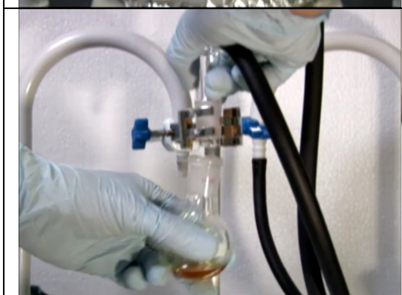
Gravity filter the warm solution rapidly through a loose cotton or glass wool plug using a small glass funnel. Collect the filtrate in a 10 mL Erlenmeyer flask. Any unreacted tin metal will remain in the funnel.

Add a boiling stone to the filtrate and concentrate the solution on a steam bath (HOOD!) to approximately 2 mL. Cool the resulting solution in an ice-water bath, and collect the orange crystals of tin(IV) iodide by suction filtration using a Hirsch funnel. Wash the crystals with two 0.5 mL portions of cold chloroform and dry the crystals on a piece of filter paper.

Weigh the product, determine its melting point and calculate a percentage yield.

Below are selected screenshots from the flip video on the synthesis of tin(IV) iodide, showing how to filter the reaction mixture after completion of reaction. On the right are transcriptions of the narration corresponding to each screenshot.

Screenshots on preparation for filtration	**Narration**
	While waiting for the reaction to complete, get ready a cork ring, a 10ml Erlenmeyer flask, a small glass funnel.

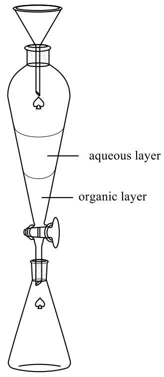
 	Place a loose plug of cotton wool in the funnel, to act as the filter.
	Turn off the hot plate and loosen the jaws of the clamp on the condenser.
	Loosen the screw of the clamp of the flask, and lift the entire setup above the water bath. Re-secure by tightening all the screws.
	Remove the water bath.
 	Loosen the jaws of the clamp at the neck of the flask, and transfer the flask to the cork ring.
 	Turn off the water and ensure that the condenser is well secured before moving on to the filtration.

	Filter the warm solution rapidly through the cotton plug to remove any unreacted tin powder.
	Add boiling stone to the filtrate, and take the flask over to the steam bath.

Appendix B: Year 2 Wittig synthesis

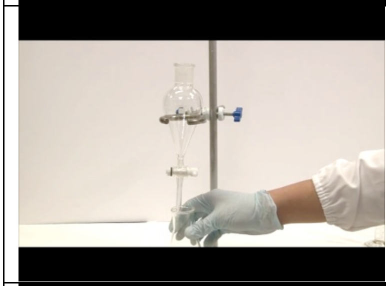
Practical procedure (extracted from the laboratory manual):

1. Add 0.50 g of 9-anthraldehyde, 1.06 g of benzyltriphenylphosphonium bromide and 7.5 mL of methylene chloride into a clean dry 25 mL conical flask containing a stirring bar.
2. Stir vigorously. Add 1.25 mL of 50% NaOH dropwise cautiously, being careful to avoid splattering.
3. Stir for 30 minutes.
4. Add 5 mL of methylene chloride and 5 mL of water into a 100 mL separatory funnel. Transfer the reaction mixture into the separatory funnel.

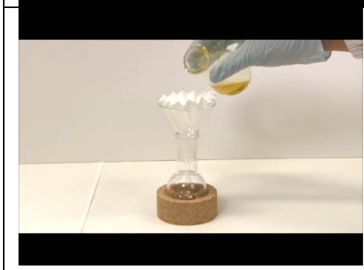


5. Shake, venting often.
6. Allow the layers to separate and remove the lower organic layer to a clean dry conical flask.
7. Extract the aqueous layer with another 5 mL portion of methylene chloride.
8. Combine the organic layers and dry with anhydrous sodium sulphate.
9. Filter the dry organic solution into a 50 mL round bottomed flask and remove the solvent under reduced pressure using a rotary evaporator.
10. Recrystallize the crude yellow crystals from 2-propanol.
11. Collect the crystals using a Buchner funnel and flask.
12. Air dry the yellow crystals and weigh.
13. When the crystals are completely dry, take a small quantity for melting point determination.

Below are selected screenshots from the flip video on Wittig synthesis, demonstrating the liquid-liquid extraction technique to extract the pure compound.

Screenshots on the extraction	Narration
	Next, we are going to isolate the crude product using liquid-liquid extraction.
	Setup a conical flask underneath the separatory funnel in case there is any leakage.
	Add 5 mil of methylene chloride, and 5mil of water into the separatory funnel.
	Next, transfer the reaction mixture into the separatory funnel.
	Add a stopper at the top of the separatory funnel.

		In order to mix these two layers, you need to swirl the separatory funnel gently.
		Vent occasionally to release built-up pressure. Make sure you vent away from your face, and away from other people as well.
		We are now ready to separate the two layers.
		Remove the stopper at the top of the separatory funnel.
		Drain off the organic layer into a clean dry conical flask.
		Leave the aqueous layer in the separatory funnel and add in 5 mil of methylene chloride.
		Add a stopper to the separatory funnel, and repeat the extraction procedure.

	Drain off the lower layer, and combine it with the previously collected organic extracts.
 	Next, dry the organic extracts with anhydrous sodium sulphate.
	Filter the dry organic solution into a 50 mil round bottom flask using a fluted filter paper. Remove the solvent under reduced pressure using a rotary evaporator